DOE/EIA-M064(2000)

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

January 2000

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

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

Model Summary

The NEMS Industrial Demand Model is a dynamic accounting model, bringing together the disparate industries and uses of energy in those industries, and putting them together in an understandable and cohesive framework. The Industrial Model generates mid-term (up to the year 2020) forecasts of industrial sector energy demand as a component of the NEMS integrated forecasting system. From the NEMS system, the Industrial Model receives fuel prices, employment data, and the value of industrial output. Based on the values of these variables, the Industrial Model passes back to the NEMS system estimates of consumption by fuel types.

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

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

Archival Media

The model will be archived on IBM RISC 6000 magnetic tape storage as part of the National Energy Modeling System production runs used to generate the Annual Energy Outlook 2000.

Model Contact

T. Crawford Honeycutt
(202)586-1420
choneycu@eia.doe.gov

Office of Integrated Analysis and Forecasting
Energy Demand Analysis Branch
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 quantities, and the relationship of the Industrial Model to the other modules of the NEMS system. Chapter 3 of the report describes the rationale behind the Industrial Model design, providing insights into further assumptions utilized in the model. 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 consists of a model abstract. Appendix C provides the input data.

2. Model Purpose

Model Objectives

The NEMS Industrial Demand Model was designed to forecast industrial energy consumption by fuel type and Standard Industrial Classification (SIC). The Industrial Model generates mid-term (up to the year 2020) forecasts of industrial sector energy demand as a component of the NEMS integrated forecasting system. From the NEMS system, the Industrial Model receives fuel prices, employment data, and the value of output for industrial activity. All dollar values are expressed in 1987 dollars. Based on the values of these variables, the Industrial Model passes back to the NEMS system estimates of fuel consumption for 17 main fuels (including feedstocks and renewables) for each of 15 SIC industry groups. The Industrial Model forecasts energy consumption at the four Census region levels; energy consumption is allocated to the Census division level based on SEDS data.

The NEMS Industrial Model is an annual energy forecasting model; as such, it does not 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 output is, in part, a function of energy prices. Therefore, the effect on industrial energy consumption of policies that change relative fuel prices can be analyzed endogenously in the model.

To a lesser extent, the Industrial Model can endogenously analyze specific technology programs or energy standards. 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 their major production processes or end uses, is used to model the energy-intensive industries. This approach provides considerable detail about how energy is consumed in that particular industry. The industrial model uses "technology bundles" to characterize technical change in the energy-intensive industries. These bundles are defined for each production process step for five of the industries and for end use in two of the industries. The process step industries are pulp and paper, glass, cement, steel, and aluminum. The end use industries are food and bulk chemicals.

The unit energy consumption is defined as the energy use per ton of throughput at a process step or as energy use per dollar of output for the end use industries. The "Existing UEC" is the current average installed intensity (as of 1994). The "New 1994 UEC" is the intensity expected to prevail for a new installation in 1994. Similarly, the "New 2020 UEC' is the intensity expected to prevail for a new installation in 2020. For intervening years, the intensity is interpolated.

The rate at which the average intensity declines is determined by the rate and timing of new additions to capacity. In our current model, 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 output Employment	Macro
Refinery consumption of: Natural gas Steam coal Distillate oil Residual oil LPG Still gas Petroleum coke Other petroleum Purchased Electricity	Petroleum Market Module
Lease and Plant Natural Gas Consumption	Natural Gas Transmission and Distribution Module

Table 1. Interaction with Other NEMS Modules (continued)

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

3. Model Rationale

Theoretical Approach

Introduction

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

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

Modeling Approach

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

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

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

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

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

- The industrial model uses "technology bundles" to characterize technical change in the energy-intensive industries. These bundles are defined for each production process step or end use.

- Technology penetration for each technology bundle for each production process step or end use in each energy-intensive industry is based upon engineering judgment.

