DOE/EIA-M064(2004)

Model Documentation Report: Industrial Sector Demand Module of the National Energy Modeling System

February 2004

Office of Integrated Analysis and Forecasting
Energy Information Administration
U.S. Department of Energy
Washington, DC

Table of Contents

Text Tables

Text Figures

Appendix Tables

1. Introduction

Purpose of this Report

This report documents the objectives and analytical approach 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 in 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 2025) 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 shipments. Based on the values of these variables, the Industrial Model passes back to the NEMS system estimates of industrial 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 manufacturing industries are modeled through the use of a detailed process flow or end use accounting procedure. The nonmanufacturing industries are represented in less detail. The industrial model forecasts energy consumption at the four Census region levels; energy consumption at the Census division level is allocated by using data from the *State Energy Data Report 1999*. EIA reviewed and revised how it collects, estimates, and reports fuel use for facilities producing electricity.[1] These revisions were initially published in the *Annual Energy Review 2001*. The specific impacts of this revision on reported industrial energy consumption are discussed in Energy Information Administration, *Annual Energy Outlook 2003*, pp. 32-34.[2] The national-level values reported in *Annual Energy Review 2002* were allocated to the Census Divisions using the *State Energy Data Report 1999*.

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

---

[1]For a detailed discussion, see Energy Information Administration, Annual Energy Review 2001, DOE/EIA-0384 (2001), November 2002, Appendix H, “estimating and Presenting Power Sector Fuel Use in EIA Publications and Analyses,” web site www.eia.doe.gov/emeu/aer/pdf/pages/sec_h.pdf.

[2]Energy Information Administration, Annual Energy Outlook 2003, DOE/EIA-0383(2003) (January 2003), web site www.eia.doe.gov/oiaf/aeo/pdf/issues.pdf.

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 manufacturing industries, the PA component is separated into the major production processes or end uses.

Archival Media
The model is archived as part of the National Energy Modeling System production runs used to generate the Annual Energy Outlook 2004.

Model Contacts

T. Crawford Honeycutt	Brian Unruh
(202)586-1420	(202)586-1344
crawford.honeycutt@eia.doe.gov	brian.unruh@eia.doe.gov

Office of Integrated Analysis and Forecasting
Demand and Integration Division
1000 Independence Avenue, SW
EI-84, Room 2F-094
Washington, DC 20585

Organization of this Report

Chapter 2 of this report discusses the purpose of the NEMS Industrial Demand Model, detailing its objectives, input and output variables, 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. The first section in Chapter 4 provides an outline of the model. The second section in Chapter 4 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 is a bibliography of data sources and background materials used in the model development process. Appendix B provides the input data. Appendix C is the model abstract.

2. Model Purpose

Model Objectives

The NEMS Industrial Demand Model was designed to forecast industrial energy consumption by fuel type and industry as defined in the North American Industrial Classification System (NAICS).[3] The Industrial Model generates mid-term (up to the year 2025) 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 shipments, which are expressed in 1996 dollars, for industrial activity. Based on the values of these variables, the Industrial Model passes back to the NEMS system estimates of fuel consumption for 17 main fuels (Table 1), including feedstocks and renewables, (Table 1) for each of 15 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 project seasonal or daily 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 shipments 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. The model distinguishes among the energy-intensive manufacturing industries, the non-energy-intensive manufacturing industries, and the non-manufacturing industries.

A process flow approach, represented by major production processes or end uses, is used to model the manufacturing industries. This approach provides considerable detail about how energy is consumed in that particular industry. The industrial model uses “technology bundles” to characterize technical change. These bundles are defined for each production process step for five of the industries and for each end use in four of the industries. The process step industries are pulp and paper, glass, cement, steel, and aluminum. The end use industries are food, bulk chemicals, metal-based durables, and the balance of manufacturing.

The Unit Energy Consumption (UEC) is defined as the energy use per ton of throughput at a process step or as energy use per dollar of shipments for the end use industries. The “Existing UEC” is the current average installed intensity (as of 1998). The “New 1998 UEC” is the intensity expected to prevail for a new installation in 1998. Similarly, the “New 2025 UEC’ is the intensity expected to prevail for a new installation in 2025. For intervening years, the intensity is interpolated.

---

[3]Executive Office of the President, Office of Management and Budget, *North American Industry Classification System*. Washington, DC, 1997.

The rate at which the average intensity declines is determined by the rate and timing of new additions to capacity. The rate and timing of new additions are a function of retirement rates and industry growth rates.

The model uses a vintage capital stock accounting framework that models energy use in new additions to the stock and in the existing stock. This capital stock is represented as the aggregate vintage of all plants built within an industry and does not imply the inclusion of specific technologies or capital equipment.

Interaction with Other NEMS Modules

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 shipments Employment	Macroeconomic Module
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	
INPUTS	**From Module**
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, combining economic and engineering data and knowledge. Its architecture brings together the disparate industries, and uses of energy in those industries, and combines them 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 projected changes in composition of the products produced will be automatically taken into account when computing energy consumption. Industrial modeling approaches other than NEMS have either lumped together 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 when the composition of products produced is projected to change.

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, 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 manufacturing industries are modeled with a structure that explicitly describes the major process flows or major consuming uses in the industry.

- The industrial model uses “technology bundles” to characterize technical change. These bundles are defined for each production process step or end use.

- Technology improvement for each technology bundle for each production process step or end use is based upon engineering judgment.

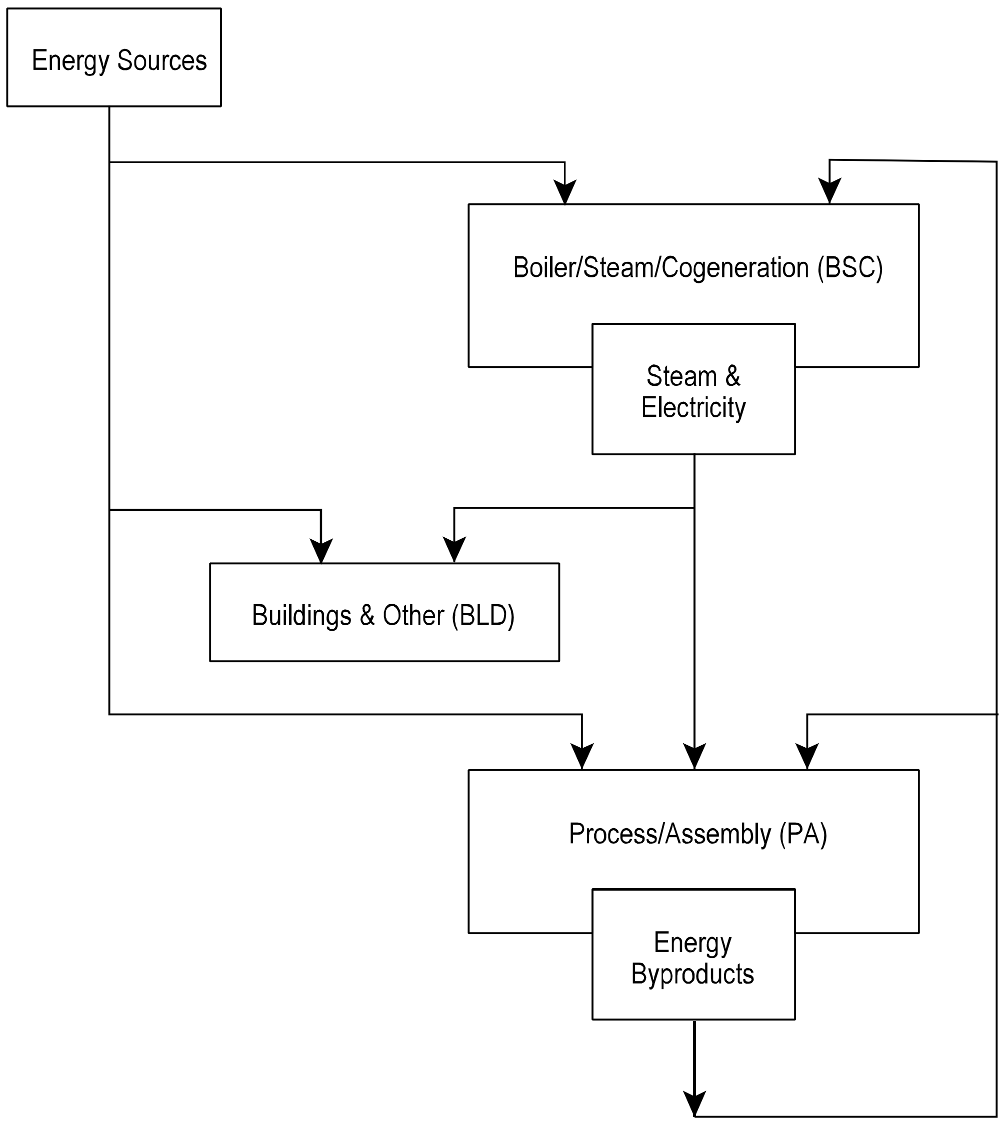
- The model structure accommodates several industrial sector activities including: fuel switching, cogeneration, renewables consumption, recycling and byproduct consumption. The principal model calculations are performed at the four Census region level and aggregated to a national total.

Fundamental Assumptions

The industrial sector consists of numerous heterogeneous industries. The Industrial Model classifies these industries into three general groups: 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 (NAICS 311); paper and allied products (NAICS 322); bulk chemicals (parts of NAICS 325); glass and glass products (NAICS 3272); hydraulic cement (NAICS 32731); blast furnaces and basic steel products (NAICS 331111); and aluminum (NAICS 3313). Also within the manufacturing group are metal-based durables (NAICS 332-336) and the balance of manufacturing (all NAICS manufacturing sectors that are not included elsewhere). The eighth energy-intensive industry, petroleum refining (NAICS 32411) is modeled in detail in the Petroleum Market Model, a separate module of NEMS, and the projected energy consumption is included in the manufacturing total. The forecasts of lease and plant fuel and cogeneration consumption for Oil and Gas (NAICS 211) are modeled in the Oil and Gas Supply Module and included in the Industrial Sector energy consumption totals.

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 manufacturing 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 shipments produced by each industry group. The value of shipments by NAICS classification is provided to the Industrial Model by the NEMS Macroeconomic Module. As the level of industrial economic activity increases, the amount of energy consumed to produce the relevant industrial products typically increases, but at a slower rate.

The amount of energy consumption reported by the Industrial Model is also a function of the vintage of the capital stock that produces the shipments. It is assumed that new capital 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 1998 capital stock is reflected in the parameter of the Technology Possibility Curve (TPC) estimated for each process step or end use. 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 the buildings component is assumed to grow at the same rate as the average growth rate of employment and output in that industry.[4] Energy consumption in the BSC is assumed to be a function of the steam demand of the other two components.

Industry Disaggregation

Table 2 identifies the industry groups modeled in the industrial sector along with their North American Industrial Classification System (NAICS) 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 in more detail, with aggregate process flows. The industry categories are also chosen to be as consistent as possible with the categories that are available from the Manufacturing Energy Consumption Survey (MECS). Table 2 identifies six nonmanufacturing industries and nine manufacturing industries. Of the manufacturing industries, seven of the most energy-intensive are modeled in greater detail in the Industrial Demand Model. Energy consumption for Petroleum Refining (NAICS 32411), also an energy-intensive industry, is modeled by the Petroleum Market Model of NEMS.

[4]Note that manufacturing employment generally falls in a typical *Annual Energy Outlook* forecast. As a result, buildings' energy consumption falls over time.

Table 2. Industry Categories

Energy-Intensive Manufacturing	Nonmanufacturing Industries
Food and Kindred Products (NAICS 311)	Agriculture, Crops (NAICS 111)
Paper and Allied Products (NAICS 322)	Agriculture, Other (NAICS 112-115)
Bulk Chemicals (see footnote)	Coal Mining (NAICS 2121)
Glass and Glass Products (NAICS 3272)	Oil and Gas Mining (NAICS 211)
Hydraulic Cement (NAICS 32731)	Other Mining (NAICS 2122-2123)
Blast Furnaces and Basic Steel (NAICS 331111)	Construction (NAICS 233-235)
Aluminum (NAICS 3313)	
Nonenergy-Intensive Manufacturing	
Metal-Based Durables (NAICS 332-336)	
Balance of Manufacturing (all remaining manufacturing NAICS)	

NAICS = North American Industrial Classification System
Bulk Chemicals include the following: 325110, 325120, 325181, 325188, 325192, 325199, 325211, 325222, 325311, 325312.
Source: Office of Management and Budget, *North American Industrial Classification System* (Springfield, VA, National Technical Information Service, 1997).

Energy Sources Modeled

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

- Electricity
- Natural Gas
- Steam Coal
- Distillate Oil
- Residual Oil
- LPG for heat and power
- Other Petroleum
- Renewables (biomass and hydropower)
- Motor Gasoline

Other energy sources[5] that are used in specific industries are also modeled:

[5]Still gas and petroleum coke are consumed primarily in the refining industry, which is modeled in the Petroleum Market Module of NEMS.

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

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 NAICS industry group. UEC is defined as the amount of energy required to produce one dollar's worth of shipments. The distinction between existing and new capital equipment is maintained with a vintage-based accounting procedure. In practice, the fuel use pattern typically is similar across vintages.

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 9 percent of allocated heat and power energy consumption in manufacturing industries.[6] Estimates of 1998 manufacturing sector building UEC's are presented in Table B1. Energy consumption in industrial buildings is assumed to grow at the average of the growth rates of employment and shipments in that industry. This assumption appears to be reasonable since lighting and heating, ventilation, and air conditioning (HVAC) are used primarily for the convenience of humans rather than machines.

Process and Assembly Component UEC

The process and assembly component (PA) accounted for the largest share, 55 percent, of direct energy consumption for heat and power in 1998. Of the PA total, natural gas accounted for 51 percent and electricity accounted for 40 percent.

---

[6]Computed from Energy Information Administration, *Manufacturing Energy Consumption Survey 1998*, (www.eia.doe.gov/emeu/mecs/MECS98/datatables/contents.html). Note that byproduct and non-energy use of combustible fuels are excluded from the computation.

Estimation of the PA component UECs depends on the particular industry. For the manufacturing industries, engineering data relating energy consumption to the product flow through the process steps or end uses are used. In addition, engineering judgment is used to characterize autonomous change in the manufacturing industries through the use of Technology Possibility Curves (TPCs). The energy intensity of the new capital stock relative to 1998 capital stock is reflected in the parameter of the TPC estimated for each process step or end use. These curves are based on engineering judgment of the likely future path of energy intensity changes. The non-manufacturing industries do not use process steps or end-uses due to data limitations.

Fuel shares for process and assembly energy use in eight manufacturing industries[7] are adjusted for changes in relative fuel prices. These industries are food, paper, chemicals, glass, cement, steel, metal-based durables, and other manufacturing. 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 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:

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

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

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

The user-specified coefficients β_j are 0.05 for the *Annual Energy Outlook 2004*.

The form of the equation results in unchanged fuel shares when the price indices are all 1, or unchanged from their 1998 levels. The implied own-price elasticity of demand is about -0.1 for the assumed values of β_j, and for the boiler shares typically observed.

Manufacturing Industry UEC Estimation

[7]Aluminum is excluded due to the extremely limited substitution possibilities in the process and assembly component.

For the nine manufacturing industry groups, energy consumption for the PA component is modeled according to the process flows or end uses 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, aluminum, metal-based durables, and the balance of manufacturing.

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 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 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 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, bulk chemicals, metal-based durables, and the balance of manufacturing). A motor stock model calculates the electricity consumption for the machine drive end-use for these four industries.

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

- Fossil Fuels;
- Electricity (valued at 3412 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 B and are referenced in the text as appropriate. The process steps are model inputs with the variable name *INDSTEPNAME*.

Food and Kindred Products (NAICS 311)

The food and kindred products industry accounted for 10.4 percent of manufacturing value of shipments in 1998.

The food and kindred products industry consumed approximately 1,044 trillion Btu of energy in 1998.[8] 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:

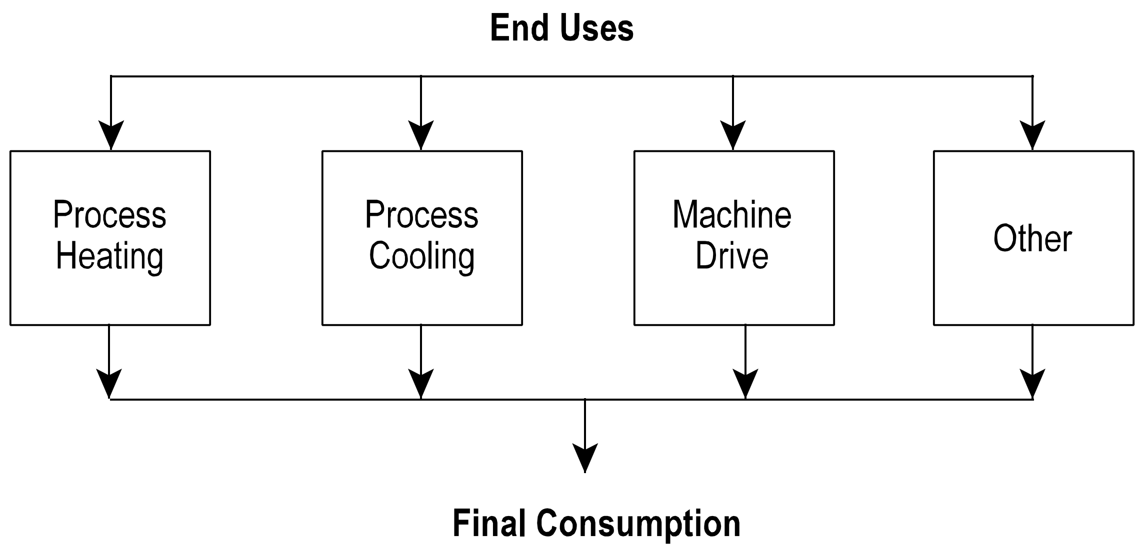
---

[8]Energy Information Administration, *Manufacturing Energy Consumption Survey 1998*, (www.eia.doe.gov/emeu/mecs/MECS98/datatables/contents.html).

- Process Heating;
- Process Cooling;
- Machine Drive;
- Other.

Figure 2 portrays the PA component's end-use energy flow for the food and kindred products industry. A motor stock model, which is described later in this document, calculates electricity consumption for the machine drive end-use. The UECs estimated for the remaining end-uses in this industry are provided in Table B2. The dominant end-use was direct heat, which accounted for 79 percent of the total PA energy

Figure 2. Food and Kindred Products End Use



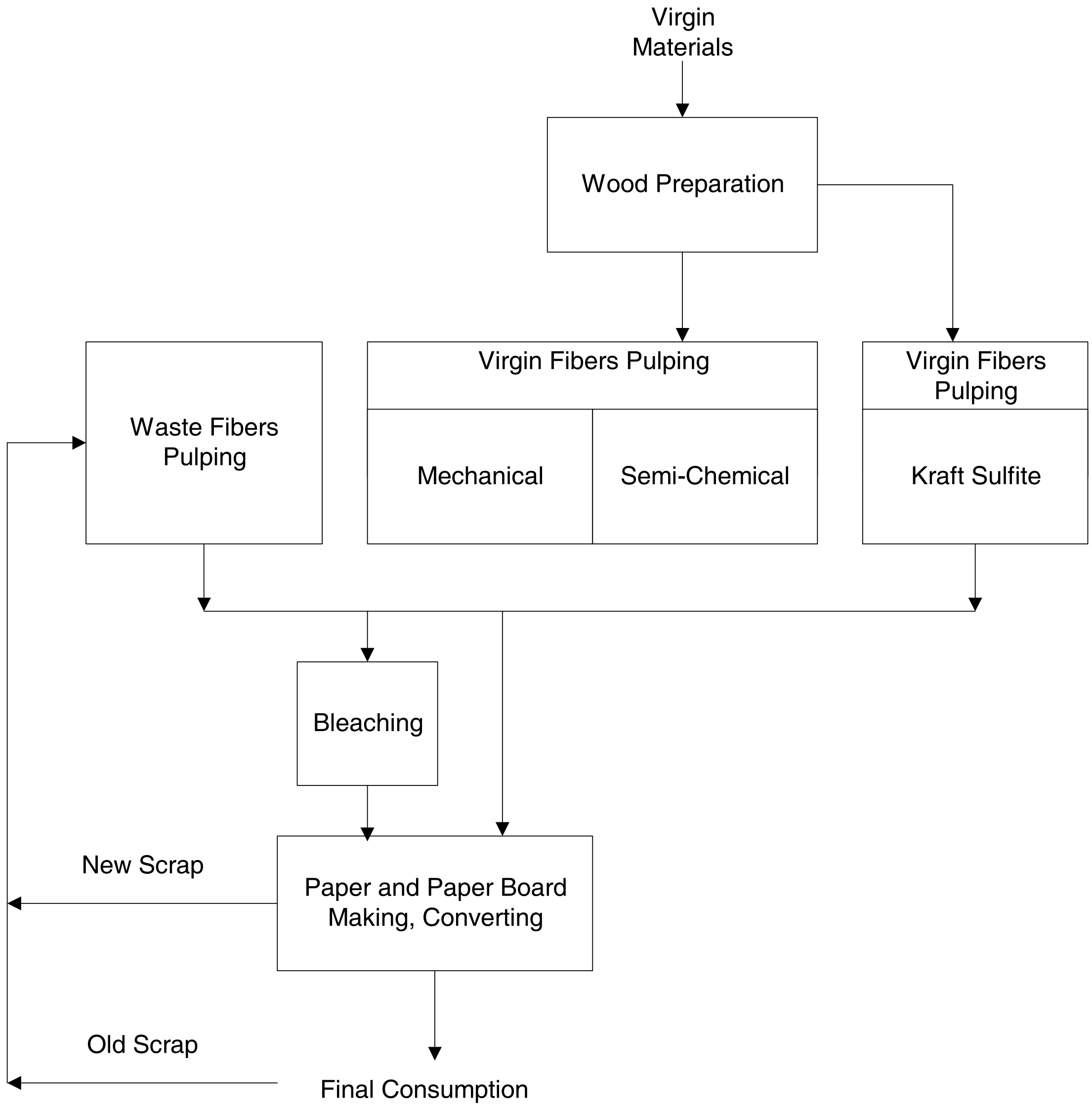
consumption.

Paper and Allied Products (NAICS 322)

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 by 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. 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 paper-making step include papermaking, converting/packaging, coating/redrying, effluent treatment, and other miscellaneous processes.

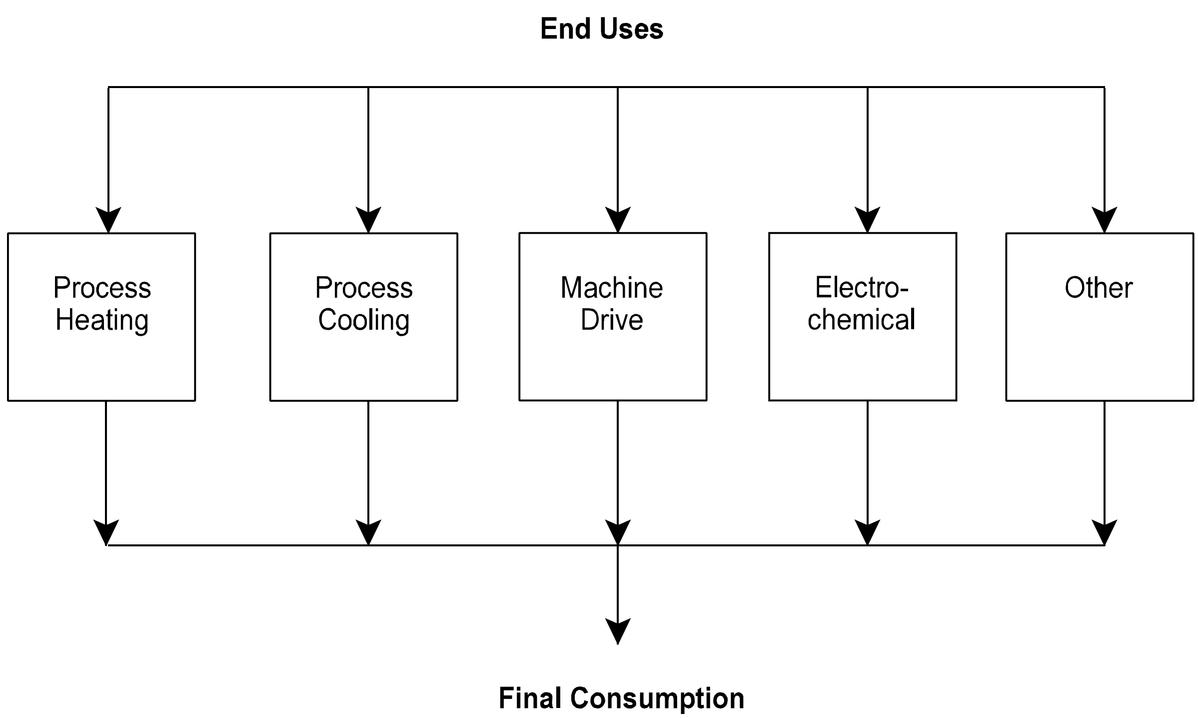
In 1998, 96 million tons of paper and paperboard products were produced. The major paper products include wood-free printing paper, groundwood printing paper, newsprint paper, tissue paper and packaging paper. The major paper board products include kraft paperboard, corrugating medium and recycled paperboard. Of the total pulp production, 49 percent was produced from kraft chemical process, 4 percent from semi-chemical, 5 percent from mechanical (groundwood) and 42 percent from waste fibers. The unit energy use estimates for this industry are provided in Table B3. The largest component of this energy (including steam) use is in the paper and paper board making process step and kraft pulping step, accounting for 40 percent and 37 percent, respectively. 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 B11.

Bulk Chemical Industry (parts of NAICS 325)

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 bulk chemical industry is estimated to consume 23 percent (5.4 quadrillion Btu) of the total energy consumed in the manufacturing 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. A motor stock model, which is described later in this document, calculates electricity consumption for the machine drive end-use. The UECs estimated for the remaining end-uses in the bulk chemical industry are shown in Table B4. The end-uses for the industry are shown in Figure 4.

Figure 4. Bulk Chemical Industry End Use



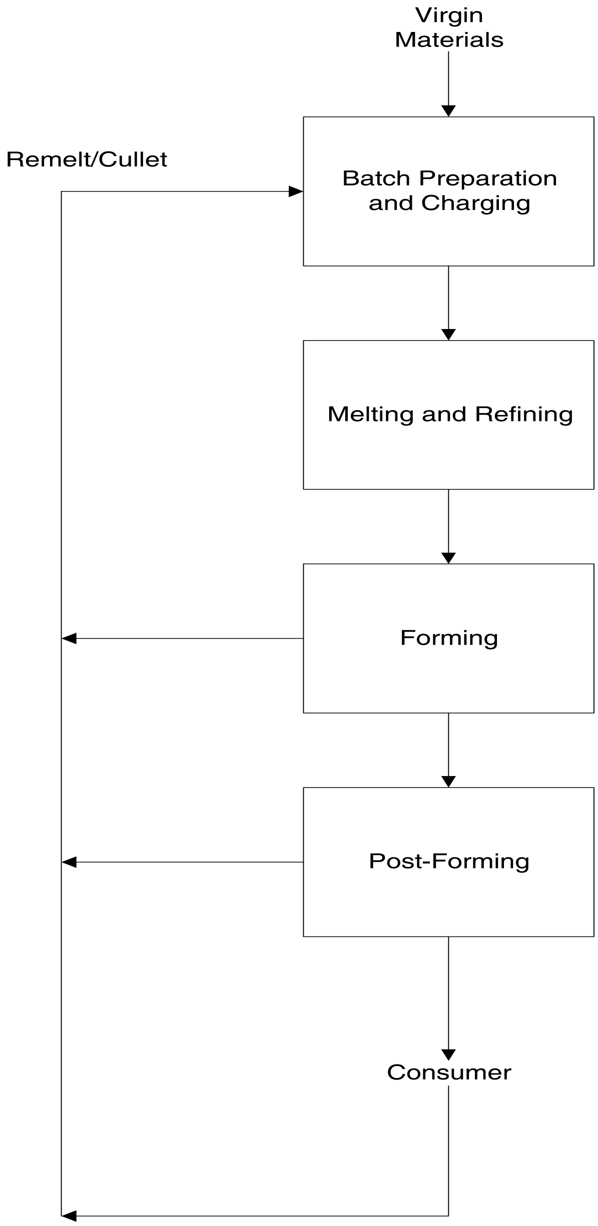
Glass and Glass Products Industry (NAICS 3272)

The energy use profile has been developed for the total glass and glass products industry, NAICS 3272. This definition includes glass products made from purchased glass. 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 1998, the glass and glass product industry produced approximately 19 million tons of glass products.

The glass and glass product industry consumed approximately 205 trillion Btu of energy in 1998.[9] This accounts for about 20 percent 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 B5 shows the unit energy consumption values for each process step.

[9]Energy Information Administration, *Manufacturing Energy Consumption Survey 1998*, (www.eia.doe.gov/emeu/mecs/MECS98/datatables/contents.html).

Figure 5. Glass and Glass Products Industry Process Flow



Hydraulic Cement Industry (NAICS 32731)

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 wet process accounted for 25 percent of production, while the dry process accounted for about 75 percent in 1998. The dry process tends to be less costly and 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 cement industry produced 93 million tons of cement in 1998. 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 hydraulic cement industry exhibits one of the highest unit energy consumption values (MMBtu/dollar value of shipments) in the U.S. industrial sector. The industry consumed approximately 356 trillion Btu of energy in 1998.[10] Direct fuel, used in clinker-producing kilns, accounted for 88 percent of the total PA energy consumption.

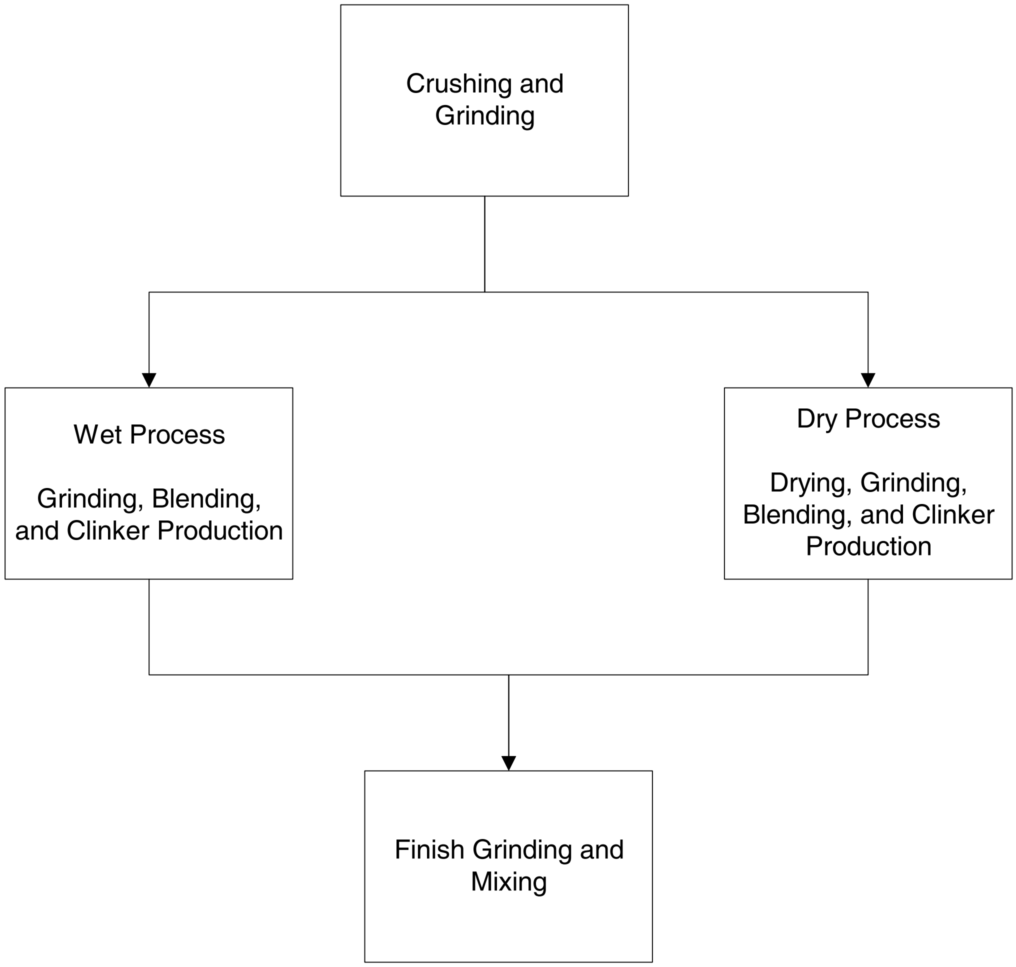
The wet process requires significantly larger amounts of energy which can be largely attributed to fuels used to dry the feed. While wet grinding requires less energy than dry grinding, the entire wet process has longer kilns, requiring greater energy use than does the dry process. Higher air flows, 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 B6. 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 B11.

---

[10]Energy Information Administration, *Manufacturing Energy Consumption Survey 1998*, (www.eia.doe.gov/emeu/mecs/MECS98/datatables/contents.html).

Figure 6. Cement Industry Process Flow



<u>Blast Furnace and Basic Steel Products Industry (NAICS 331111)</u>

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 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 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 in the following.

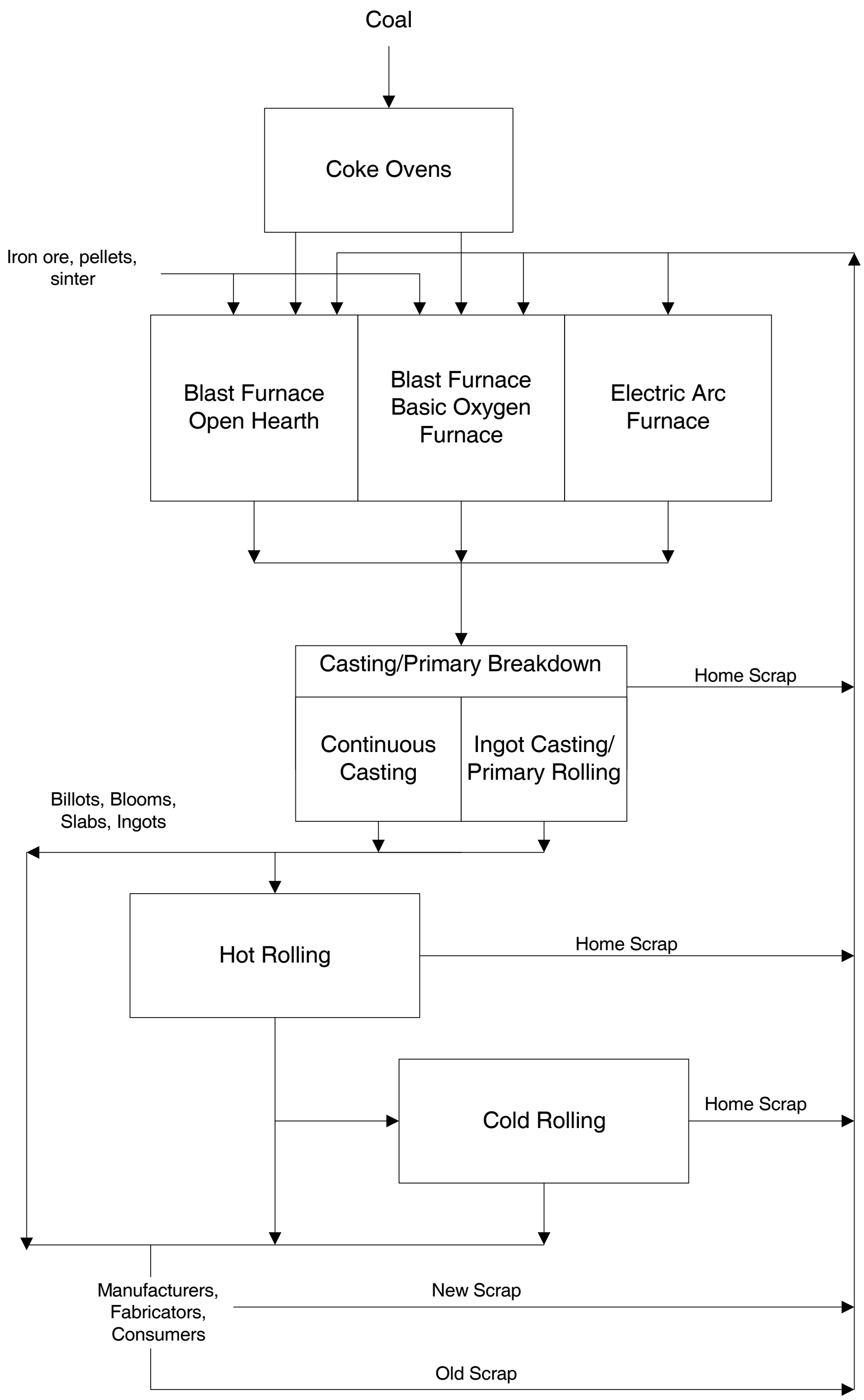
Iron is produced in the Blast Furnace (BF), which is then charged into a Basic Oxygen Furnace (BOF) or Open Hearth (OH) to produce raw steel. The OH is now obsolete. The Electric Arc Furnace (EAF) is utilized to produce raw steel from an all scrap charge, sometimes supplemented with direct reduced iron (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 1998, the U.S. steel industry produced 109 million tons of raw steel utilizing the BF/BOF and the EAF. Taking process yields into account, the total shipments were approximately 102 million tons. The EAF accounted for 45 percent of the raw steel production. Continuous casting was the predominant casting process whereas ingot casting is declining.

Table B7 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 furnaces also produce a significant amount of byproduct fuels, which are used throughout the steel plant. The regional distribution of steel-making technologies is presented in Table B11.

Figure 7. Iron and Steel Industry Process Flow



Aluminum Industry (NAICS 3313)

The U.S. aluminum industry consists of two majors sectors: the primary aluminum sector, which is dependent on 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 have historically catered to different markets but these distinctions are fading. Traditionally, the primary industry bought little scrap and supplied wrought products, including sheet, plate and foil. The secondary industry is scrap-based and has historically supplied foundries that produce die, permanent mold and sand castings. More recently, secondary aluminum smelters have started supplying wrought (sheet) stock. In addition, in the past decade, the primary producers have been moving aggressively into recycling aluminum, especially used beverage cans, into wrought products. Figure 8 provides an overview of the process steps involved in the aluminum industry. The energy use analysis accounts for energy used in NAICS 3313 which includes:

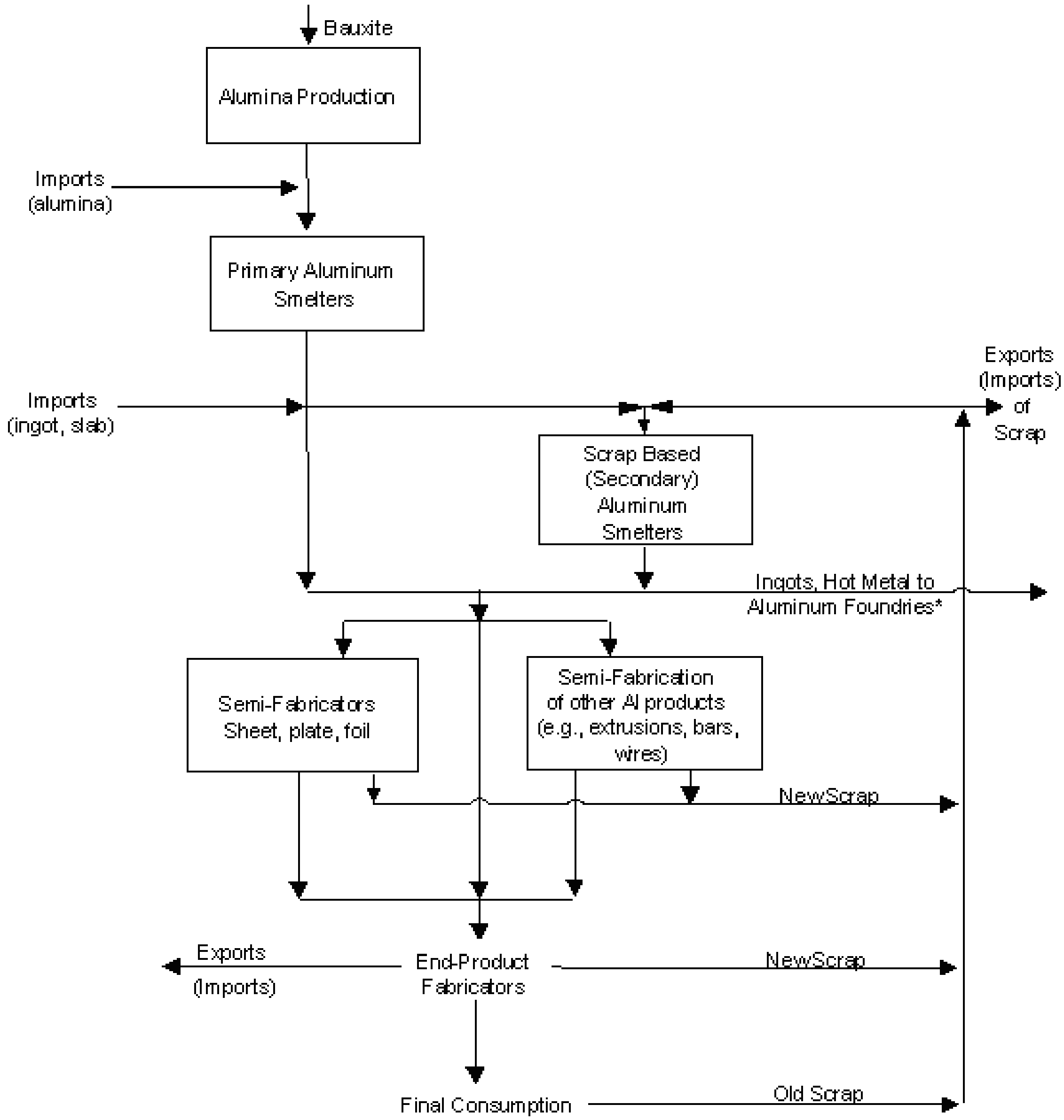
Alumina Refining (NAICS 331311)
Primary Aluminum Production (NAICS 331312)
Secondary Smelting and Alloying of Aluminum (NAICS 331314)
Aluminum Sheet, Plate, Foil Manufacturing (NAICS 331315)
Other Aluminum Semi-fabrication found in NAICS 3316 and Semi-fabrication of flat products found in NAICS 331319 such as extrusions, tube, cable, wire, etc.

Note that aluminum foundry castings (die-casting/permanent mold/other) are not considered as part of NAICS 331311).

The primary sector produced approximately 3.6 million tons of aluminum in 1998. Domestic aluminum production plus aluminum ingot imports resulted in about 7.6 million tons of mill products like sheet, plate, and foil, cable, wire, etc. (Aluminum Association, 1999) and 3.09 million tons of ingots largely destined for aluminum foundries.

The UEC estimates developed for the process steps are presented in Table B8. The principal form of energy used is electricity. The regional distribution of smelters in the aluminum Industry is presented in Table B11.

Figure 8. Aluminum Industry Process Flow

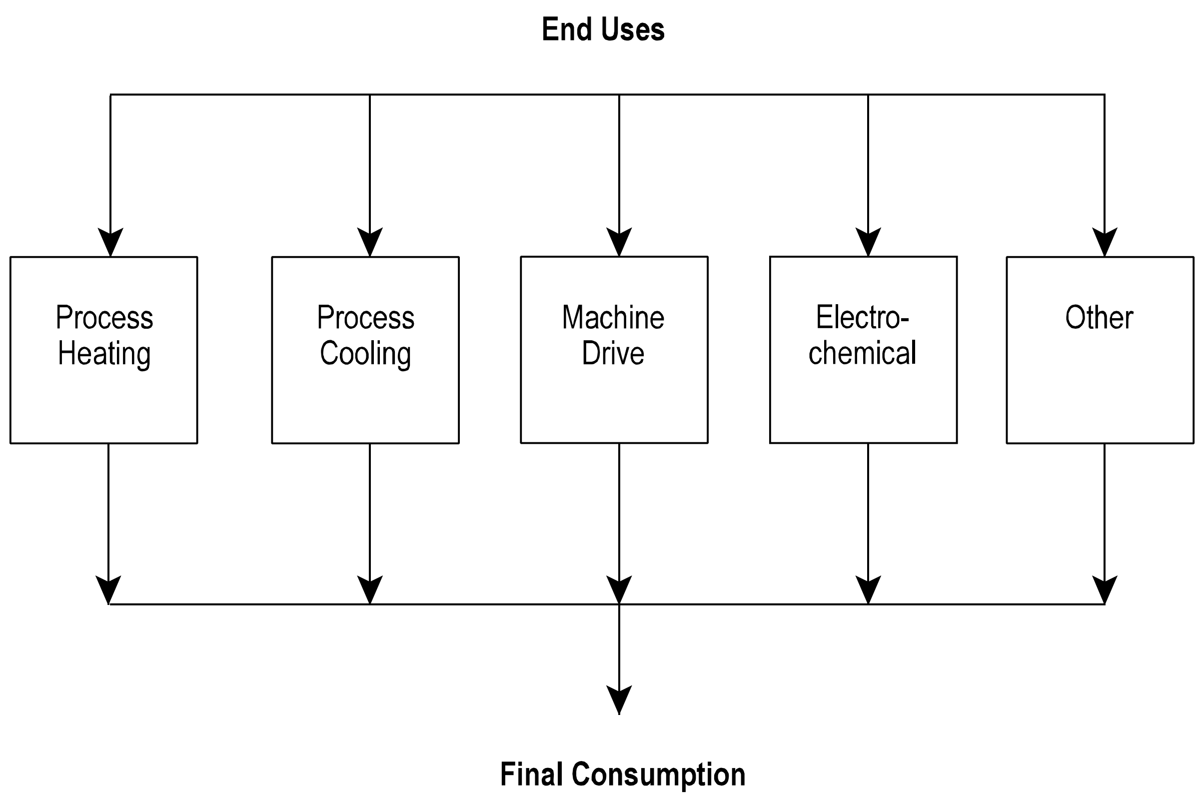


Metal-Based Durables Industry (NAICS 322-336)

This industry group consists of industries engaged in the manufacture of fabricated metals, industrial machinery and equipment, electronic and other electric equipment, transportation equipment, and instruments. Typical processes found in this group include remelting operations followed by casting or molding, shaping, heat treating processes, coating, and joining and assembly. Given this diversity of processes, the industry group's energy is characterized by the generic end uses in MECS 1998. These end uses are shown in Figure 9.

In 1998, the metal-based durables industry consumed 1.5 quadrillion Btu of energy.[11] A motor stock model, which is described later in this document, calculates electricity consumption for the machine drive end-use. Unit energy consumption values for the other end uses in the PA component for the metal-based durables industry are given in Table B9.

Figure 9. Metal-Based Durables End Use



[11]Energy Information Administration, *Manufacturing Energy Consumption Survey 1998*, (www.eia.doe.gov/emeu/mecs/MECS98/datatables/contents.html).

Balance of Manufacturing Industry (all other manufacturing NAICS)

This is a group of miscellaneous industry sectors ranging from the manufacture of tobacco and leather products to furniture and textiles. This industry group's PA energy is characterized by the same generic end uses as the metal-based durables industry.

In 1998, the balance of manufacturing industry consumed 3.3 quadrillion Btu of energy.[12] A motor stock model, which is described later in this document, calculates electricity consumption for the machine drive end-use. Unit energy consumption parameters for the other end uses in the PA component of the balance of manufacturing industry group are given in Table B9.

Non-Manufacturing Industries

The non-manufacturing industries do not have a single source for energy consumption data as the manufacturing industries do. Instead, UECs for the agriculture, mining, and construction industries are derived from various sources collected by a number of Federal Government agencies.

Energy consumption data for the two agriculture sectors (crops and other agriculture) are largely based on information contained in the *1997 Census of Agriculture* conducted by the U.S. Department of Agriculture.[13] Expenditures for five energy sources were collected for fourteen groups of agricultural establishments categorized based on the North American Industry Classification System. These data were aggregated into the two agriculture sectors included in the Industrial Demand Model and converted from dollar expenditures to energy quantities using prices from the Department of Agriculture and the EIA.

The mining industry is divided into three sectors in the Industrial Demand Model – coal mining, oil and gas, and other mining. The quantities of seven energy types consumed by 29 mining sectors were collected as part of the *1997 Economic Census of Mining* by the U.S. Census Bureau.[14] The data for the 29 sectors were aggregated into the three sectors included in the Industrial Demand Model and the physical quantities were converted to Btu for use in NEMS.

There is only one construction sector included in the Industrial Demand Model so the Construction Industry Summary from the *1997 Economic Census* was used as the source for

---

[12]Energy Information Administration, *Manufacturing Energy Consumption Survey 1998*, (www.eia.doe.gov/emeu/mecs/MECS98/datatables/contents.html).

[13]U.S. Department or Agriculture, *1997 Census of Agriculture*, AC97-A-51 (Washington, DC, March 1999).

[14] U.S. Census Bureau, *1997 Economic Census, Mining Industry Series*, EC97N-2111A through EC97N-2131E (Washington, DC, various dates in 1999).

energy consumption data. Expenditure amounts for five energy sources were collected by the U.S. Census Bureau.[15] These expenditures were converted from dollars to energy quantities using prices from the EIA.

The various Censuses are considered to be the most complete and consistent data available for each of the three non-manufacturing sectors. These data, supplemented by available data from the EIA, are used to derive total energy consumption for the non-manufacturing industrial sectors. The additional EIA data sources include the *State Energy Data Report 1999,*[16] the *1998 Manufacturing Energy Consumption Survey,*[17] and *Fuel Oil and Kerosene Sales 1997.*[18] The source data relate to total energy consumption and provide no information on the processes or end-uses for which the energy is consumed. Therefore, the UECs for the non-manufacturing sectors relate energy consumption for each fuel type to value of shipments. These UECs are presented in Table B10 for non-manufacturing.

Technology Possibility Curves, Unit Energy Consumption, 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 1998 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 1998 average energy use (Table B12).

The improvement for new plants assumes the plant has been built with the SOA technologies available for that process. A second and often more important set of substantial improvements is often realized when advanced technologies become available for a certain process. Often one sees a number of

---

[15]U.S. Census Bureau, *1997 Economic Census, Construction Industry Summary*, EC97C23S-IS (Washington, DC, January 2000).

[16]Energy Information Administration, *State Energy Data Report 1999, Consumption Estimates*, DOE/EIA-0214(99) (Washington, DC, May 2001).

[17]Energy Information Administration (EIA), *1998 Manufacturing Energy Consumption Survey*, (http://www.eia.doe.gov/emeu/mecs/MECS98/datatables/contents.html).