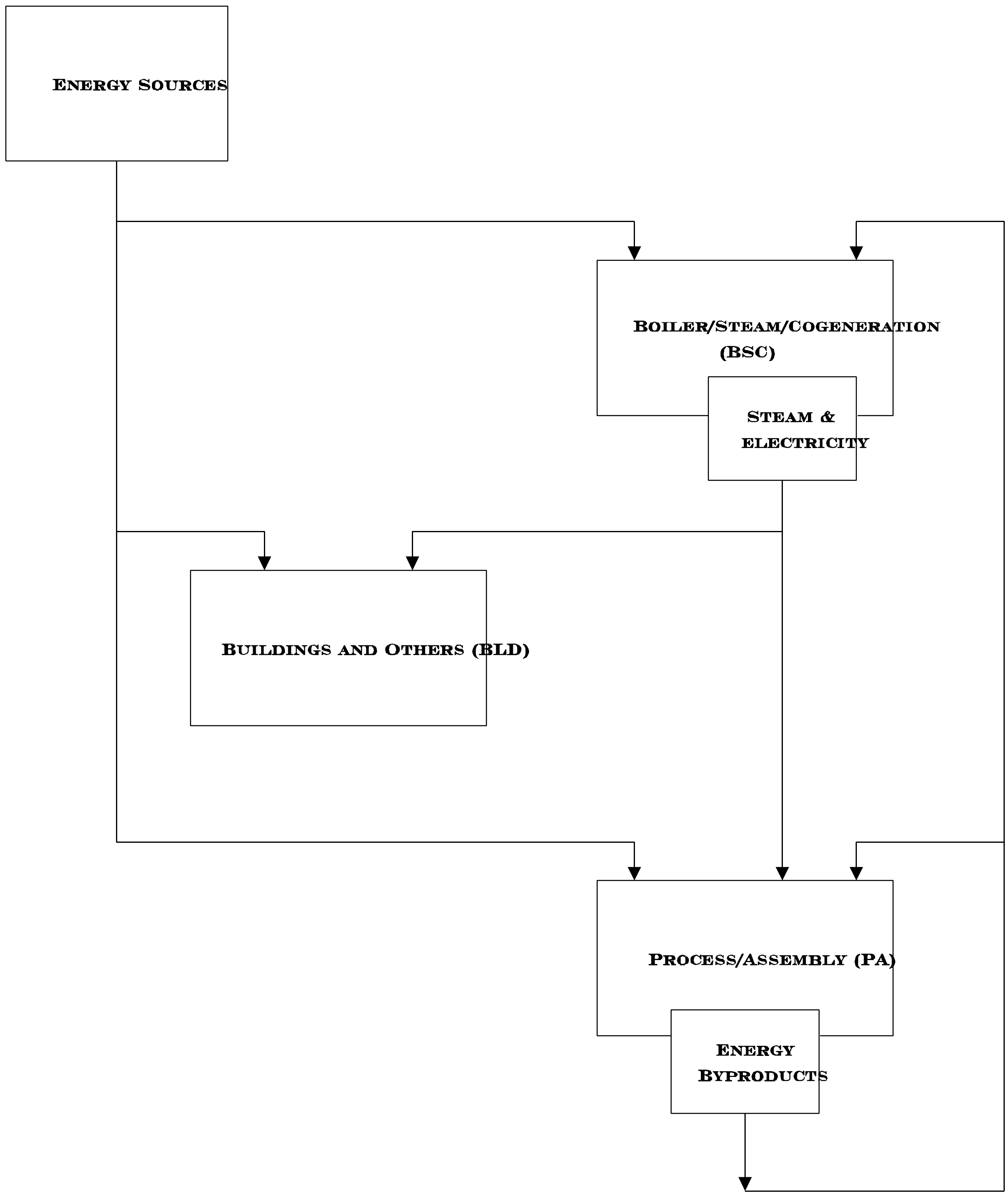
- The model structure accommodates several industrial sector activities including: fuel switching, cogeneration, renewables consumption, recycling and byproduct consumption. The principal model calculations are performed at the four Census region levels and aggregated to a national total.

Fundamental Assumptions

The industrial sector consists of a wide variety of heterogeneous industries. The Industrial Model classifies these industries into three groups by Standard Industrial Classification (SIC) - energy-intensive industries, non-energy-intensive industries, and non-manufacturing industries. There are eight energy-intensive manufacturing industries; seven of these are modeled in the industrial model. These are as follows: food and kindred products (SIC 20); paper and allied products (SIC 26); bulk chemicals (SICs 281, 282, 286, and 287); glass and glass products (SICs 3211, 3221, and 3229); hydraulic cement (SIC 3241); blast furnaces and basic steel products (primarily SIC 331); and aluminum (primarily SICs 3334 and 3353). Petroleum refining (SIC 2911) is modeled in detail in a separate module of NEMS, and the projected energy consumption is included in the manufacturing total. The forecasts of lease and plant and cogeneration consumption for Oil and Gas (SIC 1311) are exogenous to the Industrial Model, but endogenous to the NEMS modeling system.