[18]Energy Information Administration, *Fuel Oil and Kerosene Sales 1997*, DOE/EIA-0535(97) (Washington, DC, August 1998). The 1997 fuel oil data were used in conjunction with the 1997 Economic Census data.

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 1998 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 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 2025, old processes (1998 stock) still operating can achieve up to 50 percent of the energy savings of SOA technology due to retrofits and other reasons listed above. Thus, if SOA technology has an REI of 0.80, old processes in the year 2025 will have an REI of 0.90. As a convenience for modeling purposes, the rate of change between the initial point and final point is defined as the technology possibility curve (TPC) and used to interpolate for the intervening points. The TPCs for the reference case are given in Table B12. For scenario analysis, a set of TPCs that reflect more rapid technology changes are also given in Appendix B. The TPCs for the high technology case are given in Table B13. The list of SOA and advanced technologies considered in the analysis is presented in Table B14.

The savings shown in the appendix for the listed technologies represent savings over "average" 1998 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 current UEC for the old and new vintage is calculated as the product of the previous year's UEC and a factor that reflects the assumed rate of intensity decline over time and the impact of energy price changes on the assumed decline rate:

$$ENPINT_{v,f,s} = ENPINTLAG_{v,f,s} * (1 + TPCRate_v) \qquad (2)$$

where:

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

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

$TPCRate_v$ = Energy intensity decline rate after accounting for the impact of increased energy prices.

The $TPCRate_v$ are calculated using the following relationships if the TPCPrat is above a threshold (1.1 in AEO2004). Otherwise, the default value for the intensity decline rate is used, $BCSC_{v,fuel,step}$.

Above the TPCPrat threshold, the following relationships hold:

$$X = TPCPrat^{TPCBeta}$$

$$TPCPriceFactor = 2 * \frac{X}{(1 + X)} \qquad (3)$$

$$TPCRate_v = TPCPriceFactor * BCSC_{v,fuel,step}$$

where:

where:	*TPCPrat*	=	Ratio of current year average industrial energy price to 1998 price;
	TPCBeta	=	Parameter of logistic function, currently specified as 4;
	TPCPriceFactor	=	TPC price factor, ranging from 0 (no price effect) to 2 for *ENPINT*;
	$TPCRate_v$	=	Intensity decline rate after accounting for changes due to energy price increases for vintage *v*; and
	$BCSC_{v,fuel,step}$	=	Default intensity rate for old and new vintage (*v*) for each fuel *f* and step *s*.

Motor Model

Electricity consumption by the machine drive end-use for the food, bulk chemicals, metal-based durables, and balance of manufacturing industries is modeled differently than for the other end-uses in these industries. Instead of using the TPC approach described above, a motor stock model calculates machine drive electricity consumption. Seven motor size groups are tracked for each industry (1-5 horsepower (hp), 6-20 hp, 21-50 hp, 51-100 hp, 101-200 hp, 201-500 hp, >500 hp).

The data for the basic motor stock model were derived from *United States Industrial Electric Motor Systems Market Opportunities Assessment*[19], a report produced for the U.S. Department of Energy's Office of Industrial Technologies (Table B15).

The motor stock model can be broken down into seven sections. The steps are outlined as follows:

[19] U.S. Department of Energy, *United States Industrial Electric Motor Systems Market Opportunities Assessment* (Burlington, MA, December 1998).

I For each failed motor, evaluate whether the motor is repaired or replaced. The cost and performance characteristics for the motor options are from the *MotorMaster+* version 4.0 software[20] (Table B16).

a. Determine the cost differential for replacing the motor. This is the difference between the cost of the new EPACT minimum efficiency motor and the cost of repairing the motor.

b. Determine the annual electricity expenditure savings from replacing the motor. This calculation requires the rated motor horsepower, the average motor part-load, the conversion factor from horsepower to kilowatts, the annual operating hours for the motor, the industrial electricity price, the efficiency rating for an EPACT minimum efficiency motor, and the efficiency rating for a repaired motor. For purposes of the analysis, the electricity price is assumed to remain constant at the level in the year the choice is made.

c. Determine the payback period needed to recover the cost differential for replacing the motor. The payback is determined by dividing the new motor cost differential by the annual electricity expenditure savings.

II Assess the market penetration for replacement motors based on the payback period and the payback acceptance curve.

a. Given the payback for each motor size group in each industry, estimate the fraction of replacement motors purchased. This analysis begins with an assumed distribution of required investment payback periods, deemed the payback acceptance curve. Rather than an actual curve, a lookup table is used (Table B17). In the table, for each integer payback period from 0 to 4 years, a fraction of new motors is specified. This quantifies the notion that the shorter the payback, the greater the fraction of firms that would choose the higher efficiency option, in this case replacing a failed motor.

b. Determine the number of new motors purchased as a result of replacements. This is the difference between the total number of motors failed and the number of replacement motors purchased.

III Determine the change in the motor stock for the year. Tracking the number, vintage, and condition of motors in the stock is necessary for calculating average efficiency and average electricity consumption for the machine drive end-use.

a. Given the value of shipments growth for each industry and the number of new motors purchased to replace failed motors, total purchases of new motors for each size group within each industry can be determined. The new motors will have a higher efficiency than the beginning stock.

---

[20] U.S. Department of Energy, *MotorMaster+ 4.0* software database (March 6,2003).

b. Given the assumed failure rate for the beginning stock of motors and the number of failed motors replaced, the number of rewound motors for each size group within each industry can be determined. Rewinding typically reduces the efficiency of motors.

c. Those motors in the beginning stock for the period which were not retired or rewound remain at their previous efficiency.

IV For each of the new motors purchased up to 500 horsepower, evaluate whether EPACT minimum efficiency motors or premium motors are chosen. The cost and performance characteristics for the motor options are also from the *MotorMaster+* version 4.0 software (Table B16).

a. Determine the cost differential for the premium motor option. This is the difference between the cost of the premium motor and the cost of the EPACT minimum efficiency motor.

b. Determine the annual electricity expenditure savings from the premium motor. This calculation requires the rated motor horsepower, the average motor part-load, the conversion factor from horsepower to kilowatts, the annual operating hours for the motor, the industrial electricity price, the efficiency rating for an EPACT minimum efficiency motor, and the efficiency rating for a premium efficiency motor. For purposes of the analysis, the electricity price is assumed to remain constant at the level in the year the choice is made.

c. Determine the payback period needed to recover the cost differential for the premium motor. The payback is determined by dividing the premium motor cost differential by the annual electricity expenditure savings.

V Assess the market penetration for premium efficiency motors based on the payback period and the payback acceptance curve.

a. Given the payback for each motor size group in each industry, estimate the fraction of premium efficiency new motors purchased. This analysis begins with an assumed distribution of required investment payback periods, deemed the payback acceptance curve. Rather than an actual curve, a lookup table is used (Table B17). In the table, for each integer payback period from 0 to 4 years, a fraction of premium motors is specified. This quantifies the notion that the shorter the payback, the greater the fraction of firms that would purchase the higher efficiency motor.

b. Determine the number of EPACT minimum efficiency motors purchased. This is the difference between the total number of motors purchased and the number of premium efficiency motors purchased.

VI Calculate the average efficiency of the end-of-year motor stock and the average electricity consumption for machine drive.

a. Determine the average electricity consumption for the motor stock as a weighted average of the electricity consumption for new premium efficiency motors, new EPACT minimum efficiency motors, rewound motors, and surviving motors.

b. Determine the average efficiency for the motor stock as a weighted average of the efficiency for new premium efficiency motors, new EPACT minimum efficiency motors, rewound motors, and surviving motors.

VII Calculate the total electricity consumption for machine drive, and the effect of system efficiency improvements. Efficiency improvements in the machine drive end-use can be accomplished by modifying the system within which the motor operates as well as by choosing a more efficient motor.

a. Determine the total electricity consumption for the motor stock from the stock of motors and the average efficiency.

b. Determine the adjusted total electricity consumption for the motor stock. Several parameters may be modified to reflect the assumptions on how the motor systems will change. There are three main types of motor systems: pump systems, fan systems, and compressor systems. For each of these types, there is a parameter which represents the total percentage of motor systems within an industry which are of that type, and one for the amount by which the system efficiency can be improved.

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 31 percent of total manufacturing heat and power energy consumption.[21] Within the BSC component, natural gas accounts for 70 percent and coal 21 percent of consumption.

The steam demand and byproducts from the PA and BLD components are passed to the BSC component, which allocates the steam demand to conventional boilers and to cogeneration. The allocation is based upon an estimate of useful thermal energy supplied by cogeneration plants. Energy for cogeneration is subtracted from total indirect fuel use as reported in MECS (given in Table B18) to obtain conventional boiler fuel use and the associated steam. An assumed average boiler efficiency and a fuel sharing equation is used to estimate the required energy consumption to meet the steam from conventional boilers.

---

[21]Computed from Energy Information Administration, Energy Information Administration, *Manufacturing Energy Consumption Survey 1998*, (www.eia.doe.gov/emeu/mecs/MECS98/datatables/contents.html). Note that byproduct and non-energy use of combustible fuels are excluded from the computation.

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 for each industry is as follows:

$$ShareFuel_i = \frac{(P_i^{\alpha_i} \beta_i)}{\sum_{i=1}^{3} P_i^{\alpha_i} (\beta_i)} \tag{4}$$

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 1998 fuel shares using the relative prices that prevailed in 1998. 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 1998 MECS and exclude waste and byproducts.

The α_i sensitivity parameters are posited to be a positive function of average energy prices of industrial boiler fuels (coal, residual fuel, and natural gas). For years after 1998, the ratio of the current year's average boiler fuel price to the corresponding average price in 1998 is computed, SwitchPrat.

Above the SwitchPrat threshold (1.05 in AEO2004), the following relationships hold:

$$X = SwitchPrat^{SwitchBeta}$$
$$SwitchPriceFactor = 4 * \frac{X}{(1 + X)} \tag{5}$$
$$\alpha_{iPrice} = SwitchPriceFactor * \alpha_i$$

where:	*SwitchPrat*	=	Ratio of current year average industrial energy price to 1998 price;
	SwitchBeta	=	Parameter of logistic function, currently specified as 4;
	SwitchPriceFactor	=	Fuel switching price factor, ranging from 0 (no price effect) to 4 for boiler shares;
	α_{iPrice}	=	Fuel switching sensitivity parameters after accounting for energy price increases;
	α_i	=	Default fuel switching sensitivity parameters.

Cogeneration capacity, generation, fuel use, and thermal output are determined from exogenous data and simulated new additions as determined from an engineering and economic evaluation. Existing cogeneration capacity and planned additions are derived from EIA's Form 860B (and predecessor) survey. The most recent data used is for 2002, with planned additions (units under construction) through 2004.[22]

The data is processed outside the model to separate industrial cogeneration from commercial sector cogeneration, cogeneration from refineries and enhanced oil recovery operations, and offsite cogeneration. Offsite cogenerators are primarily merchant power plants selling to the grid and often supplying relatively small amounts of thermal energy. The remainder, or onsite industrial cogeneration portion, is approximately 40 percent of the total cogeneration generating capacity. The cogeneration data is available on a plant basis and identifies the capacity, generation, useful thermal energy, energy use by fuel, and the shares of that energy for electricity and thermal. The data is aggregated by census region, industry, and fuel type for input to the model.

The modeling of unplanned cogeneration begins with the model year 2003, under the assumption that planned units under construction cover only some of the additions expected through 2004. In addition, we assume that any existing cogeneration capacity will remain in service throughout the forecast, or equivalently, will be refurbished or replaced with like units of equal capacity. The modeling of unplanned capacity additions is done in two parts: biomass-fueled and fossil-fueled. The biomass cogeneration is assumed to be added to the extent possible as increments of biomass waste products are produced, primarily in the pulp and paper industry. The amount of biomass cogeneration added is equal to the quantity of new biomass available (in Btu), divided by the total heat rate assumed from biomass steam turbine cogeneration.

Additions to fossil-fueled cogeneration are based on an economic assessment of capacity that could be added to generate the industrial steam requirements that are not already met by existing cogeneration. The driving assumption is that the technical potential for traditional cogeneration is primarily based on supplying thermal requirements. We assume that the cogenerated electricity can be used to either reduce purchased electricity or it can be sold to the grid. For simplicity, the approach is generic such that the characteristics of the cogeneration plants are set by the user. The fuel used is assumed to be natural gas.

The steps to the approach are outlined as follows:

I Assess the steam requirements that could be met by new cogeneration plants

1. Given total steam load for the industry in a region from the process-assembly and the buildings components, subtract steam met by existing cogenerators.

2. Classify non-cogenerated steam uses into eight size ranges, or load segments, based on an exogenous data set providing the boiler size distribution for each industry and assuming that steam loads are distributed in the same proportions as boiler capacity (Table B19). Also obtained from the same exogenous data set is the average boiler size (in terms of fuel input per hour) in each load segment, which is used to size the

[22]EIA has comprehensively reviewed and revised how it collects, estimates, and reports fuel use for facilities producing electricity. For a detailed discussion, see Energy Information Administration, Annual Energy Review 2001, DOE/EIA-0384 (2001), November 2002, Appendix H, “estimating and Presenting Power Sector Fuel Use in EIA Publications and Analyses,” web site www.eia.doe.gov/emeu/aer/pdf/pages/sec_h.pdf.

prototypical cogeneration system in each load segment. The prototype cogeneration system sizing is based on meeting the steam generated by the average-sized boiler in each load segment.

3. Establish the average hourly steam load in each segment from the aggregate steam load to determine total technical potential for cogeneration (discussed further below).

II Evaluate a gas turbine system prototype for each size range

a. A candidate cogeneration system is established for each load segment with thermal output that matches the steam output of the average-sized boiler in each load segment. To do this, the user-supplied characteristics for eight cogeneration systems are used (Table B20):

- Net electric generation capacity in kilowatts
- Total installed cost, in 2003 dollars per kilowatt hour-electric
- System capacity factor
- Total fuel use per kilowatt hour
- Fraction of input energy converged to useful heat and power

From the above user-supplied characteristics, the following additional parameters for each system are derived:

- Fraction of input energy converted to electric energy, or electric energy efficiency
- Electric generation from the cogeneration plant in megawatt hours
- Cogeneration system fuel use per year in billion Btu
- Power-Steam Ratio
- Steam output of the cogeneration system

b. Determine the investment payback period needed to recover the prototypical cogeneration investment for each of the eight system sizes. The analysis considers the annual cash flow from the investment to be equal to the value of the cogenerated electricity, less the cost of the incremental fuel required to generate it. For this purpose, the annual cost of fuel (natural gas) and the value of the electricity are based on the prices in effect in the model year in which the evaluation is conducted. For electricity, we assume the electricity is valued at the average industrial electricity price in the region, net of standby charges that would be incurred after installing cogeneration. The standby charges were assumed to be some fraction of the industrial electricity rate (usually 10 percent). For natural gas, the price of firm-contract natural gas was assumed to apply. The payback is determined by dividing the investment by the average annual cash flow.

III Assess Market Penetration Based on Payback and Payback Acceptance Curve

a. Determine the maximum technical potential for cogeneration under the assumption that all non-cogeneration steam for each load segment is converted to cogeneration. This assumes that the technical potential is based on 1) sizing systems, on average, to meet the average hourly steam load in each load segment and 2) the power-steam ratio of the prototype cogeneration system.

b. Given the payback for the prototype system evaluated, estimate the fraction of total technical potential that is considered economical. To do this, we start with an assumption about the distribution of required investment payback periods deemed the payback acceptance curve. Rather than using an actual curve, we use a table of assumptions that, when plotted, is referred to as a payback acceptance curve (Table B21). In the table, for each integer payback period from 0 to 12 years, we assume that some fraction of cogeneration investments would be considered acceptable. This quantifies the notion that the shorter the payback, the greater the fraction of firms that would be willing to invest. It can also capture the effect that market barriers have in discouraging cogeneration investment.

c. Given the total economic potential for cogeneration, estimate the amount of capacity that would be added in the current model year. The annual capacity additions can be estimated based on some pattern on market penetration over time. For simplicity, it is assumed that the economic potential would penetrate over a 20 year time period. Thus, 5 percent of the economic potential is assumed to be adopted each year. Since the amount of technical and economic potential is reevaluated in each model year as economic conditions and steam output change, the annual additions will vary. However, over the 20-year forecast horizon, if economic conditions remained constant and steam loads did not increase, the cumulative capacity additions would be equal to the total economic potential determined in the first model forecast year.

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 1998 and is assumed to retire at a fixed rate each year. Middle vintage capital is that which is added from 1998 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-1998 capital stock. The retirement rates used in the Industrial Model for the various industries are listed in Table B12.

Existing old and middle vintage production is reduced by the retirement rate of capital through the following equations. The retirement rate is posited to be a positive function of energy prices. For years after 1999, the ratio of the current year's average industrial energy price to the average price in 1998 is computed as RetirePrat.

Above the RetirePrat threshold, the following relationships hold:

$$X = RetirePrat^{RetireBeta}$$

$$RetirePriceFactor = 2 * \frac{X}{(1 + X)} \tag{6}$$

$$RetireRate_s = RetirePriceFactor * ProdRetr_s$$

where:	*RetirePrat*	=	Ratio of current year average industrial energy price to 1998 price;
	RetireBeta	=	Parameter of logistic function, currently specified as 2 for capital stock retirement;
	RetirePriceFactor	=	TPC price factor, ranging from 0 (no price effect) to 2;
	$RetireRate_s$	=	Retirement rate after accounting for energy price increases for step *s*; and
	$ProdRetr_s$	=	Default retirement rate for step *s*.

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. The expected percentage for recycling in the Paper and Allied Products and Blast Furnace and Basic Steel Products industries are shown in Table B22.

Legislative Implications

The Energy Policy Act of 1992 (EPACT) and the Clean Air Act Amendments of 1990 (CAAA90) 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. EPACT sets minimum efficiency levels for all motors up to 200 horsepower purchased after 1998. All of the motors available in the motor model are at least as efficient as the EPACT standards. The industrial model incorporates the necessary reductions in unit energy consumption for the energy-intensive industries.

Cogeneration

The cogeneration assessment requires three basic sets of assumptions: 1) cost and performance characteristics of prototypical plants in various size ranges; 2) data to disaggregate steam loads by industry into several size ranges, or load segments; and 3) market penetration assumptions to quantify the relationship between the economics of cogeneration and its adoption over time. These assumptions are introduced into the model through a spreadsheet file. The cogeneration assumptions used for the *Annual Energy Outlook 2004* are presented in Tables B19, B20, and B21.

Benchmarking

The Industrial Model energy demand forecasts are benchmarked to values presented in *Annual Energy Review 2002*. The national-level values reported in *Annual Energy Review 2002* were allocated to the Census Divisions using the *State Energy Data Report 1999*. 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. EIA has comprehensively reviewed and revised how it collects, estimates, and reports fuel use for facilities producing electricity.[23] The specific impacts on reported industrial energy consumption are discussed in Energy Information Administration, *Annual Energy Outlook 2003*, pp. 32-34.[24] Additional calibration for the years 2001-2004 are performed to conform with the *Short-Term Energy Outlook*.

---

[23]For a detailed discussion, see Energy Information Administration, Annual Energy Review 2001, DOE/EIA-0384 (2001), November 2002, Appendix H, "estimating and Presenting Power Sector Fuel Use in EIA Publications and Analyses," web site www.eia.doe.gov/emeu/aer/pdf/pages/sec_h.pdf.

[24]Energy Information Administration, Annual Energy Outlook 2003, DOE/EIA-0383(2003) (January 2003), web site www.eia.doe.gov/oiaf/pdf/0383(2003).pdf.

4. Model Structure

Outline of Model

Table 3 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 calls some data initialization subroutines, including one to retrieve energy price and macroeconomic data (Setup_Mac_and_Price), and calls routines to solve the model (ISEAM) and to export its results to NEMS global variables (WEXOG).

Table 3. Outline of NEMS Industrial Module

Industrial Module Solution Outline

I. First Year: Initialize Data

A. RCNTL: Read Control Options

B. IRCOGEN: Read cogeneration data files (called from IND)

C. MecsLess860B: Calculate 1998 boiler fuel by subtracting 860B cogeneration fuel from 1998 Mecs indirect fuels.

D. REXOG: Assign exogenous macroeconomic and energy price variables that come from NEMS.

E. IEDATA: Read ENPROD file with industry production parameters, base year industrial output, UECs, elasticities and other coefficients; Much of the data originally read from ENPROD is now read from two files, ITECH.txt and Prodflow.txt via subroutines UECTPC and MECS94, respectively.

  1. MECS98: Read PRODFLOW.TXT containing process/assemplty step definitions and flow rates from most recent MECS data (1998)

F. UECTPC: Read ITECH.txt file with MECS-based UEC rates and the TPC assumptions

G. RSTEO: Read Short Term Energy Outlook File with last available history data and national projections for the next two years.

Industry Processing:

Loop through each of 15 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

H. RDBIN: Read memory management file with previous year's data for this industry, region

I. CALPROD: Compute revised productive capacity and throughput by process/assembly step and vintage; implement retirement and vintaging assumptions.

J. CALCSC: Conservation Supply Curve: Evaluate changes in UECs based on Technological Possibility

K. CALBYPROD: Calculate consumption of byproduct fuels

L. CALPATOT: Compute consumption of energy in the process assembly component

  1. MOTORS: Compute consumption of electricity for machine-drive for four end-use industries
  2. 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.

M. CALBTOT: Compute consumption of energy in the buildings component

N. CALGEN: Compute electricity generation for sale and internal use by fuel. Calculates steam for cogeneration and estimates penetration of new builds. Calls the following routines:

  1. COGENT Read cogen assumptions spreadsheet (first year)
  2. SteamSeg Assign fraction of steam load in current load segment for current industry
  3. COGINIT Initialize the cogen data arrays with capacity, generation, and fuel use data
  4. EvalCogen Evaluate investment payback of a cogen system in a given year

O. CALBSC: Estimate boiler fuel shares as a function of changing boiler fuel prices.

P. CALSTOT: Compute Energy consumption in the Boiler-Steam-Cogeneration (BSC) component

Q. WRBIN: Write memory management file with data on this industry, region

R. INDTOTAL: Accumulate total energy consumption for the industry

II. National Sums:

A. NATTOTAL: Accumulate total energy consumption over all industries

B. CONTAB: Accumulate aggregates for non-manufacturing heat and power

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

A. SEDS Benchmarking:

  1. SEDS years (through 1999): calculate regional benchmark factors as the ratio of actual consumption to model consumption for each fuel in four Census regions.
  2. Post SEDS Years (2000-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 2001 to 2003, multiply model consumption by the STEO benchmark factors.

E. Assign final results to NEMS variables

Setup_Mac_and_Price

In subroutine "Setup_Mac_and_Price," the value of shipments data from the NEMS Macroeconomic (MACRO) model is processed. 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. The Industrial Model energy demand forecasts are benchmarked to values presented in *Annual Energy Review 2001* in subroutine WEXOG. The national-level values reported in *Annual Energy Review 2001* were allocated to the Census Divisions using the *State Energy Data Report 1999*. Because detailed 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.

$$PRCX_{elec,r} = \frac{\sum_{d=1}^{NUM_r} DPRCX_{elec,r} \ x \ QSELIN_{d,1999}}{\sum_{d=1}^{NUM_r} QSELIN_{d,1999}} \qquad (7)$$

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

$QSELIN_{d,1998}$ = SEDS consumption of electricity in Census division *d* in 1999.

IND calls two subroutines: ISEAM, the subroutine that guides the industrial model calculations, and WEXOG, the subroutine that reports the results back to NEMS. The other fuels are calculated in the same manner.

ISEAM

ISEAM controls all of the industrial model calculations and initiates some of the model input operations. It opens external files for debugging, binary files for restarting on successive iterations and forecast years, and opens the input data files. In the first model year and only on the first iteration, ISEAM calls RCNTRL to read runtime parameters file (INDRUN.TXT) and base year boiler data (ITLBSHR.TXT). ISEAM also reads a data file, INDBEU.TXT, containing building energy use containing energy for lighting, heating, ventilation, and air conditioning. ISEAM 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, UECTPC, CALBYPROD, CALPATOT, CALBTOT, CALGEN, CALBSC, 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 subroutines ADDUPCOGS and INDCGN to aggregate and report industrial cogeneration estimates to NEMS.

Subroutine RCNTRL

RCNTRL reads data from the input files INDRUN.TXT and ITLBSHR.TXT. The INDRUN.TXT 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. The ITLBSHR.TXT data contain estimated 1998 boiler energy use by fuel and is used for calculating boiler fuel shares.

Subroutine REXOG

REXOG prepares exogenous data obtained from the NEMS MACRO model for use in the industrial model. Dollar value of shipments and employment are aggregated over the appropriate Census divisions to obtain data at the Census region level. The macroeconomic variables used by the industrial model continue to be based on SIC categories rather than NAICS categories. For value of shipments, the SIC categories are mapped directly into the appropriate NAICS category. Employment data is obtained from NEMS at the two digit SIC level and mapped into the appropriate NAICS category. For some industries, employment data must be shared out between industries at the same two digit SIC level. (Note that the MACRO model's employment forecasts are based on Standard Industrial Classification Codes rather than NAICS codes.) In particular, the chemical industry (SIC 28) is grouped into bulk chemicals (SICs 281, 282, 286, and 287) and other chemicals. 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.TXT is the name of the initial 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. However, most of the data originally read from the ENPROD file is now read from several other files from other routines, including PRODFLOW.TXT (subroutine MECS98), ITECH.TXT (Subroutine UECTPC), INDBEU.TXT (Subroutine ISEAM), and ITLBSHR.TXT (Subroutine RDCNTL). As a result, many of the routines previously called by IEDATA have been removed. The remaining routines (and replacement routines in parentheses) are as follows:

Subroutine IRHEADER

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

The ratio of physical output to 1998 value of shipments for pulp and paper, glass, cement, steel and aluminum industries is calculated. This constant ratio is applied to value of shipments in subsequent years.

$$PHDRAT_i = \frac{PHYSICAL_i}{PRODVX_{i,r}} \tag{8}$$

where: $PHDRAT_i$ = Ratio of physical units to value of shipments for industry *i*,

$PHYSICAL_i$ = Physical units of output for industry *i*, and

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

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

$$PRODX_{i,r} = PHDRAT_i \ x \ PRODVX_{i,r} \tag{9}$$

where: $PRODX_{i,r}$ = Output in physical units for industry *i* in Census region *r*,

$PHDRAT_i$ = Ratio of physical units to value of shipments in industry *i*, and

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

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

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

where: $PRODX_{i,r}$ = Value of shipments for industry *i* in Census region *r*, and

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

Subroutine MECS98 (previously, IRSTEPDEF)

Get production throughput coefficients, process step retirement rates, and other process step flow information from the file PRODFLOW.TXT.. This 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:

$Y_1 =$ Output, in tons
$Y_2 = 0.443\ Y_1$
$Y_3 = 0.164\ Y_1 + 0.164\ Y_2$
$Y_4 = 0.068\ Y_1 + 0.068\ Y_2$
$Y_5 = 0.037\ Y_1 + 0.037\ Y_2$
$Y_6 = 0.424\ Y_1 + 0.424\ Y_2$
$Y_7 = 0.998\ Y_4 + 0.998\ Y_5 + 0.998\ Y_6$

If $Y_1 = 81$ million tons of paper produced, 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 1998 or earlier. Middle vintage includes installations from 1999 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 (routines in parentheses are routines that replace routines that originally read that data from the ENPROD.TXT file.)

(ISEAM)	Get building energy use data including lighting; heating, ventilation, and air conditioning; facility support; and onsite transportation from INDBEU.TXT
IRBSCBYP	Get byproduct fuel information for the boiler/steam/cogeneration component. These data consist of fuel identifier numbers of steam intensity values.
(RDCNTL)	Reads INDRUN.TXT and ITLBSHR.TXT. The latter contains base year boiler fuel use and is used to calculate boiler fuel shares. Biomass data is retrieved in the IRBSCBYP routine.
(IRCOGEN)	Get cogeneration information from file EXSTCAP.TXT, including capacity, generation, fuel use, and thermal output from 1990 through 2000. Get corresponding data for planned units from file PLANCAP.TXT
IRSTEPBYP	Get byproduct data for process and assembly component. These data consist of fuel identifier numbers and heat intensity values.
(MECS98)	Get process step data for the energy intensive industries from PRODFLOW.TXT. These data consist of fuel identifier numbers, base year process step flow rates and retirement rates.
(UECTPC)	Reads a data file, Industrial Technology (ITECH.TXT), to update the initial ENPROD.TXT data file with 1998 values of UECs and TPCs. The second half of this file is reserved for use in a high technology case.
(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:

$$PRODSUM_{s,l} = PRODFLOW_{old,s,l} \times PRODX_{i,r} \qquad (11)$$

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:

$$PRODSUM_{s,l} = PRODFLOW_{old,s,l} \times PRODCUR_{total,IP} \qquad (12)$$

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

$PRODCUR_{total,IP}$ = 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:

$$PRODCUR_{total,s} = \sum_{l=1}^{NTMAX_s} PRODSUM_{s,l} \qquad (13)$$

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. The TPC for biomass byproducts is posited to be a positive function of energy prices. Other byproducts, such as blast furnace gas, are unrelated to energy prices. Currently, only the paper and allied products industry has a TPC for biomass byproducts. For all other industries the UEC remains unchanged. For years after 1998, the ratio of the current year's average industrial energy price to the average price in 1998 is computed, TPCPrat. If TPCPrat is above a threshold, the positive TPC (0.001 by default) is an increasing function of TPCPrat.

Above the TPCPrat threshold, the following relationships hold:

$$X = TPCPrat^{TPCBeta}$$

$$TPCPriceFactor = \frac{X}{(1 + X)} \tag{14}$$

$$TPCRate_v = 2 * TPCPriceFactor * BYPCSC_{v,f,s}$$

where:	$TPCPrat$	=	Ratio of current year average industrial energy price to 1998 price;
	$TPCBeta$	=	Parameter of logistic function, currently specified as 4;
	$TPCPriceFactor$	=	TPC price factor, ranging from 0 (no price effect) to 2 for byproducts;
	$TPCRate_v$	=	TPC multiplier on TPC rate due to energy price increases for vintage v;
	$BYPCSC_{v,f,s}$	=	Initial TPC for vintage v, fuel f, and step s.

CALBYPROD calculates the rate of byproduct energy produced for each process step, fuel, for the new and old vintages as 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.

$$BYPINT_{v,f,s} = (BYPINTLag_{v,f,s})^{TPCRate_v} \tag{15}$$

where:	$BYPINT_{v,f,s}$	=	Rate of byproduct energy production (or UEC) 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

$TPCRate_v$ = TPC for vintage v.

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

$$BYPINT_{mid,f,s} = \left(\frac{(PRODLag_{mid,s} * BYPINTLag_{mid,f,s}) + (PRODLag_{new,s} * BYPINTLag_{new,f,s})}{PRODLag_{mid,s} + PRODLag_{new,s}} \right)^{TPCRate_{old}} \quad (16)$$

where: $PRODLAG_{new,s}$ = Prior year production from new capacity at process step s,

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

$PRODLAG_{mid,s}$ = Prior year production from middle capacity at process step s, and

$TPCRate_{old}$ = TPC multiplier for vintage *old*.

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.

$$BYPQTY_{v,f,s} = PRODCUR_{v,s} \ x \ BYPINT_{v,f,s} \quad (17)$$

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.

$$ENBYPM_{f,v} = \sum_{s=1}^{MPASTP} BYPQTY_{v,f,s} \quad (18)$$

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. 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.

$$ENPQTY_{v,f,s} = PRODCUR_{v,s} \times ENPINT_{v,f,s} \quad (19)$$

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.

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:[25]

- 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,

[25]Still gas and petroleum coke are consumed primarily in the refining industry, which is modeled in the Petroleum Market Module of NEMS.

- 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 although only the first three are represented in the model:

- 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.

$$ENPMQTY_f = \sum_{s=1}^{MPASTP} ENPQTY_{total,f,s} \tag{20}$$

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.

$$ENPMQTY_{coke} = ENPIQTY_{coke} - \left[PRODCUR_{total,co} \ x \ \frac{24.8}{10^6} \right] \tag{21}$$

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 MOTORS

Subroutine MOTORS calculates machine drive energy consumption for the end use manufacturing industries (food, bulk chemicals, metal-based durables, and the balance of manufacturing). The motor model is a stock model which tracks the number of motors in each of these four industries for seven size groups (1-5 horsepower (hp), 6-20 hp, 21-50 hp, 51-100 hp, 101-200 hp, 201-500 hp, >500 hp). The first step is to initialize the following variables for their base year (1998) values:

$MotorStock_{i, s, r, y}$	=	Motor stock for industry *i*, motor size group *s*, Census region *r*, and year *y* (1998), number of motors,
$MotAvgEnergy_{i, s, r, y}$	=	Average energy consumption per motor for industry *i*, motor size group *s*, Census region *r*, and year *y* (1998), kWh per motor per year,
$MotAvgEff_{i, s, r, y}$	=	Average motor energy efficiency for industry *i*, motor size group *s*, Census region *r*, and year *y* (1998),
$FailurePct_{i, s}$	=	Percentage of motors which fail each year for industry *i* and motor size group *s,*
$MotorRetPct_{i, s}$	=	Percentage of motors retired upon failure for industry *i* and motor size group *s,*
$MotorRewDrop_{i, s}$	=	Drop in efficiency for rewound motors in industry *i* and motor size group *s,*
$MotorSysLife_{i, s}$	=	Motor system efficiency improvement life for motors in industry *i* and motor size group *s,*
$PumpAppPct_{i, s}$	=	Motor system efficiency applicability, percentage of pump systems in industry *i* and motor size group *s,*
$FanAppPct_{i, s}$	=	Motor system efficiency applicability, percentage of fan systems in industry *i* and motor size group *s,*

$CompAppPct_{i,\,s}$ = Motor system efficiency applicability, percentage of compressor systems in industry i and motor size group s,

$PumpSavPct_{i,\,s}$ = Motor system efficiency savings fraction for pump systems in industry i and motor size group s,

$FanSavPct_{i,\,s}$ = Motor system efficiency savings fraction for fan systems in industry i and motor size group s, and

$CompSavPct_{i,\,s}$ = Motor system efficiency savings fraction for compressor systems in industry i and motor size group s.

Once these variables have been initialized, the base year energy consumption is calculated:

$$TotalMotorEnergy_{i,\,s,\,r,\,y} = MotorStock_{i,\,s,\,r,\,y} * MotAvgEnergy_{i,\,s,\,r,\,y} * 3412 \;/\; 10^{12} \qquad (22)$$

where: $TotalMotorEnergy_{i,\,s,\,r,\,y}$ = Motor energy consumption in trillion Btu for industry i, motor size group s, Census region r, and year y (1998), and

$MotorStock_{i,\,s,\,r,\,y}$ and $MotAvgEnergy_{i,\,s,\,r,\,y}$ are defined above.

Projections of the motor stock, and the associated energy consumption are grounded in these initial base year values. The growth in the value of shipments for each industry provided by the macroeconomic module is the driving force determining the overall stock of motors. New motors are purchased to accommodate the projected industrial growth as well as to replace retired motors. The number of motors retired upon failure is evaluated using a cost and performance algorithm. The initial cost differential for replacing the failed motor is weighed against the energy expenditure savings to determine the payback period in years. A payback acceptance curve provides the split between replaced and repaired motors. The first calculation is the price differential for the new motor:

$$ReplacePrPrem_{i,\,s} = EEListPrice * (1 - DealerDisc) - RewindCost_{i,\,s} \qquad (23)$$

where: $ReplacePrPrem_{i,\,s}$ = Premium for replacing the failed motor for industry i, and motor size group s,

$EEListPrice$ = The manufacturers' list price for a minimum efficiency motor,

$DealerDisc$ = The average dealer discount offered on purchases of minimum efficiency motors, and

$RewindCost_{i,\,s}$ = The cost to rewind the failed motor.

The energy expenditure savings are calculated as follows:

$$ReplaceAnnSav_{i,s,r,y} = MotorHP_{i,s} * AvgPartLoad_{i,s} * HPtoKW * MotorOpHr_{i,s} * IndElecPrice_{r,y} * ((1 / RewoundEff_{i,s}) - (1 / EEPctEff_{i,s})) \quad (24)$$

where:

$ReplaceAnnSav_{i,s}$ = The expected annual savings from the replacing the failed motor with a minimum efficiency motor for industry *i*, and motor size group *s*, in 2002 dollars,

$MotorHP_{i,s}$ = The rated motor horsepower for industry *i*, and motor size group *s*,

$AvgPartLoad_{i,s}$ = The average motor part load for industry *i*, and motor size group *s*,

$HptoKW_{i,s}$ = The conversion factor from horsepower to kilowatts,

$MotorOpHr_{i,s}$ = The annual operating hours for motors in industry *i*, and motor size group *s*,

$IndElecPr_{r,y}$ = The industrial electricity price for region *r*, and year *y*, in 2002 dollars per kWh,

$RewoundEff_{i,s}$ = The efficiency rating for a rewound motor for industry *i*, and motor size group *s*, and

$EEPctEff_{i,s}$ = The efficiency rating for an EPACT minimum efficiency motor for industry *i*, and motor size group *s*.

The simple payback period in years is:

$$ReplacePayback_{i,s,r,y} = ReplacePrPrem_{i,s} / ReplaceAnnSav_{i,s,r,y} \quad (25)$$

where:

$ReplacePayback_{i,s,r,y}$ = Payback, in years, for replacing a failed motor with a minimum efficiency motor purchased for industry *i*, motor size group *s*, Census region *r*, and year *y*, and

$ReplacePrPrem_{i,s}$ and $ReplaceAnnSav_{i,s,r,y}$ are defined above.

Given the payback calculated for each industry and motor size group, the model estimates the number of failed motors which are replaced with EPACT minimum efficiency motors and the number of failed motors which are retired. This calculation uses an assumed distribution of required investment payback periods referred to as the payback acceptance curve. Rather than using an actual curve, a table of assumed acceptance rates is used for each integer payback period from 0 to 4 years. To obtain an acceptance fraction, or economic fraction, from a non-integer value for payback, a linear interpolation is done. The economic fraction is determined from a table lookup and interpolation function called Acceptance, given the table of acceptance fractions, the number of rows in the table (5), and the payback period for the motor size group:

$$ReplaceAccept_{i,s,r,y} = Acceptance\ (\ PremAccept\ ,\ 5\ ,\ ReplacePayback_{i,s,r,y}\ ) \tag{26}$$

where: $ReplaceAccept_{i,s,r,y}$ = Fraction of premium efficiency motors purchased based on payback period acceptance assumptions,

$PremAccept$ = Array of payback acceptance rates corresponding to integer payback periods ranging from 0 to 4 (5 rates altogether), and

$ReplacePayback_{i,s,r,y}$ is defined above.

The number of failed motors is given by:

$$FailedMotors_{i,s,r,y} = MotorStock_{i,s,r,y-1} * FailurePct_{i,s} \tag{27}$$

Finally, the number of motors purchased to replace failed motors is given by:

$$RepMotorFlow_{i,s,r,y} = FailedMotors_{i,s,r,y} * ReplaceAccept_{i,s,r,y} \tag{28}$$

where: $RepMotorFlow_{i,s,r,y}$ = The number of new motors purchased to replace failed motors based on payback period acceptance assumptions, and

$Failed\ Motors_{i,s,r,y}$ and $ReplaceAccept_{i,s,r,y}$ are defined above.

The total number of motors purchased is:

$$TotalMotorFlow_{i,s,r,y} = MotorStock_{i,s,r,y-1} * IndShipGr_{i,r,y} + RepMotorFlow_{i,s,r,y} \tag{29}$$

where: $TotalMotorFlow_{i,s,r,y}$ = New motors purchased for industry i, motor size group s, Census region r, and year y,

$IndShipGr_{i,r,y}$ = Growth from previous year in industrial value of shipments for industry i, Census region r, and year y, and

$MotorStock_{i,s,r,y-1}$ and $RepMotorFlow_{i,s,r,y}$ are defined above.

The new motor stock is then:

$$MotorStock_{i,s,r,y} = MotorStock_{i,s,r,y-1} - FailedMotors_{i,s,r,y} + RewoundMotors_{i,s,r,y} + TotalMotorFlow_{i,s,r,y} \quad (30)$$

All variables are defined above.

In order to track the various vintages with their differing efficiencies, one additional calculation is required:

$$RewoundMotors_{i,\,s,\,r,\,y} = FailedMotors_{i,\,s,\,r,\,y} * RepMotFlow_{i,\,s,\,r,\,y} \quad (31)$$

where: $RewoundMotors_{i,\,s,\,r,\,y}$ = Number of motors rewound for industry *i*, motor size group *s*, Census region *r*, and year *y*, and

$FailedMotors_{i,\,s,\,r,\,y-1}$ and $RepMotFlow_{i,\,s,\,r,\,y}$ are defined above.

Before calculating the projected motor energy consumption for the four industries, a decision must be made whether EPACT minimum efficiency motors, or premium efficiency motors are purchased. This decision is made for all new motors purchased, whether to accommodate growth in the industry, or to replace failed motors. The decision is evaluated by a cost and performance algorithm. The initial cost differential for the premium motor is weighed against the energy expenditure savings to determine the payback period in years. A payback acceptance curve provides the split between premium and minimum efficiency motors purchased. The first calculation is the price differential for the premium efficiency motor:

$$PEPricePrem_{i,\,s} = (PEListPrice_{i,\,s} - EEListPrice_{i,\,s}) * (1 - DealerDisc) \quad (32)$$

where: $PEPricePrem_{i,\,s}$ = The price premium for the premium efficiency motor for industry *i*, and motor size group *s*, in 2002 dollars,

$PEListPrice_{i,\,s}$ = The price for the premium efficiency motor for industry *i*, and motor size group *s*, in 2002 dollars,

$EEListPrice_{i,\,s}$ = The price for the EPACT minimum efficiency motor for industry *i*, and motor size group *s* in 2002 dollars, and

DealerDisc = The average dealer discount offered on motor purchases.

The EPACT minimum efficiency standards only apply to motors up to 200 horsepower, and the Motor Master+ database only includes premium motor characteristics for motors up to 350 horsepower, so there currently is no premium efficiency motor option for the largest motor size group.

The energy expenditures savings are calculated as follows:

$$PEAnnSav_{i,s,r,y} = MotorHP_{i,s} * AvgPartLoad_{i,s} * HPtoKW * MotorOpHr_{i,s} * IndElecPrice_{r,y} * ((1 / EEPctEff_{i,s}) - (1 / PEPctEff_{i,s})) \tag{33}$$

where:

$PEAnnSav_{i,s}$ = The expected annual savings from the premium efficiency motor for industry i, and motor size group s, in 2002 dollars

$MotorHP_{i,s}$ = The rated motor horsepower for industry i, and motor size group s,

$AvgPartLoad_{i,s}$ = The average motor part load for industry i, and motor size group s,

$HPtoKW_{i,s}$ = The conversion factor from horsepower to kilowatts,

$MotorOpHr_{i,s}$ = The annual operating hours for motors in industry i, and motor size group s,

$IndElecPr_{r,y}$ = The industrial electricity price for region r, and year y, in 2002 dollars per kWh

$EEPctEff_{i,s}$ = The efficiency rating for an EPACT minimum efficiency motor for industry i, and motor size group s, and

$PEPctEff_{i,s}$ = The efficiency rating for a premium efficiency motor for industry i, and motor size group s.

The simple payback period in years is:

$$PEPayback_{i,s,r,y} = PEPrPrem_{i,s} / PEAnnSav_{i,s,r,y} \tag{34}$$

where:

$PEPayback_{i,s,r,y}$ = Payback, in years, for premium efficiency motors purchased for industry i, motor size group s, Census region r, and year y,

$PEPrPrem_{i,s}$ and $PEAnnSav_{i,s,r,y}$ are defined above.

Given the payback calculated for each industry and motor size group, the model estimates the number of premium motors and the number of EPACT minimum efficiency motors purchased. This calculation uses an assumed distribution of required investment payback periods referred to as the payback acceptance curve. Rather than using an actual curve, a table of assumed acceptance rates is used for each integer payback period from 0 to 4 years. To obtain an acceptance fraction, or economic fraction, from a non-integer value for payback, a linear interpolation is done. The economic fraction is determined from a table lookup and interpolation function called Acceptance, given the table of acceptance fractions, the number of rows in the table (5), and the payback period for the motor size group:

$$MotAccept_{i,s,r,y} = Acceptance\ (\ PremAccept\ ,\ 5\ ,\ PEPayback_{i,s,r,y}\ ) \tag{35}$$

where: $MotAccept_{i,s,r,y}$ = Fraction of premium efficiency motors purchased based on payback period acceptance assumptions

$PremAccept$ = Array of payback acceptance rates corresponding to integer payback periods ranging from 0 to 4 (5 rates altogether)

$PEPayback_{i,s,r,y}$ is defined above.

Finally, with all the motor rewind and purchase decisions complete, the projections of energy consumption for motors are made. The number of premium efficiency motors is calculated as:

$$PremMotorFlow_{i,s,r,y} = TotalMotorFlow_{i,s,r,y} * MotAccept_{i,s,r,y} \tag{36}$$

where: $PremMotorFlow_{i,s,r,y}$ = Number of premium efficiency motors purchased for industry i, motor size group s, Census region r, and year y,

$TotalMotorFlow_{i,s,r,y}$ and $MotAccept_{i,s,r,y}$ are defined above.

The number of EPACT minimum efficiency motors follows:

$$EffMotorFlow_{i,s,r,y} = TotalMotorFlow_{i,s,r,y} - PremMotorFlow_{i,s,r,y} \tag{37}$$

where: $EffMotorFlow_{i,s,r,y}$ = Number of EPACT minimum efficiency motors purchased for industry i, motor size group s, Census region r, and year y,

$TotalMotorFlow_{i,s,r,y}$ and $PremiumMotorFlow_{i,s,r,y}$ are defined above.

When motors are rewound, there is generally a drop in efficiency. The magnitude of the efficiency decline can be specified by the user. The equation to calculate the efficiency of rewound motors is:

$$RewoundEff_{i,s,r,y} = MotAvgEff_{i,s,r,y-1} - MotRewDrop_{i,s} \tag{38}$$

where: $RewoundEff_{i,s,r,y}$ = The efficiency of rewound motors for industry i, motor size group s, Census region r, and year y,

$MotRewDrop_{i,s}$ = The drop in efficiency for rewound motors in industry *i*, motor size group *s*, and

$MotAvgEff_{i,s,r,y}$ is defined above.

The efficiency of new motors is calculated as a weighted average of the EPACT minimum efficiency and the premium efficiency motors purchased:

$$NewMotorEff_{i,s,r,y} = ((EEPctEff_{i,s} * EffMotorFlow_{i,s,r,y} + (PEPctEff_{i,s} * PremMotorFlow_{i,s,r,y})) / TotalMotorFlow_{i,s,r,y} \quad (39)$$

where: $NewMotorEff_{i,s,r,y}$ = The average efficiency of new motors for industry *i*, motor size group *s*, Census region *r*, and year *y*,

$EEPctEff_{i,s}$, $EffMotorFlow_{i,s,r,y}$, $PEPctEff_{i,s}$, $PremMotorFlow_{i,s,r,y}$, and $PremMotorFlow_{i,s,r,y}$ are defined above.

The average amount of energy consumed by the new motors purchased is given by:

$$NewMotorEnergy_{i,s,r,y} = MotAdjEnergy_{i,s,r,y-1} * \left(1 - \frac{(NewMotorEff_{i,s,r,y} - MotAvgEff_{i,s,r,y-1})}{NewMotorEff_{i,s,r,y}}\right) \quad (40)$$

where: $NewMotorEnergy_{i,s,r,y}$ = The average energy consumed by new motors for industry *i*, motor size group *s*, Census region *r*, and year *y*, in kWh per motor per year.

$MotAdjEnergy_{i,s,r,y-1}$ = The adjusted average energy consumed by motors for industry *i*, motor size group *s*, Census region *r*, and year *y-1*, in kWh per motor per year. The process used to adjust the average energy is described below,

$NewMotorEff_{i,s,r,y}$, and $MotAvgEff_{i,s,r,y-1}$ are defined above.

The average amount of energy consumed by the rewound motors is given by:

$$RewMotorEnergy_{i,s,r,y} = MotAdjEnergy_{i,s,r,y-1} * \left(1 - \frac{(RewoundEff_{i,s,r,y} - MotAvgEff_{i,s,r,y-1})}{RewoundEff_{i,s,r,y}}\right) \quad (41)$$

where: $RewMotorEnergy_{i,s,r,y}$ = The average energy consumed by rewound motors for industry *i*, motor size group *s*, Census region *r*, and year *y*, in kWh per motor per year,

$MotAdjEnergy_{i,s,r,y-1}$ = The adjusted average energy consumed by motors for industry *i*, motor size group *s*, Census region *r*, and year

y-1, in kWh per motor per year. The process used to adjust the average energy is described below,

$RewoundEff_{i,s,r,y}$, and $MotAvgEff_{i,s,r,y-1}$ are defined above.

The average amount of energy consumed by all motors in the stock is given by:

$$MotAvgEnergy_{i,s,r,y} = (((MotorStock_{i,s,r,y-1} - RewoundMotors_{i,s,r,y} - RetiredMotors_{i,s,r,y}) * MotAdjEnergy_{i,s,r,y-1}) + (TotalMotorFlow_{i,s,r,y} * NewMotorEnergy_{i,s,r,y}) + (RewoundMotors_{i,s,r,y} * RewMotorEnergy_{i,s,r,y})) / MotorStock_{i,s,r,y} \quad (42)$$

where: $MotAvgEnergy_{i,s,r,y}$ = The average energy consumed by all motors for industry i, motor size group s, Census region r, and year y, in kWh per motor per year, and

$MotAdjEnergy_{i,s,r,y-1}$ = The adjusted average energy consumed by motors for industry i, motor size group s, Census region r, and year y-1, in kWh per motor per year. The process used to adjust the average energy is described below.

$MotorStock_{i,s,r,y-1}$, $RewoundMotors_{i,s,r,y}$, $RetiredMotors_{i,s,r,y}$, $MotAdjEnergy_{i,s,r,y-1}$, $TotalMotorFlow_{i,s,r,y}$, $NewMotorEnergy_{i,s,r,y}$, and $RewMotorEnergy_{i,s,r,y}$ are defined above.

The average energy efficiency of the stock of motors is given by:

$$MotAvgEff_{i,s,r,y} = (((MotorStock_{i,s,r,y-1} - RewoundMotors_{i,s,r,y} - RetiredMotors_{i,s,r,y}) * MotAvgEff_{i,s,r,y-1}) + (EffMotorFlow_{i,s,r,y} * EEPctEff_{i,s}) + (PremMotorFlow_{i,s,r,y} * PEPctEff_{i,s}) + (RewoundMotors_{i,s,r,y} * RewoundEff_{i,s,r,y})) / MotorStock_{i,s,r,y} \quad (43)$$

where: $MotAvgEff_{i,s,r,y}$ = The average energy efficiency of motors for industry i, motor size group s, Census region r, and year y.