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

Figure 1. Industrial Model Components



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

The amount of energy consumption reported by the Industrial Model is also a function of the vintage of the capital stock that produces the output. 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 1994 capital stock is reflected in the parameter of the Technology Possibility Curve estimated for each of the energy-intensive industries. These curves are based on engineering judgment of the likely future path of energy intensity changes.

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

Energy consumption in buildings is assumed to grow at the same rate as the average growth rate of employment and output in that industry.[1] 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 to be modeled in the industrial sector along with their Standard Industrial Classification[2] (SIC) code coverage. These industry groups have been chosen for a variety of reasons. The primary consideration is the distinction between energy intensive groups (or large energy consuming industry groups) and non-energy-intensive industry groups. The energy-intensive industries are modeled more in detail, with aggregate process flows. The industry categories are also chosen to be as consistent as possible with the categories which are available from the Manufacturing Energy Consumption

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

[2]The Standard Industrial Classification (SIC) codes have been modified at various points in time, leading to occasional difficulties with tracking specific industries over time.

Survey (MECS).[3] Table 2 identifies 6 nonmanufacturing industries and 9 manufacturing industries. Within the manufacturing industries, the seven most energy-intensive are modeled in greater detail in the Industrial Demand Model. Refining (SIC 2911), also an energy-intensive industry, is modeled elsewhere in NEMS.

Table 2. Industry Categories

Energy-Intensive Manufacturing	Nonmanufacturing Industries
Food and Kindred Products (SIC 20)	Agricultural Production - Crops (SIC 01)
Paper and Allied Products (SIC 26)	Other Agriculture including Livestock (SIC 02, 07, 08, 09)
Bulk Chemicals (SIC 281, 282, 286, 287)	Coal Mining (SIC 12)
Glass and Glass Products (SIC 3211, 3221, 3229)	Oil and Gas Mining (SIC 13)
Hydraulic Cement (SIC 324)	Metal and Other Nonmetallic Mining (SIC 10, 14)
Blast Furnaces and Basic Steel (SIC 331)	Construction (SIC 15, 16, 17)
Aluminum (SIC 3334, 3353)	
Nonenergy-Intensive Manufacturing	
Metals-Based Durables (SIC 34, 35, 36, 37, 38)	
Other Manufacturing (all remaining manufacturing SIC)	

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

Energy Sources Modeled

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

- Electricity
- Natural Gas
- Steam Coal
- Distillate Oil
- Residual Oil

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

- LPG for heat and power
- Other Petroleum
- Renewables
- Motor Gasoline

Other energy sources[4] that are used in specific industries are also modeled:

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

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

Key Computations

The key computations of the Industrial Model are the Unit Energy Consumption (UEC) estimates made for each SIC industry group. UEC is defined as the amount of energy required to produce one dollar's worth of output. Distinguishing between the characteristics of the process when new capital equipment is put into place and the characteristics of the process with existing capital equipment is done with a vintage-based accounting procedure. 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.

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

Buildings Component UEC

Buildings are estimated to account for 8 percent of allocated heat and power energy consumption in manufacturing industries.[5] Estimates of 1994 manufacturing sector building UEC's are presented in Table C1 in Appendix C. Energy consumption in industrial buildings is assumed to grow at the same rate as employment in that industry. This assumption appears to be reasonable since lighting and HVAC are used primarily for the convenience of humans rather than machines.

Process and Assembly Component UEC

The process and assembly component accounted for the largest share, 58 percent, of direct energy consumption for heat and power in 1994. Of the total, natural gas accounts for 51 percent and electricity accounts for 40 percent.

Estimation of the PA component UECs differs according to whether the industry is an energy-intensive industry or an energy non-intensive industry. For the energy-intensive industries, engineering data relating energy consumption to the product flow through the process steps are used. In addition, engineering judgment is also used to characterize autonomous change in the energy-intensive industries through the use of Technology Possibility Curves. The energy-non-intensive industries do not use product flows through process steps or for end-uses due to data limitations.

Fuel shares for process and assembly energy use in six of the energy-intensive manufacturing industries[6] are adjusted for changes in relative fuel prices. The six industries are food, paper, chemicals, glass, cement, and steel. In each industry, two logit fuel-sharing equations are applied to revise the initial fuel shares obtained from the process-assembly component. The resharing does not affect the industry's total energy use--only the fuel shares. The methodology adjusts 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:

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

[5]Computed from Energy Information Administration, *Manufacturing Consumption of Energy 1994*, DOE/EIA-0512(94) (Washington, DC, December 1997), Table 10. Note that byproduct and non-energy use of combustible fuels are excluded from the computation.

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

where:

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

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

The coefficients β_j are user-specified. They were assumed to be 0.20 for the *Annual Energy Outlook 2000*.

The form of the equation results in unchanged fuel shares when the price indices are all 1, or unchanged from their 1997 levels. The implied own-price elasticity of demand is about -0.1 for the assumed values of β_j.

Energy-Intensive Industry UEC Estimation

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

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

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

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

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

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

Food and Kindred Products (SIC 20)

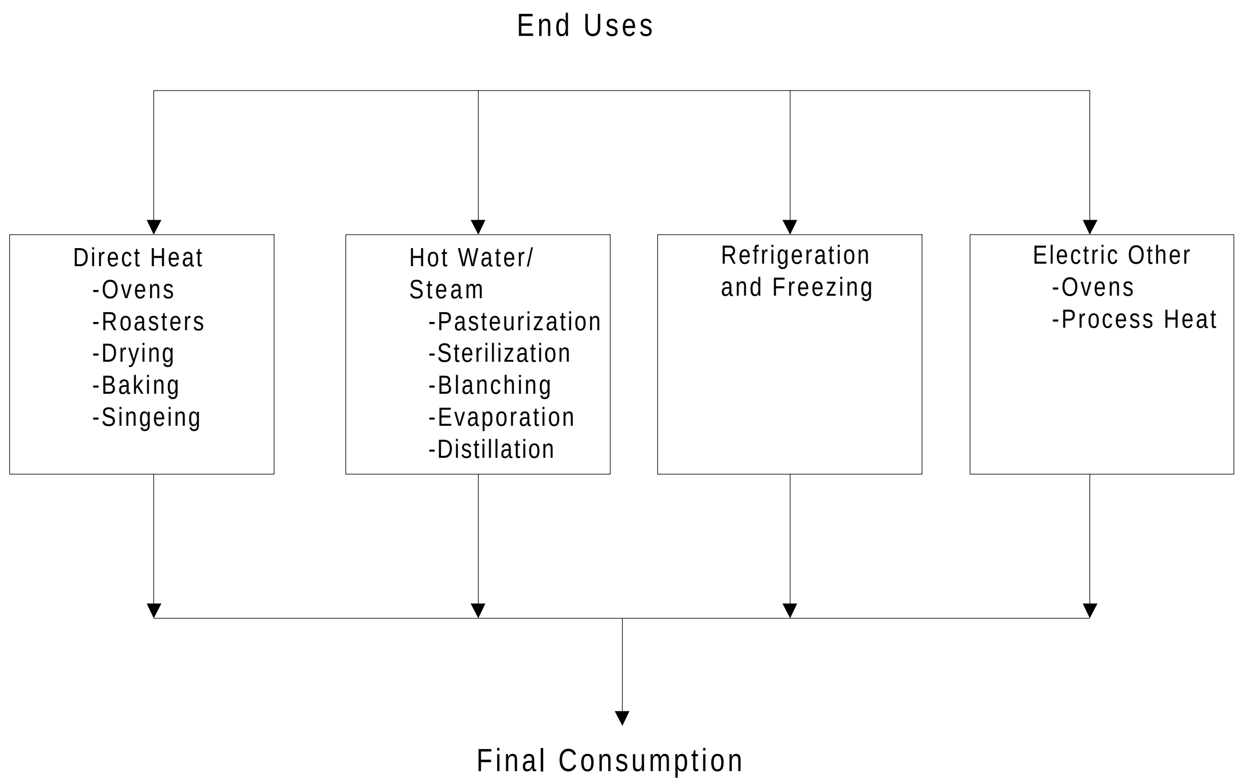
The food and kindred products industry accounted for 13 percent of manufacturing gross output in 1994.