$MotorStock_{i,s,r,y-1}$, $RewoundMotors_{i,s,r,y}$, $RetiredMotors_{i,s,r,y}$, $EffMotorFlow_{i,s,r,y}$, $EEPctEff_{i,s}$, $PremMotorFlow_{i,s,r,y}$, $PEPctEff_{i,s}$, and $RewoundEff_{i,s,r,y}$ are defined above.

Energy efficiency of motor systems is affected not only by the efficiency of the motors themselves, but also by the efficiency of the systems of which the motors are a component. The three largest categories of motor systems are pump systems, fan systems, and compressor systems. The following equation calculates the overall motor system energy savings percentage:

$$SystemSavingsR_{i,s} = ((PumpAppPct_{i,s} * PumpSavPct_{i,s,r,y}) + (FanAppPct_{i,s} * FanSavPct_{i,s}) + (CompAppPct_{i,s} * CompSavPct_{i,s})) / MotSysLife_{i,s} \quad (44)$$

where: $SystemSavingsR_{i,s}$ = The overall savings percentage from pump, fan, and compressor system efficiency improvements for industry *i* and motor size group *s*,

$PumpAppPct_{i,s}$ = Motor system efficiency applicability, percentage of pump systems in industry *i* and motor size group *s,*

$PumpSavPct_{i,s}$ = Motor system efficiency savings fraction for pump systems in industry *i* and motor size group *s,*

$FanAppPct_{i,s}$ = Motor system efficiency applicability, percentage of fan systems in industry *i* and motor size group *s,*

$FanSavPct_{i,s}$ = Motor system efficiency savings fraction for fan systems in industry *i* and motor size group *s,*

$CompAppPct_{i,s}$ = Motor system efficiency applicability, percentage of compressor systems in industry *i* and motor size group *s,*

$CompSavPct_{i,s}$ = Motor system efficiency savings fraction for compressor systems in industry *i* and motor size group *s*, and

$MotorSysLife_{i,s}$ = Motor system efficiency improvement life for motors in industry *i* and motor size group *s*.

Applying the overall motor system energy savings percentage to the total energy consumption for the motor stock results in the total energy consumption by motor systems:

$$MotAdjEnergy_{i,s,r,y} = MotAvgEnergy_{i,s,r,y} * (1 - SystemSavingsR_{i,s}) \quad (45)$$

where: $MotAdjEnergy_{i,s,r,y}$ = The adjusted average energy consumption of the motor stock for industry *i*, motor size group *s*, Census region *r*, and year *y*, in kWh per motor per year.

$MotAvgEnergy_{i,s,r,y}$, and $SystemSavingsR_{i,s}$ are defined above.

The total amount of energy is calculated for the stock and converted from GWh to trillion Btu:

$$TotalMotorEnergy_{i,s,r,y} = ((MotorStock_{i,s,r,y} * MotorAvgEnergy_{i,s,r,y}) * 3412) / 10^{12} \quad (46)$$

where: $TotalMotorEnergy_{i,s,r,y}$ = The total motor energy consumption of the motor stock for industry *i*, motor size group *s*, Census region *r*, and year *y*, in trillion Btu per year.

$MotorStock_{i, s, r, y}$, and $MotorAvgEnergy_{i, s, r, y}$ are defined above.

Finally, the adjusted total amount of energy is calculated for the stock and converted from GWh to trillion Btu:

$$TotalAdjMotorEnergy_{i, s, r, y} = ((MotorStock_{i, s, r, y} * MotorAdjEnergy_{i, s, r, y}) * 3412) / 10^{12} \quad (47)$$

where: $TotalAdjMotorEnergy_{i, s, r, y}$ = The total adjusted motor energy consumption of the motor stock for industry *i*, motor size group *s*, Census region *r*, and year *y*, in trillion Btu per year.

$MotorStock_{i, s, r, y}$, and $MotorAdjEnergy_{i, s, r, y}$ are defined above.

Subroutine CALBTOT

CALBTOT calculates the total energy consumption for buildings. The energy consumption for buildings is calculated for three building uses, lighting , HVAC, and onsite transportation. Total energy consumption is determined as a weighted average of the industry employment UEC and the industry output UEC.

$$ENBQTY_{e,f} = (EWeight * [EMPLX_{i,r} * ENBINT_{e,f}] + PWeight * [ProdVX_{i,r} * ONBINT_{e,f}]) * BldPFac \quad (48)$$

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

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

$ProdVX_{i,r}$ = Output of industry *i* in Census region *r*,

$ENBINT_{e,f}$ = Employment unit energy consumption of fuel *f* for building end use *e*;

$ONBINT_{e,f}$ = Output unit energy consumption of fuel *f* for building end use *e*;

EWeight = Weight for Employment unit energy consumption;

PWeight = Weight for Output unit energy consumption; and

BldPfac = Reflects the effect of energy price increases on buildings energy consumption.

The BldPfac variable adjusts buildings energy consumption if the average industrial energy price increases above a threshold. Below the threshold, BldPfac is equal to 1. Above the threshold, the value of BldPfac is calculated as follows:

$$BldPFac = BldPRat^{BldElas} \tag{49}$$

where: *BldPRat* = Ratio of current year average industrial energy price to 1998 price; and

BldElas = Assumed elasticity, currently -0.2.

Subroutine CALGEN

Subroutine CALGEN accounts for electricity generation from cogeneration by combining existing and planned cogeneration with an estimate of new, unplanned penetration based on an economic and engineering evaluation. The subroutine estimates market penetration of new (unplanned) cogeneration capacity as a function of steam load, steam already met through cogeneration, and cost and performance factors affecting cogeneration economics. CALGEN calls subroutine COGENT to read in the cogeneration assumptions and calls subroutine EvalCogen to evaluate the economics of prototypical cogeneration systems sized to match steam loads in four size ranges. A function SteamSeg is also called to access a size distribution of steam loads for the current industry. Generation for own use and electricity sales to the grid are calculated from the share of sales to the grid from EIA-860B data.[26]

CALGEN begins by computing total steam demand as the sum of steam use in buildings and steam use from the process and assembly component.[27]

$$STEMCUR = ENBQTY_{hvac,steam} + ENPIQTY_{steam} \tag{50}$$

where: *STEMCUR* = Total steam demand,

$ENBQTY_{hvac,steam}$ = Consumption of steam for HVAC, and

$ENPIQTY_{steam}$ = Consumption of steam in the process/assembly component.

[26]Several subroutines not shown here perform the calculations required to initialize, aggregate, and summarize the cogeneration data derived from the EIA-860B survey and incorporate changes from model additions. These subroutines include IRCOGEN, COGINIT, MECSLESS860B, and ADDUPCOGS.

[27]This subroutine also calculates the amount of steam produced by byproduct fuels, which reduces the amount of steam required to be produced by purchased fuels.

Next, the portion of steam requirements that could be met by new cogeneration plants, up to the current model year, is determined as follows:

$$\boldsymbol{NonCogSteam = STEMCUR - CogSteam2000_{inddir,indreg}} \quad (51)$$

where:

	$NonCogSteam$	=	Non-cogenerated steam based on existing cogeneration capacity
	$STEMCUR$	=	Total steam demand, and
	$CogSteam2000_{inddir,indreg}$	=	Steam met by existing cogenerators as of the last data year, for each industry, *inddir*, and region, *indreg*.

Non-cogeneration steam uses are disaggregated into eight size ranges, or segments, based on an exogenous data set providing the boiler size distribution for each industry. These data are accessed through function $SteamSeg_{inddir,loadsegment}$. It is assumed for this purpose that steam loads are distributed in the same proportions as boiler capacity:

$$\boldsymbol{AggSteamLoad_{loadsegment} = NonCogSteam * SteamSeg_{inddir,loadsegment}} \quad (52)$$

where:

	$AggSteamLoad_{loadsegment}$	=	Aggregate steam load for a load segment
	$SteamSeg_{inddir,loadsegment}$	=	the fraction of total steam in each of eight boiler firing ranges (expressed in million Btu/hour) of 1.5-3, 3-6.5, 6.5-10, 10-50, 50-100, 100-250, 250-500, and greater than 500.

The average hourly steam load, $AveHourlyLoad_{loadsegment}$, in each segment is calculated from the aggregate steam load, $AggSteamLoad_{loadsegment}$, based on 8760 hours per year and converting from trillions to millions of Btu per hour:

$$\boldsymbol{AveHourlyLoad_{loadsegment} = AggSteamLoad_{loadsegment} / .008760} \quad (53)$$

The maximum technical potential for cogeneration is determined under the assumption that all non-cogeneration steam for each load segment is converted to cogeneration. This assumes that the technical potential is based on sizing systems, on average, to meet the average hourly steam load in each load segment, using the power-steam ratio of the prototype cogeneration system selected for each load segment (from subroutine EvalCogen):

$$\boldsymbol{TechPot_{loadsegment} = AveHourlyLoad_{loadsegment} * PowerSteam_{isys}} \quad (54)$$

where:

	$TechPot_{loadsegment}$	=	Technical potential for cogeneration, in megawatts, for this load segment if all cogeneration was adopted, irrespective of the economics
	$AveHourlyLoad_{loadsegment}$	=	Average hourly steam load in each load segment

$PowerSteam_{isys}$	=	Power-Steam ratio of the cogeneration system (equivalent to the ratio of electrical efficiency to thermal efficiency), *isys*.

The economic potential is determined from the technical potential and the fraction of that potential estimated to be adopted over an extended time period based on market acceptance criteria (as applied in subroutine EvalCogen):

$$\boldsymbol{EconPot_{loadsegment} = TechPot_{loadsegment} * EconFrac_{loadsegment}} \tag{55}$$

where:

$EconPot_{loadsegment}$	=	Economic potential for cogeneration (megawatts)
$TechPot_{loadsegment}$	=	Technical potential for cogeneration
$EconFrac_{loadsegment}$	=	Economic fraction based on the payback period and the assumed payback acceptances curve.

Given the total economic potential for cogeneration, the amount of capacity that would be added in the current model year is given by:

$$\boldsymbol{CapAddMW_{loadsegment} = EconPot_{loadsegment} * PenetrationRate} \tag{56}$$

where:

$CapAddMW_{loadsegment}$	=	Cogeneration capacity added (megawatts) in current model year
$EconPot_{loadsegment}$	=	Economic potential for cogeneration
$PenetrationRate$	=	Constant annual rate of penetration, assumed to be 5 percent based on the economic potential being adopted over a 20-year time period.

Since most of the cogeneration system cost and performance characteristics used were based on gas turbines, the capacity additions are assumed to be natural gas fired. The corresponding generation and fuel use from these aggregated capacity additions are calculated from the assumed capacity factors and heat rates of the prototypical systems. The energy characteristics of the additions are use to increment the model's cogeneration data arrays: capacity (COGCAP), generation (COGGEN), thermal output (COGTHR) and electricity-related-fuel use (COGELF). These arrays are all indexed by nine census divisions, year, industry, and fuel. Since the model runs at the 4-census region level, results are shared equally among the census divisions using a factor, DSHR, where DSHR is either one half or one third. The assignment statements to increment the arrays are:

$$\boldsymbol{COGGEN_{cdiv,year,inddir,ngas} = COGGEN_{cdiv,year,inddir,ngas} + CAPADDGWH * DSHR} \tag{57}$$

$$\boldsymbol{COGCAP_{cdiv,year,inddir,ngas} = COGCAP_{cdiv,year,inddir,ngas} + CAPADDMW * DSHR} \tag{58}$$

$$\boldsymbol{COGTHR_{cdiv,year,inddir,ngas} = COGTHR_{cdiv,year,inddir,ngas} + STMADDTRIL * DSHR} \tag{59}$$

$$COGELF_{cdiv,year,inddir,ngas} = COGELF_{cdiv,year,inddir,ngas} + \quad (60)$$

$$((CAPADDGWH * AVEHTRT/10.**6) - (STMADDTRIL/.8)) * DSHR$$

where: *CAPADDGWH* = Generation from new capacity in gigawatthours

CAPADDMW = Capacity added in megawatts

STMADDTRIL = Thermal (steam) output of new capacity in trillion Btu

STMADDTRIL/.8 = Fuel input assumed to be associated with thermal output based on hypothetical 80 percent boiler efficiency

AVEHTRT = Heatrate, or total fuel use per unit of generation (Btu/kwh)

Cogeneration from biomass for the pulp and paper industry is also directly related to the amount of biomass available for that industry (calculated in subroutine CALBYPROD).

$$BIO = Max(0, \frac{BioAvail_{indreg,year} - BioAvail_{indreg,year-1}}{HeatRate}) \quad (61)$$

where: $BioAvail_{indreg,year}$ = Biomass available in the current year;

$BioAvail_{indreg,year-1}$ = Biomass available in the previous year; and

HeatRate = Converts Btu to kWh (assumed to be 25,000 through 2003 and decline linearly to 17,000 by 2020).

The available biomass generation is then added to the current year's cogeneration arrays (incremental assignment shown)

$$COGGEN_{cdiv,year,inddir,biomass} = COGGEN_{cdiv,year,inddir,biomass} + BIO * DSHR \quad (62)$$

where: $COGGEN_{cdiv,year,inddir,biomass}$ = Total biomass cogeneration by census division, year, and industry

DSHR = Factor to share census region addition to census divisions such that each division gets an equal share

The biomass capacity, thermal output, and electricity-related fuel use associated with the generation (*BIO)*, are also estimated and used to increment the corresponding cogeneration data arrays, *COGCAP, COGTHR*, and *COGELF*.

Once the energy input and output characteristics of the cogeneration capacity additions have been combined with those of the existing capacity, the effect of cogeneration on purchased electricity demand and conventional fuel use can be determined.

The cogeneration capacity values (COGCAP) are used only for reporting purposes and not used within the industrial module. The thermal output and fuel use from cogeneration, derived from arrays COGTHR and COGELF, are used in subroutine CALSTOT (see below) to determine the balance of the industry's steam demand that must be met by conventional boilers, then combined with boiler fuel use to estimate total BSC sector energy requirements.

The amount of cogeneration used on site ("own-use") is estimated, with the balance of total electricity needs met from purchased electricity. The shares of electricity generation for grid sales and own-use are derived from the EIA-860B survey data and assumed to remain constant for existing capacity. The grid share for each census division, industry, and fuel by year is maintained in array $COGGRD_{cdiv,year,inddir,fuel.}$ In most industries, capacity additions are assumed to have the same grid/own-use shares as that of the average (across regions) of the existing capacity in the last complete data year (2002). For three industries in which cogeneration has already penetrated extensively (Food, Paper, and Bulk Chemicals), a higher grid-share of 60 percent is assumed. As capacity is added, the average grid-sales share for each region and industry (COGGRD) is recomputed as follows:

$$NEWGEN = CapAddGWH * DSHR \qquad (63)$$

$$OLDGRD = COGGEN_{cdiv,year,inddir,fuel} * COGGRD_{cdiv,year,inddir,fuel} \qquad (64)$$

$$NEWGRD = NEWGEN * COGGRDNEW_{inddir} \qquad (65)$$

$$COGGRD_{cdiv,year,inddir,fuel} = (OLDGRD + NEWGRD) / (COGGEN_{cdiv,year,inddir,fuel} + NEWGEN) \qquad (66)$$

where:

NEWGEN	=	Generation from the capacity additions (*CapAddGWH*) equally shared to census divisions in the region (using *DSHR*)
OLDGRD	=	Generation sold to the grid, prior to adjusting the sales and generation to reflect the new additions
NEWGRD	=	Portion of new capacity's generation (NEWGEN) sold to the grid
$COGGRDNEW_{inddir}$	=	Assumed grid share for new capacity addition by industry.

Electricity generation for own use is then calculated as follows:

$$ELOWN_{year,inddir} = \sum_{cdiv} \sum_{fuel} (COGGEN_{cdiv,year,inddir,fuel} \times COGGRD_{cdiv,year,inddir,fuel}) \qquad (67)$$

where: $ELOWN_{year,inddir}$ = Electricity generation for own use, for the current industry and model year,

$COGGEN_{cdiv,year,inddir,fuel}$ = Cogeneration after adding generation from capacity additions,

$COGGRD_{cdiv,year,inddir,fuel}$ = Cogeneration grid share, recomputed as above

Electricity generation for sales to the grid is calculated similarly.

Subroutine EvalCogen

Subroutine EvalCogen is called by subroutine CALGEN to evaluate a set of prototype cogeneration systems sized to match steam loads in eight size ranges, or load segments. The thermal capacity of the systems are assigned to approximately match the average boiler size in each industry for each of the following ranges (in million Btu per hour): 1.5-3, 3-6.5, 6.5-10, 10-50, 50-100, 100-250, 250-500, and greater than 500. The corresponding steam output (or steam load) is determined from the average boiler capacity using:

$$\boldsymbol{SteamLoad_{loadsegment} = AveBoilSize_{loadsegment} * EboilEff_{loadsegment}} \quad (68)$$

where: $SteamLoad_{loadsegment}$ = Steam output of average boiler in the load segment, in millions of Btu an hour

$AveBoilSize_{loadsegment}$ = Firing capacity of average boiler in the load segment

$EboilEff_{loadsegment}$ = Assumed boiler efficiency

A candidate cogeneration system is preselected for each load segment with thermal output that roughly matches the steam output of the average-sized boiler in the load segment. A user-supplied set of characteristics for *nsys* (8) cogeneration systems are used, with the system number *isys* subscript ranging from 1 to *nsys*:

$CogSizeKW_{isys}$ = Net electric generation capacity in kilowatts

$CogCapCostKW_{isys}$ = Total installed cost, in 2003 dollars per kilowatthour-electric

$CapFac_{isys}$ = System capacity factor

$CHeatRate_{isys}$ = Total fuel use per kilowatthour-electric generated (Btu/kWhe)

$OverAllEff_{isys}$ = Fraction of input energy converged to usefuel heat and power

From the above user-supplied characteristics, the following additional parameters for each system are derived:

$ElecGenEff_{isys}$	=	Fraction of input energy converted to electric energy, or electric energy efficiency
	=	$3412. / CHeatRate_{isys}$
$ElecSizeMwh_{isys}$	=	Electric generation from the cogeneration plant in megawatt hours
	=	$CogSizeKW_{isys} * 8.76 * CapFac_{isys}$
$FuelUse_{isys}$	=	Cogeneration system fuel use per year in billion Btu
	=	$ElecSizeMwh_{isys} * Cheatrate_{isys} / 10^6$
$PowerSteam_{isys}$	=	Ratio of electric power output to thermal output
	=	$ElecGenEff_{isys} / (OverAllEff_{isys} - ElecGenEff_{isys})$
$SteamOutput_{isys}$	=	Thermal output of the cogeneration system (mmBtu/hr)
	=	$CogSizeKW_{isys} * .003412 / PowerSteam_{isys}$

The system number preselected for each steam load segment is designated by the subscript isys:

$$CogSys_{loadsegment} = isys,$$

and the following relation holds (with one exception: the largest system in terms of electrical capacity is a combined cycle system with lower thermal output then the next largest system).

$$\boldsymbol{SteamOutput_{isys} <= SteamLoad_{loadsegment} < SteamOutput_{isys+1}} \quad (69)$$

where:

$SteamOutput_{isys}$	=	Steam output of the preselected cogeneration system
$SteamLoad_{loadsegment}$	=	Thermal output to match in this load segment

Next, the investment payback period needed to recover the prototypical cogeneration investment for each load segment ($Cpayback_{loadsegment}$) is determined. This involves estimating the annual cash flow from the investment, defined as the value of the cogenerated electricity, less the cost of the incremental fuel required to generate it. For this purpose, the annual cost of fuel (natural gas) and the value of the electricity are based on the prices averaged over the first 10 years of operating the cogeneration system. For electricity, the electricity is valued at the average industrial electricity price in the region, net of standby charges that would be incurred after installing cogeneration (*CogElecPrice*). The standby charges are assumed to be some user-specified fraction of the industrial electricity rate (10 percent in the *Annual Energy Outlook 2004*).   For natural gas (*CogFuelPrice*), the price of firm-contract natural gas was assumed to apply. The steps are as follows:

Determine annual fuel cost of the cogeneration system:

$$\boldsymbol{FuelCost_{loadsegment} = FuelUse_{isys} * CogFuelPrice} \quad (70)$$

Determine the annual fuel use and cost of operating the existing system (conventional boiler):

$$\boldsymbol{ExistFuelUse_{loadsegment} = SteamOutput_{isys} * 8.76 * CapFac_{isys} / EboilEff_{loadsegment}} \quad (71)$$

$$\boldsymbol{ExistFuelCost_{loadsegment} = ExistFuelUse_{loadsegment} * CogFuelPrice} \quad (72)$$

Determine incremental fuel cost and the value of cogenerated electricity:

$$\boldsymbol{IncrFuelCost_{loadsegment} = FuelCost_{loadsegment} - ExistFuelCost_{loadsegment}} \quad (73)$$

$$\boldsymbol{ElecValue_{loadsegment} = ElecSizeMWH_{isys} * CogElecPrice * .003412} \quad (74)$$

Determine the cash flows, or operating profit, of the investment:

$$\boldsymbol{OperProfit_{loadsegment} = ElecValue_{loadsegment} - IncrFuelCost_{loadsegment}} \quad (75)$$

Determine the investment capital cost and the investment payback period

$$\boldsymbol{Investment_{loadsegment} = CogSizeKW_{isys} * CogCapCostKW_{isys}} \quad (76)$$

$$\boldsymbol{CpayBack_{loadsegment} = Investment_{loadsegment} / OperProfit_{loadsegment}} \quad (77)$$

Given the payback for the prototype system evaluated for each load segment, the model estimates the fraction of total technical potential that is considered economic. This calculation uses an assumed distribution of required investment payback periods referred to as the payback acceptance curve. Rather than using an actual curve, a table of assumptions is used acceptance rates for each integer payback period from 0 to 12 years. To obtain an acceptance fraction, or economic fraction, from a non-integer value for payback, a linear interpolation is done. The economic fraction is determined from a table lookup and interpolation function called Acceptance, given the table of acceptance fractions, the number of rows in the table (13), and the payback period for the load segment:

$$\boldsymbol{EconFrac_{loadsegment} = Acceptance(AcceptFrac, 13, Cpayback_{loadsegment})} \quad (78)$$

where:

	$EconFrac_{loadsegment}$	=	Fraction of cogeneration investments adopted based on payback period acceptance assumptions
	$AcceptFrac$	=	Array of payback acceptance rates corresponding to integer payback periods ranging from 0 to 12 (13 rates altogether)
	$Cpayback_{loadsegment}$	=	Cogeneration investment payback period

Subroutine CALSTOT

CALSTOT calculates total fuel consumption in the BSC component based on total steam demand for an industry (STEMCUR). Steam demand and fuel consumption are allocated between cogeneration and conventional boilers. Fuel use and steam demand from cogeneration, calculated in Subroutine CALGEN, are treated as inputs to the subroutine.

Steam from cogeneration (COGSTEAM) is obtained by summing the cogeneration thermal output (in array COGTHR) across fuels and census divisions. Steam demand to be met by conventional boilers (NonCOGSTEAM) is equal to total steam demand (STEMCUR) minus cogeneration steam (COGSTEAM) production.

The fuel for cogeneration is stored in two parts: that attributed to electricity (COGELF) and that associated with the thermal output (COGTHR). The fuel associated with the thermal output assumes a hypothetical 80 percent efficiency, so it is computed as COGTHR divided by .8. Thus, total cogeneration system fuel use, $FuelSys_{fuel}$. is given by:

$$FuelSys_{fuel} = \sum_{cdiv} (COGELF_{cdiv,\,year,\,inddir,\,fuel} + (COGTHR_{cdiv,\,year,\,inddir,\,fuel} / .8)) \tag{79}$$

Conventional boiler fuel use is split between biomass-derived and fossil fuel. The total available biomass is determined as by-product fuels ($BYPBSCR_{biofuel}$). Some of it is accounted for and used in cogeneration; the remainder of the available biomass (AvailBiomass) is assumed to be used as boiler fuel. The amount of steam for this biomass, BIOSTEAM, is calculated from an assumed biomass boiler efficiency (.65).

The steam that must be met through fossil-fired boilers is the total non-cogenerated system (NonCogSteam) less the biofueled steam (BIOSTEAM), or NonCogFosSteam. A trial estimate for total fossil fuel for boilers is derived from NonCogFosSteam assuming an average boiler efficiency across fuels. To share this total to fuels consistent with the MECS data source is problematic. The MECS data source indicates only the total amounts of indirect fuels associated with boilers and cogeneration, so we can not directly compute fuel-specific boiler use from MECS alone. Since we take our cogeneration fuel use and thermal output from a separate data source (EIA Form 860B) deriving an estimated conventional boiler fuel requirement consistent with MECS requires a calibration step. A calibration factor for boiler fuel is calculated such that cogeneration fuel (from Form 860b) plus conventional boiler fuel equals the MECS indirect fuel in the base year.

The derivation of the boiler fuel calibration factor is based on the results of Subroutine MecsLess860b, which, as its name implies, calculates the difference between total MECS indirect fuels (BSC98) and the cogeneration (or CHP) fuel use from form 860B (CHP98), and stores it in array BOIL98. A separate calibration is performed for biomass- and fossil-fueled boilers. The calibration factor for fossil-fuels is computed as follows in model year 1998:

$$Estimated = NonCogFosSteam / .8$$

$$Implied = \text{SUM of } (BOIL98_{inddir,indreg,ifuel}) \text{ across boiler fuels}$$

$$CALIB98\_FOS_{inddir,indreg} = Implied / Estimated$$

where: *Estimated* = Trial value for fossil fuel use from conventional boilers

Implied = Conventional boiler fuel use

$CALIB98\_FOS_{inddir,indreg}$ = Calibration factor for conventional boiler fuel use

In the forecast, the calibration factors for the base year adjust the trial calculation to yield the estimated non-cogeneration fossil fuel:

$$NonCogFosFuel = (NonCogFosSteam / .8) * CALIB98\_FOS_{inddir,indreg}$$

where: *NonCogFosFuel* = Non-Cogeneration (conventional) fossil fuel use in boilers, calibrated to match MECS when combined with 860B cogeneration data.