The food and kindred products industry consumed approximately 1,193 trillion Btu of energy in 1994. Energy use in the food and kindred products industry for the PA Component was estimated on the basis of end-use in four major categories:

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

Figure 2 portrays the PA component's end-use energy flow for the food and kindred products industry. The UECs estimated for this industry are provided in Table C2, Appendix C. Note that the steam/hot water use shown in the table represents the energy content of steam that is used in the industry sub-sector (i.e., boiler losses and efficiencies are not included in these tables). The dominant end-use was steam (and hot water), which accounted for 57 percent of the total PA energy consumption. Direct fuel use made up about 23 percent. Electric energy contributed 20 percent of the energy consumption.

Figure 2. **Food and Kindred Products End Uses**

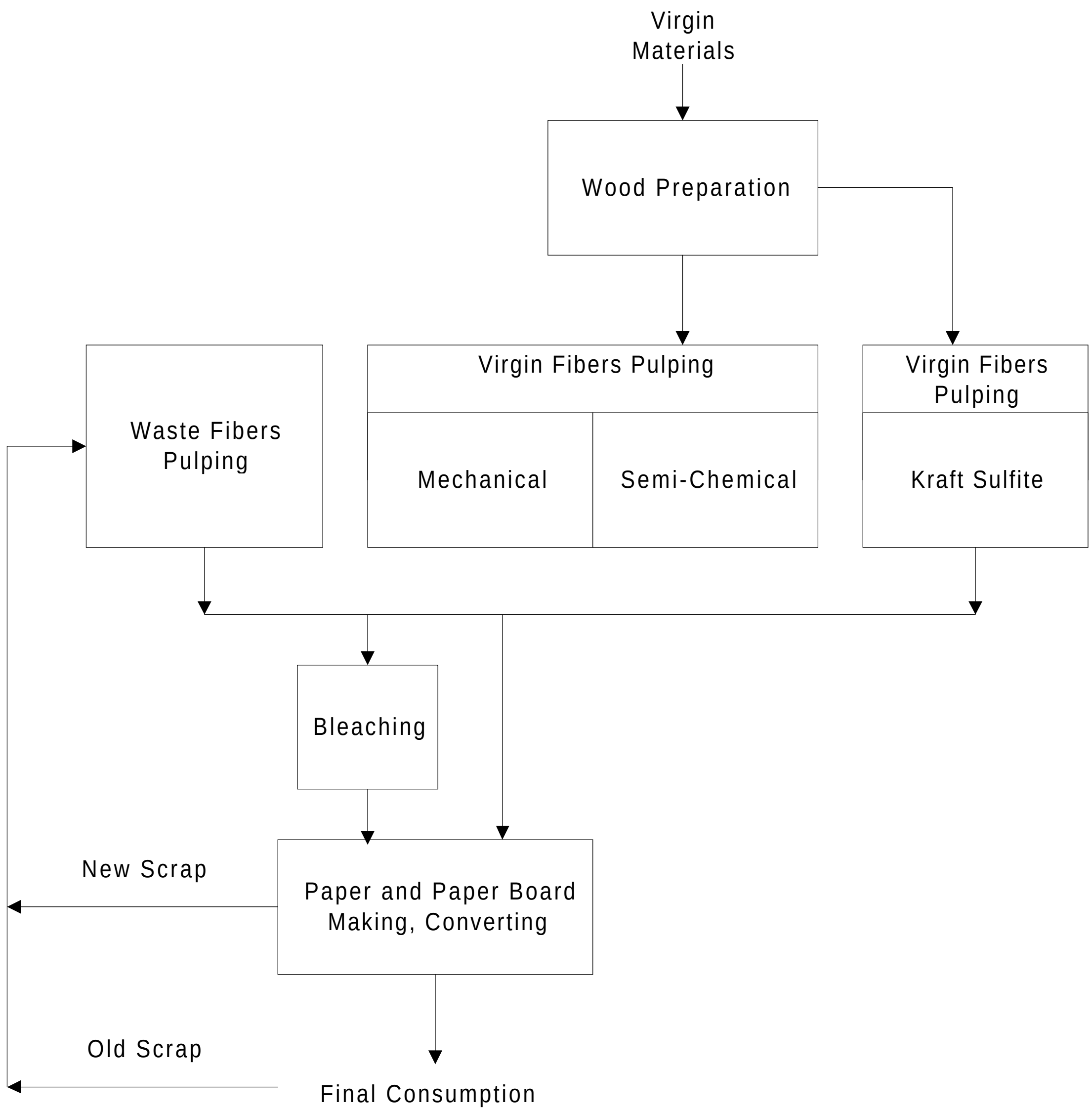


Paper and Allied Products (SIC 26)

The paper and allied products industry's principal processes involve the conversion of wood fiber to pulp, and then paper and board to consumer products that are generally targeted at the domestic marketplace. Aside from dried market pulp, which is sold as a commodity product to both domestic and international paper and board manufacturers, the industry produces a full line of paper and board products.

Figure 3 illustrates the major process steps for all pulp and paper manufacturing. The wood is prepared by removing the bark and chipping the whole tree into small pieces. Pulping is the process in which the fibrous cellulose in the wood is removed from the surrounding lignin. Pulping can be conducted with a chemical process (e.g., Kraft, sulfite) or a mechanical process. (In addition, a semi-chemical process is also available.) The pulping step also includes processes such as drying, liquor evaporation, effluent treatment and miscellaneous auxiliaries. Bleaching is required to produce white paper stock.

Figure 3. Paper and Allied Products Industry Process Flow



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

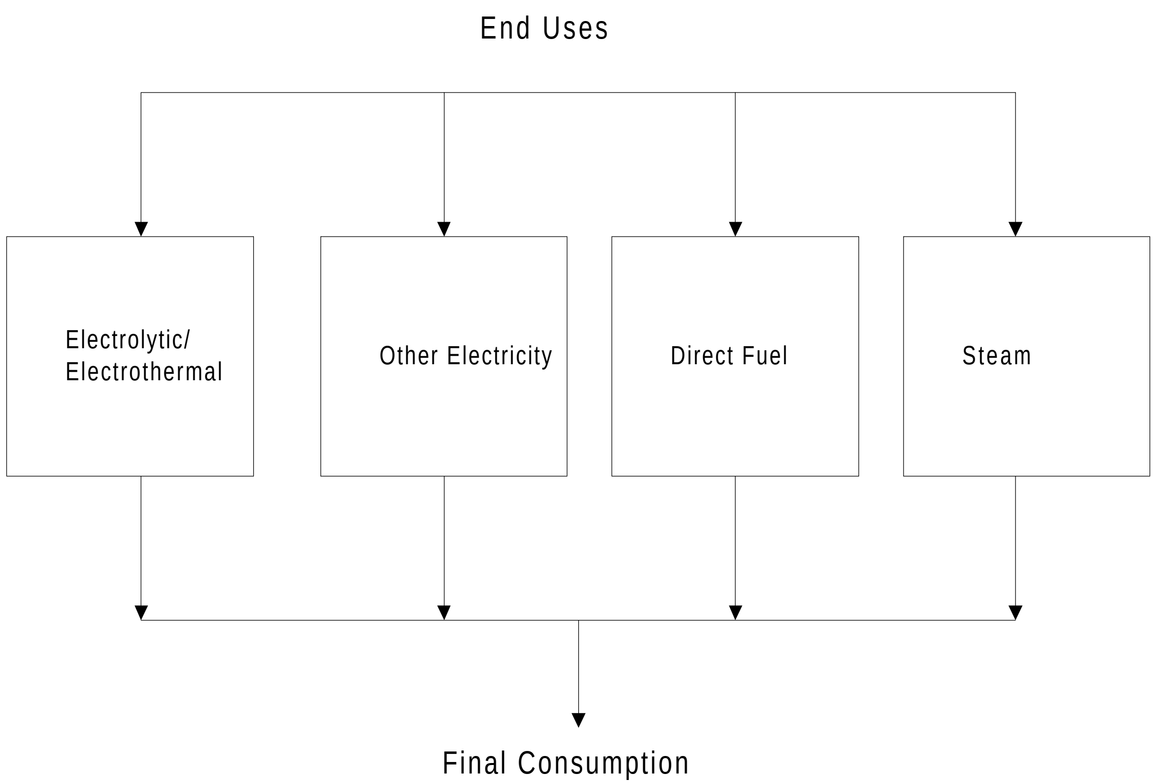
In 1994, a total of 99 million tons of paper and paperboard products were produced. The major paper products include wood-free printing paper, groundwood printing paper, newsprint paper, tissue paper and packaging paper. The major paper board products include kraft paperboard, corrugating medium and recycled paperboard. Of the total product, 52 percent was produced from kraft chemical process, 4 percent from semi-chemical, 39 percent from waste fibers and 6 percent from mechanical (groundwood). The average unit energy consumption estimated for this industry is slightly over 28 million Btu/ton of final product. The unit energy use estimates for this industry are provided in Table C3, Appendix C. The largest component of this energy use is in the paper and paper board making process step and kraft pulping step, accounting for 38 percent each. Use of recycled paper as the feedstock for the waste fiber pulping step is taken into account. The regional distribution for each technology is shown in Table C11 in Appendix C.