Conventional boiler fuel use (FuelFosSteam) is allocated to fuels based on fuel shares adjusted for price changes since 1998. The fuel shares (BSSHR) are estimated in Subroutine CALBSC:

$$FuelFosSteam_{fuel} = NonCogFosFuel * BSSHR_{fuel}$$

The fossil fuels consumed in non-cogeneration boilers are added to cogeneration fuel to yield total fuel consumption in the BSC component.

$$EnSQty_{fuel} = CogBoilFuel_{fuel} + FosFuelSteam_{fuel} \qquad (80)$$

where:

$CogBoilFuel_{fuel}$ = Fossil fuel consumption for cogeneration by *fuel*,

$FosFuelSteam_{fuel}$ = Fossil fuel consumption for conventional boilers by fuel

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.

$$QTYMAIN_{f,r} = ENPMQTY_f + ENBQTY_{total,f} + ENSQTY_f + BYPBSCM_f \qquad (81)$$

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.

$$QTYMAIN_{elec,r} = ENPMQTY_{elec} + ENBQTY_{total,elec} - ELOWN \tag{82}$$

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, from Subroutine CALGEN.

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.

$$TQMAIN_{f,r} = \sum_{i=1}^{INDMAX} QTYMAIN_{f,r} \tag{83}$$

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 individual industries. Consumption figures are reported for each of the fuels used in each particular industry. The equation below illustrates the procedure for main fuels in the food and kindred products industry.[28] All other industries have similar equations.

$$FOODCON_f = \sum_{f=1}^{NUM_{fg}} QTYMAIN_{f,total} \tag{84}$$

where:

$FOODCON_f$ = 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 sector cogeneration capacity, generation, and fuel use by summing the results of subroutine CALGEN over the 15 industries. Subroutine INDCGN shares these cogeneration results into two parts: that associated with generation for own use and that used for sales to the grid. The results are copied to the corresponding NEMS global data variables for industrial cogeneration capacity (CGINDCAP), generation (CGINDGEN), and fuel use (CGINDQ).

$$CGINDCAP_{cdiv,year,fuel,grid} = \sum_{inddir} (COGCAP_{cdiv,year,inddir,fuel} * COGGRD_{cdiv,year,inddir,fuel}) \tag{85}$$

$$CGINDCAP_{cdiv,year,fuel,ownuse} = \sum_{inddir} (COGCAP_{cdiv,year,inddir,fuel} * (1.- COGGRD_{cdiv,year,inddir,fuel}))$$

$$CGINDGEN_{cdiv,year,fuel,grid} = \sum_{inddir} (COGGEN_{cdiv,year,inddir,fuel} * COGGRD_{cdiv,year,inddir,fuel})$$

$$CGINDGEN_{cdiv,year,fuel,ownuse} = \sum_{inddir} (COGGEN_{cdiv,year,inddir,fuel} * (1.- COGGRD_{cdiv,year,inddir,fuel}))$$

$$CGINDQ_{cdiv,year,fuel,grid} = \sum_{inddir} (COGELF_{cdiv,year,inddir,fuel} * COGGRD_{cdiv,year,inddir,fuel})$$

---

[28]Another subroutine, INDFILLCON, is called from CONTAB to actually fill the FOODCON consumption array.

$$CGINDQ_{cdiv,\,year,\,fuel,\,ownuse} = \sum_{inddir} (COGELF_{cdiv,\,year,\,inddir,\,fuel} * (1.- COGGRD_{cdiv,\,year,\,inddir,\,fuel}))$$

where: *CGINDCAP* = cogeneration capacity by census division, year, fuel, and use (grid or own-use);

CGINDGEN = cogeneration generation by census division, year, fuel, and use;

CGINDG = cogeneration fuel use, electricity portion, by census division, year, fuel and use;

COGGRD = share of cogeneration sold to the grid by census divsion, year, industry, and fuel;

COGCAP = cogeneration capacity by division, year, industry, and fuel;

COGGEN = cogeneration generation by division, year, industry, and fuel; and

COGELF = cogeneration fuel use, electricity portion, by census division, year, and fuel.

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.

$$BMAIN_{fuel,region} = TQMAIN_{fuel,region} + QELRF_{region} \tag{86}$$

where: $TQMAIN_{fuel,region}$ = Consumption of *fuel* = electricity in Census *region*, and

$QELRF_{region}$ = Refinery Consumption of *fuel* = electricity in Census *region*.

The equation for total industrial natural gas consumption is:

$$BMAIN_{fuel,region} = TQMAIN_{fuel,region} + QNGRF_{region} + CGOGQ_{sales,region} + CGOGQ_{own,region} + NONTRAD_{region,fuel} \tag{87}$$

where: $BMAIN_{fuel,region}$ = Consumption of *fuel* natural gas in Census *region*,

$TQMAIN_{fuel,region}$ = Consumption of *fuel* natural gas fuel *f* in Census *region*,

$QNGRF_{region}$ = Refinery natural gas consumption in Census *region*, and

$CGOGQ_{sales,region}$ = Consumption of natural gas from cogeneration of electricity for sales to the grid in enhanced oil recovery in Census *region*, input from Oil and Gas Module,

$CGOGQ_{own,region}$ = Consumption of natural gas from cogeneration of electricity for own use in enhanced oil recovery by Census *region*, input from Oil and Gas Module, and

$NonTrad_{region,fuel}$ = Consumption of natural gas by nontraditional cogeneration in Census *region* for *fuel*, input from Electricity Market Module.

Total industrial consumption for other fuels is calculated similarly.

SEDS benchmark factors are calculated as follows:

$$SEDSBF_{fuel,region} = \frac{SEDS4_{fuel,region}}{BMAIN_{fuel,region}} \tag{88}$$

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:

$$BENCH_{fuel,region} = SEDSBF_{fuel,region} \ x \ BMAIN_{fuel,region} \tag{89}$$

STEO benchmark factors are calculated as follows:

$$STEOBF_{fuel} = \frac{STEO_{fuel,year}}{\sum_{fuel} \sum_{region} BENCH_{fuel,region}} \tag{90}$$

where: $STEOBF_{\text{fuel}}$ = 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.

$STEO_{\text{fuel,year}}$ = STEO consumption by fuel for each forecast year.

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

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

$$BENCH_{fuel,region} = STEOBF_{fuel} \ x \ BENCH_{fuel,region} \tag{91}$$

STEO benchmark factors are faded to zero beginning in the first year after the STEO forecast year until 4 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.

$$DSRENW_{f,d} = \frac{OUTIND_{13,d} + OUTIND_{11,d}}{\sum_{d=1}^{NUM_r} (OUTIND_{13,d} + OUTIND_{11,d})} \tag{92}$$

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.

$$BENCHFAC_{bm,d} = \frac{BIOFUELS_d}{\sum_{f=2}^{3} DQRENW_{f,d}} \tag{93}$$

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

$$DQRENW_{f,d} = TQRENW_{f,region} \; x \; DSRENW_d \tag{94}$$

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*,

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.

$$QELIN_{cdiv,year} = BENCH_{elec,region} \; x \; SEDSHR_{elec,region,cdiv} \tag{95}$$

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.

$$QGFIN_{cdiv,year} = \left[BENCH_{ngas,region} \; x \; SEDSHR_{ngas,region,region}\right] x \left[\frac{TQMAIN_{cng,region} + TQMAIN_{fds,region}}{BMAIN_{ngas,region}}\right] \tag{96}$$

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*,
	$SEDSHR_{ngas,region,cdiv}$	=	SEDS census region share of natural gas in census division *cdiv*,
	$TQMAIN_{cng,region}$	=	Consumption of core natural gas in Census *region*, from Subroutine NATTOTAL,

	$TQMAIN_{fds,region}$	=	Consumption of feedstock natural gas in Census *region*, from Subroutine NATTOTAL, and
	$BMAIN_{ngas,region}$	=	Total unbenchmarked consumption of natural gas in Census region *region*.

$$QGIIN_{cdiv,year} = QNGIN_{ngas,cdiv} - QGFIN_{cdiv,year} \tag{97}$$

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.

$$QBMIN_{d,y} = \left[\sum_{f=2}^{3} DQRENW_{f,d}\right] + \left[\sum_{u=1}^{2} CGOGQ_{d,y,bm,u}\right] + QBMRF_{d,y} \tag{98}$$

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 (including pulping liquor) and hydropower are nonzero.

$$QTRIN_{d,y} = QHOIN_{d,y} + QBMIN_{d,y} + QGEIN_{d,y} + QSTIN_{d,y} + QPVIN_{d,y} + QWIIN_{d,y} + QMSIN_{d,y} \tag{99}$$

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*.

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.

Subroutine 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 reduced by applying a retirement rate of capital (Table B12). The retirement rate is posited to be a positive function of energy prices. For years after 1998, the ratio of the current year's average industrial energy price to the average price in 1998 is computed, RetirePrat.

Above the RetirePrat threshold, the following relationships hold:

$$X = RetirePrat^{RetireBeta}$$

$$RetirePriceFactor = \frac{X}{(1 + X)} \qquad (100)$$

$$RetireRate_s = 2 * RetirePriceFactor * ProdRetr_s$$

where:

RetirePrat	=	Ratio of current year average industrial energy price to 1998 price;
RetireBeta	=	Parameter of logistic function, currently specified as 2 for retirements;
RetirePriceFactor	=	TPC price factor, ranging from 0 (no price effect) to 2 for retirements;
$RetireRate_s$	=	Retirement rate after accounting for energy price increases for step *s*; and
$ProdRetr_s$	=	Default retirement rate for step *s*.

$$PRODCUR_{old,s} = (PRODCUR_{old,s} + IDLCAP_{old,s}) * (1 - RetireRate_s) \qquad (101)$$

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
$RetireRate_s$	=	Retirement rate after accounting for energy price increases for step *s*.

$$PRODCUR_{mid,s} = (PRODCUR_{mid,s} + PRODCUR_{new,s}) * (1 - RetireRate_s) \qquad (102)$$

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

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

$RetireRate_s$ = Retirement rate after accounting for energy price increases for step s.

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.

$$PRODX_{i,r} = PHDRAT \ x \ PRODVX_{i,r} \tag{103}$$

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. This is complicated because retirement rates of some steps differ, as do the process flow rates of old and new capacity. In addition, several process steps may jointly provide output for one or more "downsteps." The solution to the problem is simplified by formulating the process flow relationships as input-output coefficients as described in the Leontief Input-Output Model (as described in Chiang, *Fundamental Methods of Mathematical Economics*, pp. 123-131). In this model, the output of a process step can either be a final demand or used as input to another process step. The objective is to determine the mix of old and new productive capacity at each process step such that all final demands are met. In this case, the final demand is the industry output.

The following definitions are provided to illustrate the problem:

A = input/output coefficient matrix with final demand as the first column and the production steps as the other columns. The coefficients are the values in the PRODFLOW array, placed in the array according to the IPASTP step definitions.

I = Identity Matrix

D = Final demand vector, but only the first element is nonzero. (D(1) is like PRODX)

X = Vector of productive capacity needed to meet the final demand, based on A and D. (X is equivalent to PRODCUR)

The input-output model is written as:

$$(I-A) * X = D$$

X is obtained by premultiplying both sides by the inverse of I-A

$$X = (I-A)^{-1} * D$$

Since the A coefficients for old and new capacity differ, there are two such arrays: **Aold** and **Anew**. The corresponding "technology" matrices **I-Aold** and **I-Anew** will be referred to as **IAold** and **IAnew**.

Likewise, Xold and Xnew are distinguished to account for old and new productive capacity. However, to incorporate the retirement calculation, the base year productive capacity will be referred to as Xold and the portion of that capacity that survives to a given year is called Xsurv. The portion that is retired is called Xret. Therefore, total productive capacity (Xtot) is given by:

$$Xtot = Xsurv + Xnew$$

or

$$Xtot = Xold - Xret + Xnew$$

Xold is defined in the base year as follows:

$$(IAold) * (Xold) = (D98), \text{ or}$$

$$Xold = IAold^{-1} * D$$

Xnew is defined as the cumulative capacity additions since the base year.

A set of retirement rates, R, is defined for each producing step. The final demand step need not have a designated retirement rate. So the retired capacity is given by:

$$Xret = Xold * (1-(1-R))^{(T-1998)}$$

$$Xsurv = Xold - Xret$$

The final demand that can be met by the surviving capacity is given by:

$$IAold * Xsurv$$

The remaining demand must met by new capacity, such that the following condition is met:

$$IAold * Xsurv_T + IAnew * Xnew_T = D_T \text{ where,}$$

Xnew is the cumulative additions to productive capacity since the base year. Xnew can be determined by solving the following system:

$$IAnew * Xnew^{T} = (D^{T} - IAold * Xsurv^{T})$$

Therefore,

$$Xnew = IAnew^{-1} * (D^{T} - IAold * Xsurv^{T})$$

The last equation is the only one needed to implement the approach in the model. The solution is found by calling a matrix inversion routine to determine $IAnew^{-1}$, followed by calls to intrinsic matrix multiplication functions to solve for Xnew. As a result, the amount of actual code to implement this approach is minimal.

Subroutine CALCSC

CALCSC computes UECs for all industries. The current UEC for the old and new vintage is calculated as the product of the previous year's UEC and a factor that reflects the assumed rate of intensity decline over time and the impact of energy price changes on the assumed decline rate.

$$ENPINT_{v,f,s} = ENPINTLAG_{v,f,s} * (1 + TPCRate_v) \tag{104}$$

where:

	$ENPINT_{v,f,s}$	=	Unit energy consumption of fuel *f* at process step *s* for vintage *v*;
	$ENPINTLAG_{v,f,s}$	=	Lagged unit energy consumption of fuel *f* at process step *s* for vintage *v*; and
	$TPCRate_v$	=	Energy intensity decline rate after accounting for the impact of increased energy prices.

The $TPCRate_v$ are calculated using the following relationships if the TPCPrat is above a threshold. Otherwise, the default values for the intensity decline rate is used, $BCSC_{v,fuel,step}$.

Above the TPCPrat threshold, the following relationships hold:

$$X = TPCPrat^{TPCBeta}$$

$$TPCPriceFactor = \frac{X}{(1 + X)} \tag{105}$$

$$TPCRate_v = 2 * TPCPriceFactor * BCSC_{v,fuel,step}$$

where: $TPCPrat$ = Ratio of current year average industrial energy price to 1998 price;

$TPCBeta$ = Parameter of logistic function, currently specified as 4;

$TPCPriceFactor$ = TPC price factor, ranging from 0 (no price effect) to 2 for *ENPINT*;

$TPCRate_v$ = Intensity decline rate after accounting for due to energy price increases for vintage *v*; and

$BCSC_{v,fuel,step}$ = Default intensity rate for old and new vintage (*v*) for each fuel *f* and step *s*.

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

$$ENPINT_{mid,f,s} = \frac{SUMPINT_{f,s}}{CUMPROD_{new,s}} \qquad (106)$$

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 CALBSC

The boiler fuel shares are revised each year based on changes in fuel prices since the base year. The fuel sharing is calculated using a logit formulation. The fuels shares apply only to conventional boiler fuel use. Cogeneration fuel shares are assumed to be constant and are based on data from EIA Form 860B. Base year boiler fuel use is obtained by subtracting cogeneration fuel use from total MECS indirect fuels (this calculation is done in Subroutine MecsLess860b). Waste and byproduct fuels are excluded from the logit because they are assumed to be consumed first. The boiler fuel sharing equation for each manufacturing industry is as follows:

$$ShareFuel_i = \frac{(P_i^{\alpha_i}\beta_i)}{\sum_{i=1}^{3} P_i^{\alpha_i}(\beta_i)} \qquad (107)$$

where the fuels are coal, petroleum, and natural gas. Base year boiler shares for individual petroleum products are calculated explicitly 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, the default value is -0.25; and the β_i are calibrated to reproduce the 1998 fuel shares using the relative prices that prevailed in 1998. The byproduct fuels are consumed before the quantity of purchased fuels is estimated.

The α_i sensitivity parameters are posited to be a positive function of the average price of the primary boiler fuels (coal, natural gas, and residual fuel). For years after 1998, the ratio of the current year's average boiler fuel energy price to the average price in 1998 is computed, SwitchPrat.
Above the SwitchPrat threshold, the following relationships hold:

$$X = SwitchPrat^{SwitchBeta}$$

$$SwitchPriceFactor = 4 * \frac{X}{(1 + X)} \tag{108}$$

$$\alpha_{iPrice} = SwitchPriceFactor * \alpha_i$$

where:

	SwitchPrat	=	Ratio of current year average industrial energy price to 1998 price;
	SwitchBeta	=	Parameter of logistic function, currently specified as 4;
	SwitchPriceFactor	=	Fuel switching price factor, ranging from 0 (no price effect) to 4 for boiler fuel switching;
	α_{iPrice}	=	Fuel switching sensitivity parameters after accounting for energy price increases;
	α_i	=	Default fuel switching sensitivity parameters.

Appendix A. Bibliography

Data Sources

Arthur D. Little, Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics.* Unpublished report prepared for Office of Integrated Analysis and Forecasting Energy Information Administration. Washington, DC, September 2001.

Energy Information Administration. *Annual Energy Outlook 2004*. DOE/EIA-0383(2004), January 2004.

Energy Information Administration, *Annual Energy Review 2001*, DOE/EIA-0384 (2001), November 2002.

Energy Information Administration (EIA), *1998 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/MECS98/datatables/contents.html.

Energy Information Administration. *Documentation of the Oil and Gas Supply Module (OGSM)*, DOE/EIA-M063(2003), April 2003.

Energy Information Administration. *Petroleum Market Model of the National Energy Modeling System*, DOE/EIA-M059(2003), Parts 1 and 2, February 2003.

Energy Information Administration. *State Energy Data Report, Consumption Estimates 1960-1999*, DOE/EIA-0214(99), May 2001.

Executive Office of the President, Office of Management and Budget, *North American Industry Classification System*. Washington, DC, 1997.

ONSITE SYCOM Energy Corporation. *The Market and Technical Potential for Combined Heat and Power in the Industrial Sector* (prepared for EIA), Washington, DC, January 2000.

U.S. Congress, Office of Technology Assessment. *Industrial Energy Efficiency*. OTA-E-560, August 1993.

U.S. Department of Commerce, Bureau of the Census, *Annual Survey of Manufactures, Fuels and Electric Energy Consumed*, Various Years.

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

U.S. Department of Energy, *MotorMaster+ 4.0* software database, March 6, 2003; available online: http://mm3.energy.wsu.edu/mmplus/default.stm.

U.S. Department of Energy, *United States Industrial Electric Motor Systems Market Opportunities Assessment*, Burlington, MA, December 1998.

Background Material

American Council for an Energy Efficient Economy, *Energy-Efficient Motor Systems: A Handbook on Technology, Program, and Policy Opportunities, Second Edition*, Washington, DC, 2002.

American Gas Association, *Industrial Sector Energy Analysis: Chemical and Allied Products (SIC 28)*, Arlington, Virginia, July 1988.

American Gas Association, *Industrial Sector Energy Analysis: Food & Kindred Products (SIC 20)*, Arlington, Virginia 1988.

American Gas Association, *Industrial Sector Energy Analysis: The Paper Industry*, Arlington, Virginia 1988.

American Gas Association, *Industrial Sector Energy Analysis: The Steel Industry*, Arlington, Virginia 1988.

American Gas Association, *Industrial Sector Energy Analysis: The Stone, Clay and Glass Industries*, Arlington, Virginia 1988.

Bohi, Douglas R., *Analyzing Demand Behavior: A Study of Energy*, Resources for the Future, 1981.

Bohi, Douglas R. and Mary Beth Zimmerman, *An Update on Econometric Studies of Energy Demand Behavior*, Annual Review of Energy, 1984.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET IEA/OECD), *Learning from experiences with Gas-Turbine-Based CHP in Industry*, (ISBN 90-72647-02-5), The Netherlands, April 1993.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET IEA/OECD), *Learning from experiences with Small-Scale Cogeneration*, (ISBN 90-72647-22-X), The Netherlands, November 1995.

Chiang, Alpha C., *Fundamental Methods of Mathematical Economics*, Second Edition. New York, McGraw-Hill, 1974.

Dahl, Carol, *A Survey of Energy Demand Elasticities in Support of the Development of the NEMS*, (prepared for EIA) October 1993.

Energy and Environmental Analysis, Inc. *Analysis of the Industrial Boiler Population* (prepared for the Gas Research Institute, GRI-96/0200), June 1996.

Karlson, Stephen H. and Gale Boyd. *The Impact of Energy Prices on Technology Choice in the United States Steel Industry*. The Energy Journal, Vol. 14, No. 2, 1992.

Rose, Kenneth and John F. McDonald. *Economics of Electricity Self-Generation by Industrial Firms*. The Energy Journal, Vol. 12, No. 2, 1991.

Appendix B. Data Inputs

Table B1. Building Component Energy Consumption (trillion Btu)

Industry	Region	Lighting	Heating, Ventilation, Air Conditioning			Facility Support				Onsite Transportation			
		Electricity	Electricity	Natural Gas	Steam	Electricity	Natural Gas	Distillate	LPG	Electricity	Natural Gas	Distillate	LPG
Food and Kindred Products	NE	1.50	1.69	2.49	1.87	0.28	0.58	0.00	0.00	0.09	0.00	0.25	0.03
	MW	6.46	7.27	12.11	9.10	1.21	3.18	0.00	0.00	0.40	0.00	0.17	1.20
	SO	5.63	6.34	7.75	5.82	1.06	1.84	0.00	0.00	0.35	0.00	1.00	1.20
	WE	2.48	2.79	5.60	4.21	0.47	1.39	0.00	0.00	0.16	0.00	0.58	0.60
Paper and Allied Products	NE	2.41	2.69	1.48	0.26	0.57	0.17	0.00	0.00	0.00	0.09	0.44	1.20
	MW	4.04	4.51	3.45	0.61	0.95	0.39	0.00	0.00	0.00	0.20	0.22	0.60
	SO	7.58	8.47	8.79	1.55	1.78	1.03	0.00	0.00	0.00	0.51	1.33	1.20
	WE	3.05	3.40	3.29	0.58	0.72	0.41	0.00	0.00	0.00	0.20	0.22	0.60
Bulk Chemicals	NE	1.12	1.61	0.37	0.00	0.35	0.04	0.00	0.00	0.00	0.00	0.00	0.00
	MW	3.31	4.76	1.47	0.00	1.03	0.14	0.00	0.00	0.00	0.00	0.00	0.00
	SO	10.22	14.69	18.32	0.00	3.19	1.74	0.00	0.00	0.00	0.00	0.00	0.00
	WE	1.04	1.50	1.01	0.00	0.33	0.10	0.00	0.00	0.00	0.00	0.00	0.00
Glass and Glass Products	NE	0.38	0.57	1.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	MW	0.52	0.79	1.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SO	0.81	1.21	2.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	WE	0.24	0.36	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydraulic Cement	NE	0.13	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00
	MW	0.23	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00
	SO	0.39	0.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00
	WE	0.23	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00
Steel	NE	0.87	0.73	1.90	0.00	0.15	0.32	0.00	0.00	0.00	0.00	0.47	0.00
	MW	2.46	2.05	10.76	0.00	0.41	1.79	0.00	0.00	0.00	0.00	1.47	0.00
	SO	2.01	1.68	4.35	0.00	0.34	0.73	0.00	0.00	0.00	0.00	1.25	0.00
	WE	0.52	0.43	1.03	0.00	0.09	0.17	0.00	0.00	0.00	0.00	0.17	0.00
Aluminum	NE	0.27	0.34	0.41	0.00	0.07	0.08	0.00	0.00	0.00	0.00	0.15	0.00
	MW	0.91	1.13	1.01	0.00	0.23	0.20	0.00	0.00	0.00	0.00	0.13	0.00
	SO	1.42	1.77	3.21	0.00	0.35	0.64	0.00	0.00	0.00	0.00	0.14	0.00
	WE	1.40	1.75	0.36	0.00	0.35	0.07	0.00	0.00	0.00	0.00	0.10	0.00
Metal-Based Durables	NE	12.39	15.66	28.12	10.80	3.13	0.84	1.03	0.21	0.27	0.84	0.85	1.45
	MW	39.10	49.41	100.07	38.43	9.88	3.17	0.99	0.38	0.86	3.17	0.82	2.63
	SO	25.19	31.84	44.96	17.27	6.37	1.37	3.21	0.35	0.55	1.37	2.68	2.46
	WE	13.91	17.57	19.56	7.51	3.51	0.62	0.37	0.09	0.31	0.62	0.31	0.61
Balance of Manufacturing	NE	10.00	13.55	18.69	15.45	2.11	1.76	0.06	0.00	0.13	0.00	5.44	0.58
	MW	22.00	29.82	38.07	31.48	4.63	3.74	0.00	0.00	0.29	0.00	2.32	0.96
	SO	37.12	50.30	53.41	44.16	7.81	5.20	0.00	0.00	0.49	0.00	7.32	3.74
	WE	9.43	12.77	21.65	17.91	1.98	2.14	0.00	0.00	0.12	0.00	2.40	1.14

Source: Energy Information Administration, Office of Integrated Analysis and Forecasting estimates based on 1998 Manufacturing Energy Consumption Survey.

Table B2. Food and Kindred Products Industry National UECs, 1998
(Thousand Btu/1996$ of Shipments, Unless Otherwise Indicated)

End Use	Shipments (Billion 96$)	Electricity	Natural Gas	Resid	LPG	Coal	Steam
Direct Heat	424.7	0.014	0.396	0.002	0.002	0.021	1.022
Refrigeration	424.7	0.141	0.007	0.000	0.000	0.000	0.000
Other	424.7	0.000	0.007	0.000	0.000	0.000	0.000

Source: Arthur D. Little Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*. Unpublished Report Prepared for Office of Integrated Analysis and Forecasting, Energy Information Administration, (Washington, DC, September 2001).

Table B3. Pulp and Paper Industry National UECs, 1998
(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Resid	Distillate	LPG	Coal	Steam	Byproduct Produced
Wood Preparation	108.7	0.260	0.000	0.000	0.000	0.000	0.000	0.000	3.313
Pulping									
Waste	45.8	1.250	0.000	0.000	0.000	0.000	0.000	1.430	0.000
Mech	5.8	5.200	0.000	0.000	0.000	0.000	0.000	0.510	0.000
Semi-chem	4.0	1.440	0.000	0.000	0.000	0.000	0.000	5.420	0.000
Kraft	54.4	1.440	1.510	0.302	0.013	0.013	0.063	11.570	16.605
Bleaching	48.3	0.290	0.000	0.000	0.000	0.000	0.000	5.730	0.000
Papermaking	96.3	1.640	0.397	0.079	0.003	0.003	0.017	6.760	0.000

Source: Arthur D. Little Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*. Unpublished Report Prepared for Office of Integrated Analysis and Forecasting, Energy Information Administration, (Washington, DC, September 2001).

Table B4. Bulk Chemical Industry National UECs, 1998 (Thousand Btu/1996$ of Shipments, Unless Otherwise Indicated)							
End-Use	Shipments (Billion 96$)	Electricity	Natural Gas	Resid	LPG	Steam	Petrochemical Feedstocks
Direct Heat	197.3	0.061	3.684	0.041	0.076	5.635	0.000
Refrigeration	197.3	0.213	0.046	0.000	0.000	0.000	0.000
Electrolytic	197.3	0.679	0.000	0.000	0.000	0.000	0.000
Other	197.3	0.005	0.122	0.000	0.000	0.304	0.000
Feedstocks	197.3	0.000	3.679	0.000	8.843	0.000	7.108

Source: Arthur D. Little Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*. Unpublished Report Prepared for Office of Integrated Analysis and Forecasting, Energy Information Administration, (Washington, DC, September 2001).

Table B5. Glass and Glass Products Industry National UECs, 1998 (Million Btu/Ton of Flow, Unless Otherwise Indicated)					
Process Step	Flow (MMtons)	Electricity	Natural Gas	Resid	Steam
Virgin					
Batch Prep	15.3	0.190	0.000	0.000	0.000
Melting/Refining	15.3	0.460	4.518	0.092	0.140
Scrap					
Batch Prep	3.6	0.170	0.000	0.000	0.000
Melting/Refining	4.8	0.370	3.616	0.074	0.130
Forming	20.1	0.850	1.392	0.028	0.040
Post-Forming	20.1	0.370	1.637	0.033	0.050

Source: Arthur D. Little Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*. Unpublished Report Prepared for Office of Integrated Analysis and Forecasting, Energy Information Administration, (Washington, DC, September 2001).

Table B6. Hydraulic Cement Industry National UECs, 1998
(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Distillate	Other Petroleum	Coal	Steam
Dry Process	61.3	0.230	0.269	0.011	0.616	2.554	0.000
Wet Process	20.9	0.210	0.365	0.015	0.836	3.464	0.180
Finish Grinding	92.5	0.220	0.000	0.000	0.000	0.000	0.000

Source: Arthur D. Little Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*. Unpublished Report Prepared for Office of Integrated Analysis and Forecasting, Energy Information Administration, (Washington, DC, September 2001).

Table B7. Blast Furnace and Basic Steel Products Industry National UECs, 1998
(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Resid	Distillate	Coal	Coke	Steam	Byproduct Consumed
Coke Ovens	20.0	0.100	0.018	0.010	0.000	36.800	NA	0.640	2.976
Iron & Steelmaking									
BOF	59.7	0.200	1.600	0.340	0.000	0.820	9.140	1.030	1.700
EAF	49.1	1.460	0.574	0.001	0.000	0.000	0.000	0.000	0.000
Casting									
Ingot	4.8	0.300	1.660	0.000	0.000	0.000	0.000	0.020	0.150
Continuous	103.9	0.090	0.300	0.000	0.000	0.000	0.000	0.010	0.000
Hot Rolling	107.5	0.350	1.400	0.000	0.000	0.000	0.000	0.020	0.300
Cold Rolling	40.5	0.790	1.500	0.000	0.050	0.000	0.000	1.290	0.300

Source: Arthur D. Little Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*. Unpublished Report Prepared for Office of Integrated Analysis and Forecasting, Energy Information Administration, (Washington, DC, September 2001).

Table B8. Aluminum Industry National UECs, 1998
(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Steam	Petroleum Coke
Alumina Refining	6.5	0.700	3.200	5.500	0.000
Primary Smelting	4.0	46.800	3.400	0.500	1.400
Secondary/Scrap	3.1	1.400	4.900	0.000	0.000
Semi-Fabrication					
Sheet, Plate, Foil	5.9	2.900	10.000	0.000	0.000
Other	2.6	8.800	10.200	0.000	0.000

Source: Arthur D. Little Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*. Unpublished Report Prepared for Office of Integrated Analysis and Forecasting, Energy Information Administration, (Washington, DC, September 2001).

Table B9. Non-Energy-Intensive Manufacturing Sector PA Component National UECs, 1998
(Thousand Btu/1996$ of Shipments, Unless Otherwise Indicated)

Industry	Shipments (Billion 96$)	Electricity	Natural Gas	Resid	Distillate	LPG	Coal	Steam
Metal-Based Durables								
Heating	1761.9	0.050	0.160	0.001	0.001	0.002	0.002	0.075
Refrigeration	1761.9	0.017	0.002	0.000	0.000	0.000	0.000	0.000
Electrochemical	1761.9	0.010	0.000	0.000	0.000	0.000	0.000	0.000
Other	1761.9	0.004	0.002	0.000	0.002	0.000	0.000	0.000
Other Manufacturing								
Heating	1215.3	0.109	0.538	0.012	0.016	0.021	0.050	0.660
Refrigeration	1215.3	0.051	0.002	0.000	0.000	0.000	0.000	0.000
Electrochemical	1215.3	0.017	0.000	0.000	0.000	0.000	0.000	0.000
Other	1215.3	0.001	0.012	0.001	0.000	0.000	0.000	0.000

Source: Arthur D. Little Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*. Unpublished Report Prepared for Office of Integrated Analysis and Forecasting, Energy Information Administration, (Washington, DC, September 2001).

Table B10. Non-Manufacturing Sector PA Component National UECs, 1998
(Thousand Btu/1996$ of Shipments, Unless Otherwise Indicated)

Industry	Shipments (Billion 96$)	Electricity	Natural Gas	Resid	Distillate	LPG	Motor Gasoline	Coal	Steam	Other Petrol[b]
Agri-Crops	140.6	0.661	1.164	0.000	2.241	0.444	0.377	0.000	1.000	0.086
Agri-Other	132.7	0.579	0.428	0.000	1.080	0.338	0.294	0.000	1.000	0.069
Coal mining	29.1	1.103	0.109	0.279	2.009	0.000	0.092	0.443	0.000	0.000
Oil and Gas	83.5	1.152	19.680[a]	0.418	0.596	0.000	0.190	0.000	1.000	0.106
Other Mining	31.3	3.123	7.740	0.358	3.116	0.000	0.119	4.346	1.000	0.000
Construction	890.9	0.121	0.294	0.000	0.261	0.000	0.078	0.000	0.000	1.417

[a] Natural gas includes lease and plant fuel.
[b] Other Petroleum is miscellaneous petroleum products except in the construction industry where it consists of asphalt and road oil.
Source: Arthur D. Little Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*. Unpublished Report Prepared for Office of Integrated Analysis and Forecasting, Energy Information Administration, (Washington, DC, September 2001).

Table B11. Regional Technology Shares

Industry	Technology	Census Region: Northeast	Midwest	South	West
Paper and Allied Products	Kraft (incl. Sulfite)	5.1%	3.9%	76.1%	14.9%
	Semi-Chemical	11.5%	29.5%	50.5%	8.5%
	Mechanical	12.2%	14.1%	50.8%	22.9%
	Waste Fiber	15.2%	26.2%	40.7%	17.9%
	Bleaching	7.3%	5.3%	75.1%	12.3%
	Papermaking	12.8%	18.2%	55.6%	13.4%
Hydraulic Cement	Wet Process	22.0%	26.0%	42.5%	9.5%
	Dry Process	9.5%	27.2%	32.9%	30.4%
	Clinker	11.3%	28.1%	36.8%	23.7%
Blast Furnace and Basic Steel Products	Electric Arc Furnace	11.0%	35.0%	46.0%	8.0%
	Basic Oxygen Furnace	4.0%	77.0%	16.0%	4.0%
	Coke Oven	30.0%	43.0%	23.0%	4.0%
Aluminum	Alumina Refining	0.0%	0.0%	100.0%	0.0%
	Primary Smelting	6.0%	18.0%	37.0%	39.0%
	Secondary/Scrap	8.0%	48.0%	29.0%	15.0%
	Semi-Fab: Sheet	17.0%	28.0%	48.0%	7.0%
	Semi-Fab: Other	15.0%	33.0%	38.0%	13.0%

Source: Arthur D. Little Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*. Unpublished Report Prepared for Office of Integrated Analysis and Forecasting, Energy Information Administration, (Washington, DC, September 2001).

Table B12. Coefficients for Technology Possibility Curves, Reference Case						
Industry/ Process Unit	Old Facilities		New Facilities			Retirement Rate (%/Year)
	REI 2025	TPC[a]	REI 1998	REI 2025	TPC[a]	
Food						
Process Heating	0.900	-0.0039	0.900	0.800	-0.0044	1.7
Process Cooling	0.876	-0.0049	0.850	0.750	-0.0046	1.7
Other	0.915	-0.0033	0.915	0.810	-0.0045	1.7
Pulp & Paper						
Wood Preparation	0.922	-0.0030	0.873	0.845	-0.0012	2.3
Waste Pulping	0.942	-0.0022	0.936	0.882	-0.0022	2.3
Mechanical Pulping	0.917	-0.0032	0.868	0.834	-0.0015	2.3
Semi-Chemical	0.873	-0.0050	0.876	0.747	-0.0059	2.3
Kraft, Sulfite	0.816	-0.0075	0.876	0.632	-0.0121	2.3
Bleaching	0.871	-0.0051	0.900	0.742	-0.0071	2.3
Paper Making	0.796	-0.0084	0.900	0.592	-0.0154	2.3
Bulk Chemicals						
Process Heating	0.900	-0.0039	0.900	0.800	-0.0044	1.7
Process Cooling	0.876	-0.0049	0.850	0.751	-0.0046	1.7
Electro-Chemical	0.981	-0.0007	0.950	0.850	-0.0041	1.7
Other	0.915	-0.0033	0.913	0.808	-0.0045	1.7
Glass[b]						
Batch Preparation	0.940	-0.0023	0.882	0.882	0.0000	1.3
Melting/Refining	0.712	-0.0125	0.900	0.422	-0.0277	1.3
Forming	0.905	-0.0037	0.982	0.808	-0.0072	1.3
Post Forming	0.925	-0.0029	0.968	0.850	-0.0048	1.3
Cement						
Dry Process	0.840	-0.0064	0.889	0.747	-0.0064	1.2
Wet Process[c]	0.935	-0.0025	NA	NA	NA	1.2
Finish Grinding	0.836	-0.0066	0.950	0.673	-0.0127	1.2

Table B12. Coefficients for Technology Possibility Curves, Reference Case						
Industry/ Process Unit	Old Facilities		New Facilities			Retirement Rate (%/Year)
	REI 2025	TPC[a]	REI 1998	REI 2025	TPC[a]	
Steel						
Coke Oven[c]	0.915	-0.0033	0.874	0.830	-0.0019	1.5
BF/Basic Oxygen Furnace	0.989	-0.0004	1.000	0.979	-0.0008	1.0
Electric Arc Furnace	0.995	-0.0002	0.995	0.990	0.0000	1.5
Ingot Casting[c]	1.000	0.0000	NA	NA	NA	2.9
Continuous Casting	1.000	0.0000	1.000	1.000	0.0000	2.9
Hot Rolling	0.742	-0.0110	0.742	0.485	-0.0160	2.9
Cold Rolling	0.738	-0.0112	0.924	0.474	-0.0244	2.9
Aluminum						
Alumina Refining	0.930	-0.0027	0.900	0.862	-0.0016	1.0
Primary Aluminum	0.910	-0.0035	0.950	0.816	-0.0056	1.0
Secondary/Scrap	0.781	-0.0091	0.750	0.561	-0.0107	1.0
Semi-Fabrication						
Sheet, Plate, Foil	0.746	-0.0108	0.900	0.491	-0.0222	1.0
Other	0.873	-0.0050	0.950	0.748	-0.0088	1.0
Metal-Based Durables						
Process Heating	0.900	-0.0039	0.900	0.799	-0.0044	1.3
Process Cooling	0.876	-0.0049	0.851	0.751	-0.0046	1.3
Electro-Chemical	0.981	-0.0007	0.955	0.855	-0.0041	1.3
Other	0.915	-0.0033	0.915	0.810	-0.0045	1.3
Other Manufacturing						
Process Heating	0.900	-0.0039	0.900	0.799	-0.0044	1.3
Process Cooling	0.876	-0.0049	0.851	0.751	-0.0046	1.3
Electro-Chemical	0.981	-0.0007	0.955	0.855	-0.0041	1.3
Other	0.915	-0.0033	0.915	0.810	-0.0045	1.3
Non-Manufacturing	0.973	-0.0010	0.900	0.853	-0.0020	1.0

Table B12. Coefficients for Technology Possibility Curves, Reference Case						
Industry/ Process Unit	Old Facilities		New Facilities			Retirement Rate (%/Year)
	REI 2025	TPC[a]	REI 1998	REI 2025	TPC[a]	

[a]TPC is the annual rate of change between 1998 and 2020.
[b]REIs apply to both virgin and recycled materials.
[c]No new plants are likely to be built that use these technologies.
Sources: Arthur D. Little, Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics.* Unpublished report prepared for Office of Integrated Analysis and Forecasting Energy Information Administration, (Washington, DC, September 2001); and Office of Integrated Analysis and Forecasting estimates.

Table B13. Coefficients for Technology Possibility Curves, High Technology Case

Industry/ Process Unit	Old Facilities		New Facilities		
	REI 2025	TPC[a]	REI 1998	REI 2025	TPC[a]
Food					
Process Heating	0.829	-0.0069	0.900	0.629	-0.0132
Process Cooling	0.829	-0.0069	0.850	0.594	-0.0132
Other	0.829	-0.0069	0.915	0.639	-0.0132
Pulp & Paper					
Wood Preparation	0.843	-0.0063	0.873	0.790	-0.0037
Waste Pulping	0.900	-0.0039	0.936	0.809	-0.0054
Mechanical Pulping	0.883	-0.0046	0.868	0.805	-0.0028
Semi-Chemical	0.814	-0.0076	0.876	0.634	-0.0119
Kraft, Sulfite	0.714	-0.0124	0.876	0.411	-0.0276
Bleaching	0.779	-0.0092	0.900	0.544	-0.0185
Paper Making	0.687	-0.0138	0.900	0.343	-0.0351
Bulk Chemicals					
Process Heating	0.844	-0.0063	0.900	0.644	-0.0123
Process Cooling	0.844	-0.0063	0.850	0.609	-0.0123
Electro-Chemical	0.844	-0.0063	0.950	0.680	-0.0123
Other	0.844	-0.0063	0.915	0.654	-0.0123
Glass[b]					
Batch Preparation	0.857	-0.0057	0.882	0.645	-0.0115

Table B13. Coefficients for Technology Possibility Curves, High Technology Case					
Industry/ Process Unit	Old Facilities		New Facilities		
	REI 2025	TPC[a]	REI 1998	REI 2025	TPC[a]
Melting/Refining	0.710	-0.0126	0.900	0.418	-0.0280
Forming	0.866	-0.0053	0.982	0.682	-0.0134
Post Forming	0.805	-0.0080	0.968	0.531	-0.0220
Cement					
Dry Process	0.788	-0.0088	0.889	0.558	-0.0171
Wet Process[c]	0.788	-0.0088	NA	NA	NA
Finish Grinding	0.823	-0.0072	0.950	0.628	-0.0152
Steel					
Coke Oven[c]	0.592	-0.0192	0.874	0.502	-0.0203
BF/Basic Oxygen Furnace	0.905	-0.0037	1.000	0.678	-0.0143
Electric Arc Furnace	0.801	-0.0082	0.990	0.632	-0.0165
Ingot Casting[c]	1.000	0.0000	NA	NA	NA
Continuous Casting	0.932	-0.0026	1.000	0.867	-0.0053
Hot Rolling	0.427	-0.0310	0.750	0.093	-0.0743
Cold Rolling	0.383	-0.0349	0.924	0.023	-0.1278
Aluminum					
Alumina Refining	0.859	-0.0056	0.900	0.900	0.0000
Primary Aluminum	0.816	-0.0075	0.950	0.582	-0.0180
Secondary/Scrap	0.667	-0.0149	0.750	0.388	-0.0241
Semi-Fabrication					
Sheet, Plate, Foil	0.689	-0.0137	0.900	0.353	-0.0341
Other	0.706	-0.0128	0.950	0.346	-0.0367
Metal-Based Durables					
Process Heating	0.814	-0.0076	0.900	0.614	-0.0141
Process Cooling	0.814	-0.0076	0.851	0.580	-0.0141
Electro-Chemical	0.814	-0.0076	0.955	0.651	-0.0141
Other	0.814	-0.0076	0.915	0.624	-0.0141
Other Manufacturing					
Process Heating	0.821	-0.0073	0.900	0.617	-0.0139

Table B13. Coefficients for Technology Possibility Curves, High Technology Case					
Industry/ Process Unit	Old Facilities		New Facilities		
	REI 2025	TPC[a]	REI 1998	REI 2025	TPC[a]
Process Cooling	0.821	-0.0073	0.851	0.583	-0.0139
Electro-Chemical	0.821	-0.0073	0.955	0.655	-0.0139
Other	0.821	-0.0073	0.915	0.625	-0.0139
Non-Manufacturing	0.947	-0.0020	0.900	0.808	-0.0040

[a]TPC is the annual rate of change between 1998 and 2020.
[b]REIs apply to both virgin and recycled materials.
[c]No new plants are likely to be built that use these technologies.
Sources: Arthur D. Little, Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics.* Unpublished report prepared for Office of Integrated Analysis and Forecasting Energy Information Administration, (Washington, DC, September 2001); and Office of Integrated Analysis and Forecasting estimates.

Table B14. Advanced and State of the Art (S-O-A) Technologies

	Sector	Major Process Step	Technology	Improvement in Subprocess Step	Alternative Process Step	OIT(a)
1	Pulp/Paper (S-O-A)	Wood Preparation	Whole Tree Debarking/Chipping*	x		
2			Chip Screening Equipment*	x		
3	Pulp/Paper (S-O-A)	Chemical Pulping Technologies (Kraft, Sulfite)	Continuous Digesters	x		
4			Batch Digesters	x		
5			Radar Displacement Heating	x		
6			Sunds Defibrator Cold Blow and Extended Delignification		x	
7			EKONO's White Liquor Impregnation		x	
8			Anthraquinone Pulping		x	
9			Alkaline Sulfite Anthraquinone (ASOQ) and Neutral Sulfite Anthraquinone (NSAQ) Pulping		x	
10			Tampella Recovery System	x		
11			Advanced Black Liquor Evaporator	x		
12			Process Controls System	x		
13	Pulp/Paper (S-O-A)	Mechanical and Semi-Mechanical Technologies	Pressurized Groundwood (PGW)		x	
14			PGW-Plus		x	
15			Thermo-Refiner Mechanical Pulping	x		
16			Heat Recovery in TMP*	x		

Table B14. Advanced and State of the Art (S-O-A) Technologies

17			Cyclotherm System for Heat Recovery*	x		
18			Chemimechanical Pulping	x		
19			Chemi-Thermomechanical Pulping (CTMP)	x		
20			Process Control System	x		
21	Pulp/Paper (S-O-A)	Semi-Chemical Technologies	See Chemical and Mechanical S-O-A technologies above			
22	Pulp/Paper (S-O-A)	Waste Paper Pulping Technologies	Advanced Pulping	x		
23			Advanced Deinking	x		
24	Pulp/Paper (S-O-A)	Waste Pulping	Improvements in steam use, computer control, etc.	x		
25	Pulp/Paper (S-O-A)	Bleaching Oxygen Predelignification Technologies	Oxygen Bleaching		x	
26			Displacement Bleaching	x		
27			Bio-bleaching		x	
28	Pulp/Paper (S-O-A)	Papermaking Technologies	Extended Nip Press*	x		
29			Hot Pressing	x		
30			IR Moisture Profiling*	x		
31			Reduced Air Requirement*	x		
32			Waste Heat Recovery*	x		
33			Process Control System*	x		
	Pulp/Paper (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.			
34	Pulp/Paper (Advanced Technologies)	Chemical (Kraft/Sulfite) Technologies	Improved composite tubes for Kraft Recovery Boilers*	x		x
35			Non-Sulfur Chemimechanical (NSCM) Pulping		x	
36			Advanced Alcohol Pulping		x	
37			Biological Pulping		x	
38			Ontario Paper Co. (OPCO) Process		x	

Table B14. Advanced and State of the Art (S-O-A) Technologies

39			Black Liquor Concentration*	x		
40			Black Liquor Heat Recovery *	x		
41			Steam Reforming Black Liquor Gasification*	x		x
42	Pulp/Paper (Advanced Technologies)	Mechanical Technologies	Advanced Chemical/Thermal Treatment	x		
43			Non-Sulfur Chemimechanical (NSCM)		x	
44			OPCO Process		x	
45	Pulp/Paper (Advanced Technologies)	Semi-Chemical Technologies	NSCM Process	x		
46			OPCO Process		x	
47	Pulp/Paper (Advanced Technologies)	Waste Pulping	Mechanical alternatives to chemicals in Recycle Mills		x	x
48	Pulp/Paper (Advanced Technologies)	Bleaching Technologies				
49			Ozone Bleaching		x	
50			NO2/O2 Bleaching		x	
51			Biobleaching		x	
52	Pulp/Paper (Advanced Technologies)	Paper/Paperboar d	High-Consistency Forming*	x		
53			Advances in Wet Pressing*	x		
54			Press Drying*	x		
55			Impulse Drying*	x		
56			Air Radio-Frequency-Assisted (ARFA) Drying*	x		
57			Online Paper Sensors*	x		x
58			Online Fluidics Controlled Headbox*	x		x
59			Acoustic Humidity Sensor*	x		x
60			Acoustic Separation Technology*	x		x
61			Molten-Film High-Intensity Paper Dryer*		x	x
62			Linear Corrugating		x	x
63		Sludge Combustion	Methane De-NOx Reburn Process*	x		x
64	Glass (S-O-A)	Batch Preparation Technologies	Computerized Weighing, Mixing, and Charging	x		
65	Glass (S-O-A)	Melting/Refining Technologies	Chemical Boosting	x		
66			Oxygen Enriched Combustion Air*	x		
67			Automatic Tap Charging Transformers for Electric Melters	x		

Table B14. Advanced and State of the Art (S-O-A) Technologies

68			Sealed-in Burner Systems*	x		
69			Dual-Depth Melter	x		
70			Chimney Block Regenerator Refractories	x		
71			Reduction of Regenerator Air Leakage*	x		
72			Recuperative Burners*	x		
73	Glass (S-O-A)	Forming/Post-Forming Technologies	Emhart Type 540 Forehearth	x		
74			EH-F 400 Series Forehearth	x		
75			Forehearth High-Pressure Gas Firing System	x		
76			Lightweighting	x		
77	Glass (Advanced)	Batch Preparation Technologies	Integrated Batch and Cullet Preheat for Glass Furnaces*	x		x
78			Electrostatic Batch Preheater System*			x
79			SingleChip Color Sensor*	x		x
80	Glass (Advanced)	Melting/Refining Technologies	Direct Coal Firing	x		
81			Submerged Burner Combustion	x		
82			Coal-Fired Hot Gas Generation*	x		
83			Advanced Glass Melter		x	
84			Batch Liquefaction	x		
85			Molybdenum-Lined Electric Melter		x	
86			Ultrasonic Bath Agitation/Refining*	x		
87			Excess Heat Extraction from Regenerators	x		
88			Thermochemical Recuperator	x		
89			Sol-Gel Process		x	
90			Furnace Insulation Materials*	x		
91			Pressure Swing Adsorption Oxygen Generator*	x		
92			Hollow Fiber Membrane Air Separation Process*	x		
93			Energy Efficient, Electric Rotary Furnace for Glass Molding of Precision Optical Blanks	x		x
94			High Luminosity, Low-Nox Burner	x		x
95			Phase/Doppler Laser Light-Scattering System*	x		x
96	Glass (Advanced)	Forming/Post-Forming Technologies	Mold Design*	x		
97			Mold Cooling Systems	x		

Table B14. Advanced and State of the Art (S-O-A) Technologies

98			Automatic Gob Control	x		
99			Improved Glass Strengthening Techniques*	x		
100			Improved Protective Coatings*	x		
101			Advanced Low-E Coatings	x		x
102	Cement (S-O-A)	Dry Process Technologies	Roller Mills*	x		
103			High-Efficiency Classifiers*	x		
104			Grinding Media and Mill Linings*	x		
105			Waste Heat Drying*	x		
106			Kiln Feed Slurry Dewatering*	x		
107			Dry-Preheater/Precalciner Kilns	x		
108			Kiln Radiation and Infiltration Losses*	x		
109			Kiln Internal Efficiency Enhancement*	x		
110			Waste Fuels*	x		
111			Controlled Particle Size Distribution Cement	x		
112			High-Pressure Roller Press	x		
113			Finish Mill Internals, Configuration, and Operation	x		
114			Grinding Aids*	x		
115	Cement (S-O-A)	Imports-Finish Grinding Technologies	High-Efficiency Classifiers*	x		
116			Controlled Particle Size Distribution Cement*	x		
117			High Pressure Roller Press		x	
118			Roller Mills*		x	
119			Finish Mill Internals, Configuration, and Operation	x		
120			Grinding Aids*	x		
121	Cement (Advanced)	Dry Process Technologies				
122			Autogenous Mills	x		
123			Differential Grinding	x		
124			Sensors and Controls*	x		
125			Fluidized-Bed Drying	x		
126			Stationary Clinkering Systems	x		
127			All-Electric Kilns		x	
128			Sensors for On-Line Analysis*	x		
129			Advanced Kiln Control*	x		
130			Catalyzed, Low-Temperature Calcination		x	
131			Alkali Specification Modification*	x		
132			Cone Crushers*	x		

Table B14. Advanced and State of the Art (S-O-A) Technologies

133			Advanced (Non-Mechanical) Comminution	x		
134			Modifying Fineness Specifications*	x		
135			Blended Cements*	x		
136			Advanced Waste Combustion	x		
137			Grinding Mill Optimization Software*	x		x
138	Cement (Advanced)	Finish Grinding	Sensors and Controls*	x		
139			Cone Crushers*	x		
140			Advanced (Non-Mechanical) Comminution		x	
141			Modifying Fineness Specifications*	x		
142			Blended Cements*	x		
143			Grinding Mill Optimization Software	x		x
144	I&S (S-O-A)	Cokemaking Technologies	Coke Dry Quenching (CDQ)*		x	
145			Carbonization Control	x		
146			Programmed Heating	x		
147			Wet Quenching of Coke with Energy Recovery*	x		
148			Sensible Heat Recovery of Off-Gases*	x		
149			Continuous Coke Making	x	x	
150	I&S (S-O-A)	Ironmaking Technologies	Blast Furnace			
151			-Optimize Preheated Blast Air	x		x
152			- oxygen injection	x	x	
153			-Coal Injection*	x		
154			-other fuel Injection*(e,g. natural gas, oil, Coke Oven Gas)	x		
155			-Stave-Cooling & steam recovery	x		
156			-Movable Throat Armor*	x		
157			-Top Gas Pressure Recovery*	x		
158			-Hot Stove Waste Heat Recovery*	x		
159			-Insulation of Cold Blast Main*	x		
160			-Recovery of BF Gas Released During Charging	x		
161			-Slag Waste Heat Recovery*	x		
162			-waste energy fuel injection* (e.g. plastics)	x		
163			- optimization by enhanced control systems*			
164			-Paul Wurth Top*	x		
165			External Desulfurization - injection	x		

Table B14. Advanced and State of the Art (S-O-A) Technologies

			of calcium carbide or mag-coke as a desulfurizing reagent*			
166			Direct Reduced Iron (DRI) use	x		
167			Midrex/Hyl/Other DRI Processes		x	
168			Induction Heated Hot Metal Mixer	x		
169			Submerged Arc Furnace (SAF) to produce iron from reduced pellets		x	
	I&S (S-O-A)	Steelmaking Technologies				
170		Basic Oxygen Furnace	Gas Recovery in Combination with Sensible Heat Recovery*	x		
171			Two working vessels concept*	x		
172			Combined Top and Bottom Oxygen Blowing*	x		
173			In-Process Control (Dynamic) of Temp and Carbon Content*	x		
174			Post Combustion*	x		
175		Electric Arc Furnace	Process Control by Laser Based Gas Sensor*	x		x
176			DC Arc Furnaces*	x		
177			Ultra-High Power (UHP)*	x		
178			Computerization*	x		
179			Bottom Tap Vessels*	x		
180			Water-Cooled Furnace Panels and Top*	x		
181			Water-Cooled Electrode Sections*	x		
182			Oxy-Fuel Burners*	x		
183			Long Arc Foamy Slag Practice*	x		
184			Material Handling Practices*	x		
185			Post Combustion*	x		
186			Gas stirring incuding Argon stirring	x		
187			Induction Stirring	x		
188			Scrap-Preheating*	x		
189			Induction Furnaces*		x	
190			Energy Optimizing Furnaces*		x	
191			Hot charging DRI	x		
192			Hot Briquetted Iron	x		
193	I&S (S-O-A) (continued)	Other Technologies	Ladle Drying and Preheating*	x		
194			Injection Steelmaking (ladle metallurgy)	x		
195		Specialty Steelmaking Processes	Vacuum Arc Decarburization*			
196			Electroslag Remelting (ESR)*		x	
197			Argon-Oxygen Decarburization		x	

Table B14. Advanced and State of the Art (S-O-A) Technologies

			(AOD)*			
198			Vacuum Induction Melting (VIM)*		x	
199			Electron Beam Melting (EBM)*		x	
200			Vacuum Arc Remelting (VAR)*		x	
201	I&S (S-O-A)	Steelcasting Technologies	Clean Cast Steel			x
202			Modern Casters (near net shape)*		x	
203			Continuous-Conticasting	x		
204			Plasma heated Tundish for temperature control	x		
205			Thin Strip Caster*		x	
206			Thin Slab Casting		x	
207			Slab Heat Recovery*	x		
208			Soaking Pit Utilization and Pit Vacant Time*	x		
209	I&S (S-O-A)	Steelforming (Rolling) Technologies	Hot Charging	x		
210			PC Controlled Hot Rolling	x		x
211			Preheating Furnaces	x		
212			Improved Insulation*	x		
213			Waste Heat Recovery and Air Preheating*	x		
214			Waste Heat Recovery and Fuel Gas Preheating*	x		
215			Increased Length of the Preheating Furnace	x		
216			Waste Heat Boilers	x		
217			Evaporative Cooling of Furnace Skids	x		
218			Direct Rolling			
219			Leveling Furnace*	x		
220			The Coil Box*	x		
221			Covered Delay Table*	x		
222			Air Preheating*	x		
223			Fuel Gas Preheating	x		
224			Combustion Control*	x		
225			Continuous Cold Rolling		x	
226			ultra-thin steel	x		
227		Steel finishing	Continuous Annealing		x	
228			Pickling - Insulated Floats*	x		
229	I&S (Advanced Technologies)	Scrap Preparation	Electrochemical Dezincing of Steel Scrap		x	x
230	I&S (Advanced Technologies)	Ironmaking Technologies	Hot Oxygen Injection into the Blast Furnace*	x		x

Table B14. Advanced and State of the Art (S-O-A) Technologies

231			Intelligent Control of the Cupola Furnace	x		x
232			Plasmared		x	
233			Corex		x	
234			Direct Iron Ore Smelting (DIOS)		x	
235			HiSmelt		x	
236			Fastmet		x	
237			Iron Carbide Route		x	
238			Iron Ore Reduction/Steelmaking (AISI)		x	x
239			Advanced Sensors	x		x
240			Cyclone Smelting		x	
241			Circored		x	
242	I&S (Advanced Technologies)	Direct Steelmaking Technologies	Plasmamelt		x	
243			Inred		x	
244			Elred		x	
245			Foster Wheeler-Tetronics Expanded Progressive Plasma Process		x	
246			Direct Steelmaking (AISI)		x	x
247	I&S (Advanced Technologies)	Steelmaking Technologies	Scrap Preheating*	x		
248			Flue Dust Recycling	x		x
249			Processing Electric Arc Furnace Dust into Salable Products	x		x
250			Energy Optimizing Furnace (EOF)		x	
251			Modern Electric Arc Furnace with Continuous Charging/Scrap Preheating	x		
252			Modern Basic Oxygen Furnace	x		
253			Injection of Carbonaceous Fuels			
254			Increased Scrap Use			
255			Full Post Combustion in BOF	x		
256			Full Post Combustion in EAF			
257			Ladle Drying and Preheating*	x		
258			Injection Steelmaking	x		
259			Optical Sensor for Post-Combustion Control in EAF Steelmaking	x		x
260	I&S (Advanced Technologies)	Steelcasting Technologies	Horizontal Continuous Caster*		x	
261			Magnetic Gate System for Molten Metal Flow Control*	x		x
262			Near Net Shapecasting*		x	
263			Three-Dimensional Objects by	x		x

Table B14. Advanced and State of the Art (S-O-A) Technologies

			Photosolidification*			
264			Lost Foam Casting*		x	x
265			Direct Strip Casting*		x	
266			Ultra Thin Strip Casting*		x	
267			Spray Casting		x	x
268			Clean Cast Steel	x		x
269			Advanced Sensors	x		x
270	I&S (Advanced Technologies)	Hot/Cold Rolling/Finishing	Intelligent Systems for Induction Hardening	x		x
271			Nickel Aluminide Radiant Heater	x		x
272			Phase Measurement of Galvanneal	x		x
273			On-Line Non-Destructive Mechanical Properties Measurement	x		x
274			Non-Chromium Passivation Techniques for Electrolytic Tin Plate		x	x
275			Improved Surface Quality of Exposed Automotive Sheet Steels	x		x
276			Lightweight Steel Containers	x		x
277			Laser Ultrasonics to Measure Tube Wall Thickness	x		x
278			Laser Ultrasonics to Measure Grain Size	x		x
279			Automated surface inspection	x		x
280			Direct Rolling	x		
281			Continuous Cold Rolling and Finishing	x		
282			In-Line Melting/Rolling	x		
283			Advanced Coating	x		

Note for Iron and Steel: Many advanced technologies 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.

284	Aluminum (S-O-A)	Alumina Refining Technologies	Advanced Digesters	x		
285			Heat Recovery*	x		
286	Aluminum (S-O-A)	Primary Aluminum Technologies	Advanced Cells	x		
287			Advanced Process Controls*	x		x
288			Pre-baked Anodes*	x		
289	Aluminum (S-O-A)	Semi-Fabrication Technologies	Continuous-Strip Casting		x	

Table B14. Advanced and State of the Art (S-O-A) Technologies

290			Electromagnetic Casting	x		
291			Induction Heating	x		
292	Aluminum (S-O-A)	Secondary Aluminum Technologies	Induction Melting		x	
293			Advanced Melting		x	
294	Aluminum (Advanced)	Alumina Refining Technologies	Retrofit of S-O-A Technologies	x		
295	Aluminum (Advanced)	Primary Aluminum Technologies				
296			Carbothermic Reduction		x	x
297			Inert Anodes*	x		x
298			Bipolar Cell Technology		x	
299			Wettable Cathodes*	x		x
300			Converting Spent Pot Liners (SPL) to Products*		x	x
301			Molten Aluminum Explosion Prevention	x		x
302	Aluminum (Advanced)	Semi-Fabrication Technologies	Improved Grain-Refinement Process*	x		x
303			Induction Heaters		x	
304			Preheaters*	x		x
305			Novel Technique for Increasing Corrosion Resistance of Aluminum and Al Alloys	x		x
306			Spray casting	x		x
307	Aluminum (Advanced)	Secondary Aluminum Technologies	Vertical Flotation Melter	x		x
308			New Melting Technology (submerged radiant burners)	x		
309			Preheaters*	x		
310			Heat Recovery Technology	x		
311			Aluminum Salt Cake: Electrodialysis Processing of Brine*		x	x
312			Oxidative Melt Loss Reduction*	x		x
313			Plasma Furnaces for dross treatment	x	x	
314	Chemicals and Generic Technologies (Advanced)	Synthesis	Advanced Catalytic Hydrogenation Retrofit Reactor*	x		x
315			Biofine Technology	x		x

Table B14. Advanced and State of the Art (S-O-A) Technologies

316			Novel Membrane-Based Process for Producing Lactate Esters		x	x
317		Synthesis - Engineering	Alloys for Ethylene Production*	x		x
318		Separation	Advanced Sorbents for Gas Separation*		x	x
319		Electrochemistry	Advanced Electrodeionization Technology*	x		x
320		Product Recovery	Chlorosilane Recovery from Silicone Production	x		x
321			Olefine Recovery from Chemical Waste Streams*	x		x
322			Pressure Swing Adsorption for Product Recovery*	x		x
323			Separation and Recovery of Thermo Plastics for Reuse via Froth Flotation*	x		x
324	Chemicals and Generic Technologies (Advanced)	Heating	Low-NOx High Luminosity Burner	x		x
325	Chemicals and Generic Technologies (Advanced)	Boilers	Forced Internal Recirculation Burner	x		x
326	Chemicals and Generic Technologies (Advanced)	Metal-Based Durables	Lost Foam Casting Technology		x	x
	TOTAL			224	77	61

Note: State-of-the-Art (S-O-A) and advanced technologies are listed separately by industry;
OIT supported technologies, presently or in past, are flagged in the last column.
The column labeled alternative process step is used to flag a technology that would involve a significant process change.
Source:Arthur D. Little Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*. Unpublished Report Prepared for Office of Integrated Analysis and Forecasting, Energy Information Administration, (Washington, DC, September 2001).

Table B15. 1998 Motor Characteristics

Industrial Sector Horsepower Range	1998 Stock	1998 Average Energy Use (kWh/motor)	1998 Average Efficiency	Average Part Load	Average Operating Hours
Food					
1 - 5 hp	610067	5568	0.8130	0.61	3829
6 - 20 hp	209340	24840	0.8713	0.61	3949
21 - 50 hp	57098	96574	0.9013	0.61	4927
51 - 100 hp	22241	212729	0.9272	0.61	5524
101 - 200 hp	16903	323470	0.9348	0.61	5055
201 - 500 hp	7926	6605525	0.9378	0.61	3711
> 500 hp	4049	1537901	0.9303	0.61	5362
Bulk Chemicals					
1 - 5 hp	336523	5326	0.8197	0.65	4082
6 - 20 hp	237703	29476	0.8739	0.65	4910
21 - 50 hp	114772	86578	0.9044	0.65	4873
51 - 100 hp	46756	213594	0.9241	0.65	5853
101 - 200 hp	32141	484522	0.9348	0.65	5868
201 - 500 hp	17452	1132905	0.9333	0.65	6474
> 500 hp	7990	5631554	0.9324	0.65	7566
Metal-Based Durables					
1 - 5 hp	4292589	2752	0.8189	0.62	1985
6 - 20 hp	1347038	15472	0.8704	0.62	2959
21 - 50 hp	347691	49198	0.8992	0.62	3371
51 - 100 hp	58700	157962	0.9198	0.62	4621
101 - 200 hp	34199	210203	0.9348	0.62	4905
201 - 500 hp	6372	1580555	0.9367	0.62	7409
> 500 hp	2860	3010632	0.9303	0.62	8164
Balance of Manufacturing					
1 - 5 hp	1778668	4215	0.8293	0.62	2927
6 - 20 hp	999066	17404	0.8828	0.62	3169
21 - 50 hp	330771	61787	0.9032	0.62	3774
51 - 100 hp	116896	189578	0.9268	0.62	4981
101 - 200 hp	75643	336559	0.9427	0.62	4587
201 - 500 hp	21087	832049	0.9425	0.62	5432
> 500 hp	6320	4277671	0.9289	0.62	5362

Sources: U.S. Department of Energy, *United States Industrial Electric Motor Systems Market Opportunities Assessment* (Burlington, MA, December 1998).

Table B16. Cost and Performance Parameters for Industrial Motor Choice Model

Industrial Sector Horsepower Range	1998 Stock Efficiency (%)	EPACT Minimum Efficiency (%)	EPACT Minimum Eff. Cost (2002$)	Premium Efficiency (%)	Premium Cost (2002$)
Food					
1 - 5 hp	81.3	86.7	327	88.9	351
6 - 20 hp	87.1	91.4	901	92.7	947
21 - 50 hp	90.1	92.6	1,448	93.7	1,618
51 - 100 hp	92.7	94.4	3,338	95.1	3,430
101 - 200 hp	93.5	94.6	6,734	95.9	7,670
201 - 500 hp	93.8	93.4	12,147	96.1	13,560
> 500 hp	93.0	94.8	19,148	na	na
Bulk Chemicals					
1 - 5 hp	82.0	86.9	327	89.1	351
6 - 20 hp	87.4	91.6	901	92.9	947
21 - 50 hp	90.4	92.7	1,448	93.8	1,618
51 - 100 hp	92.4	94.4	3,338	95.2	3,430
101 - 200 hp	93.5	94.7	6,734	96.0	7,670
201 - 500 hp	93.3	93.6	12,147	96.1	13,560
> 500 hp	93.2	94.9	19,148	na	na
Metal-Based Durables					
1 - 5 hp	81.9	86.8	327	88.9	351
6 - 20 hp	87.0	91.5	901	92.8	947
21 - 50 hp	90.0	92.6	1,448	93.8	1,618
51 - 100 hp	92.0	94.4	3,338	95.1	3,430
101 - 200 hp	93.5	94.6	6,734	95.9	7,670
201 - 500 hp	93.7	93.5	12,147	96.1	13,560
> 500 hp	93.0	94.8	19,148	na	na
Balance of Manufacturing					
1 - 5 hp	82.9	86.8	327	88.9	351
6 - 20 hp	88.3	91.5	901	92.8	947
21 - 50 hp	90.3	92.6	1,448	93.8	1,618
51 - 100 hp	92.7	94.4	3,338	95.1	3,430
101 - 200 hp	94.3	94.6	6,734	95.9	7,670
201 - 500 hp	94.3	93.5	12,147	96.1	13,560
> 500 hp	92.9	94.8	19,148	na	na

Sources: U.S. Department of Energy, *United States Industrial Electric Motor Systems Market Opportunities Assessment* (Burlington, MA, December 1998), and U.S. Department of Energy, *MotorMaster+ 3.0* software database (October 13,1999).
Note: The efficiencies listed in this table are operating efficiencies based on average part-loads. Because the average part-load is not the same for all industries, the listed efficiencies for the different motor sizes vary across industries.

Table B17. Payback Acceptance Rate Assumptions for Motor Decisions

Payback Period in Years	Acceptance Rate
1	100.00%
2	80.00%
3	35.00%
4	0.00%

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

Table B18. Fossil Energy Consumption in Boilers (trillion Btu)					
Industry	Region	Alpha	Natural Gas	Steam Coal	Oil
Food and Kindred Products	Northeast	-0.25	29.04	1.48	4.09
	Midwest	-0.25	159.43	91.11	4.02
	South	-0.25	92.08	11.16	11.54
	West	-0.25	69.83	15.88	5.36
Paper and Allied Products	Northeast	-0.25	38.73	23.48	69.10
	Midwest	-0.25	87.33	83.17	4.93
	South	-0.25	228.58	154.59	54.63
	West	-0.25	90.37	9.78	4.10
Bulk Chemicals	Northeast	-0.25	16.24	0.22	15.92
	Midwest	-0.25	64.29	30.55	47.57
	South	-0.25	801.60	141.68	530.42
	West	-0.25	44.26	61.56	9.40
Glass and Glass Products	Northeast	-0.25	1.02	0.00	0.00
	Midwest	-0.25	1.04	0.00	0.00
	South	-0.25	1.53	0.00	0.00
	West	-0.25	0.41	0.00	0.00
Hydraulic Cement	Northeast	-0.25	0.02	0.44	0.00
	Midwest	-0.25	0.32	0.72	0.00
	South	-0.25	0.74	1.12	0.00
	West	-0.25	0.91	0.72	0.00
Steel	Northeast	-0.25	6.01	0.08	0.05
	Midwest	-0.25	34.07	6.96	8.62
	South	-0.25	13.78	0.92	1.28
	West	-0.25	3.26	0.05	0.06
Aluminum	Northeast	-0.25	3.60	0.00	0.00
	Midwest	-0.25	8.85	0.00	0.00
	South	-0.25	28.22	0.00	0.00
	West	-0.25	3.19	0.00	0.00
Metal-Based Durables	Northeast	-0.25	23.54	5.26	5.62
	Midwest	-0.25	88.67	29.3	2.29
	South	-0.25	38.40	1.15	5.45
	West	-0.25	17.40	0.00	0.51
Balance of Manufacturing	Northeast	-0.25	64.68	26.14	19.46
	Midwest	-0.25	137.09	60.86	7.42
	South	-0.25	190.77	71.51	21.63
	West	-0.25	78.38	17.39	4.03
Source: Energy Information Administration, Office of Integrated Analysis and Forecasting estimates based on 1998 Manufacturing Energy Consumption Survey.					

Table B19. Boiler population characteristics used for cogeneration system sizing and steam load segmentation

Distribution of Boilers by Firing Capacity and Industry	1.5-10 mmbtu/hr	10-50 mmbtu/hr	50-100 mmbtu/hr	100-250 mmbtu/hr	250-500 mmbtu/hr	> 500 mmbtu/hr
Food	0%	35.9%	25.1%	25.5%	5.5%	8.0%
Pulp and Paper	0%	10.1%	10.9%	24.9%	22.2%	32.0%
Chemicals	0%	25.7%	15.7%	28.8%	12.2%	17.6%
Primary Metals	0%	28.2%	12.3%	21.9%	15.4%	22.2%
Other Manuf	38.1%	31.8%	15.3%	11.7%	1.3%	1.8%
Average Boiler Size (mmbtu/hr)	6.38	28.42	**84.24**	**141.73**	325.0	**666.7**

Sources: National Renewable Energy Laboratory, *Gas-Fired Distributed Generation Technology Characterization: Reciprocating Engines*, Final Draft, July 2003 and National Renewable Energy Laboratory, *Gas-Fired Distributed Generation Technology Characterization: Gas Turbines*, Final Draft, August 2003.

Table B20. Characteristics of Candidate Cogeneration Systems

	Systems Considered							
	1	2	3	4	5	6	7	8
System Type	Engine	Engine	Gas Turbine	Gas Turbine	Gas Turbine	Gas Turbine	Gas Turbine	Combined Cycle
Electric Capacity (kW)	1,000	3,000	1,000	5,000	10,000	25,000	40,000	100,000
Total Installed Cost (2003 $/kW)	940	935	1,910	1,024	930	800	702	692
Capacity Factor	0.8	0.8	0.8	0.8	.8	.8	.8	0.9
Overall Efficiency	0.71	0.69	0.65	0.67	0.69	0.70	0.72	0.70
Total Heat Rate (Btus/kWh)	10,035	9,700	15,580	12,590	11,765	9,945	9,220	6,826
Incremental Heat Rate (Btus/kWh)	5,394	5,599	7,186	6,311	5,883	5,508	5,187	5,118
Thermal Output (mmBtu/hour)	3.7	9.8	6.7	25.1	47.1	88.7	129.1	136.6
Power-Steam Ratio	.92	1.04	0.51	0.68	0.73	0.96	1.06	2.50

Sources: National Renewable Energy Laboratory, Gas-Fired Distributed Generation Technology Characterization: Reciprocating Engines, Final Draft, July 2003; National Renewable Energy Laboratory, Gas-Fired Distributed Generation Technology Characterization: Gas Turbines, Final Draft, August 2003.

Note: The 1000 kW Gas Turbine is not expected to be a viable option in the future.

Table B21. Payback Acceptance Rate Assumptions for Cogeneration Market Penetration

Payback Period in Years	Acceptance Rate
0	100.00%
1	91.00%
2	71.50%
3	51.00%
4	32.00%
5	18.50%
6	11.00%
7	6.50%
8	4.00%
9	2.13%
10	0.88%
11	0.25%
12	0.00%

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

Table B22. 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).

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 2003.

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

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

Official Model Representatives:

T. Crawford Honeycutt
(202)586-1420
crawford.honeycutt@eia.doe.gov
Office of Integrated Analysis and Forecasting
EI-84
1000 Independence Avenue, SW
Washington, DC 20585

Brian Unruh
(202)586-1344
brian.unruh@eia.doe.gov

Documentation:
Model Documentation Report: Industrial Sector Model of the National Energy Modeling System, January 2004.

Archive Media and Installation Manual(s):
The model is archived as part of the National Energy Modeling System production runs used to generate the *Annual Energy Outlook 2004*.

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, 1998 through 2025.

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: The energy intensive industries are modeled through the use of a detailed process flow accounting procedure. The remaining industries use the same general procedure but do not include a detailed process flow.

Non-DOE Input Sources:
Historical Dollar Value of Shipments in the Industrial Sector
Energy Expenditures in the Agriculture and Construction sectors
Energy Consumption in the Mining sector

DOE Input Sources:
Form EI-860B: Annual Electric Generator Report – Nonutility

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

Manufacturing Energy Consumption Survey 1998, December 2000
State Energy Data System 1999, May 2001

Computing Environment:

Hardware Used: x86 Family 6, Model 7
Operating System: Microsoft Windows NT
Language/Software Used: Compaq Visual Fortran, Ver 6.1
Estimated Run Time: 7 seconds for a 1998-2025 run in non-iterating, stand-alone mode.
Special Features: None.