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

The bulk chemical sector is very complex. Industrial inorganics and industrial organics are the basic chemicals, while plastics, agricultural chemicals, and other chemicals are either intermediates or final products. The chemical industry is estimated to consume 24 percent (5 quadrillion Btu) of the total energy consumed in the industrial sector. This industry is a major energy feedstock user and a major cogenerator of electricity.

The complexity of the bulk chemical industry, with its wide variety of products and use of energy as both a fuel and feedstock, has led to an end-use modeling approach. The unit energy consumption in the PA component for the bulk chemical industry is shown in Table C4 in Appendix C. The end-uses for the industry is shown in Figure 4.

Figure 4. **Bulk Chemical Industry End Use**

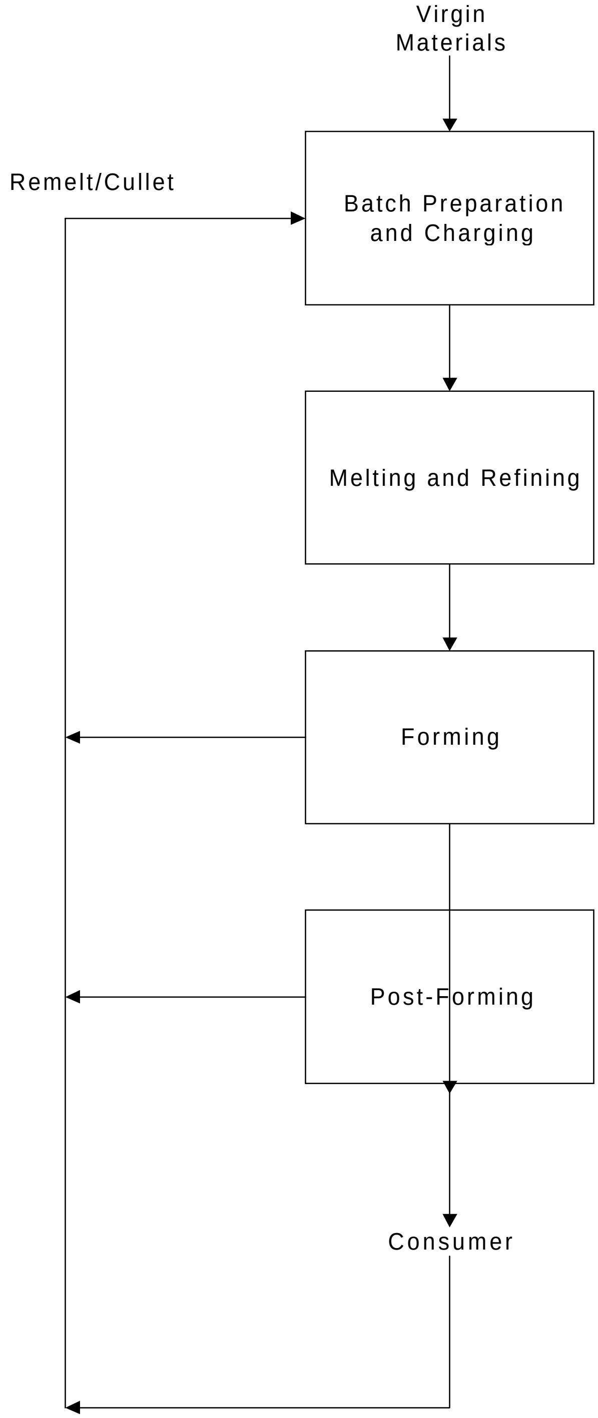


Glass and Glass Products Industry (SIC 3211, 3221, 3229)

The energy use profile has been developed for the total glass and glass products industry, SIC 3211, 3221, and 3229. 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 19941, the glass and glass product industry produced approximately 18 million tons of glass products.

The glass and glass product industry consumed approximately 198 trillion Btu of energy in 1994 as identified in the *1994 Manufacturing Consumption Survey*. 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 C5 in Appendix C shows the unit energy consumption values for each process step.

Figure 5. Glass and Glass Products Industry Process Flow



Hydraulic Cement Industry (SIC 3241)

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

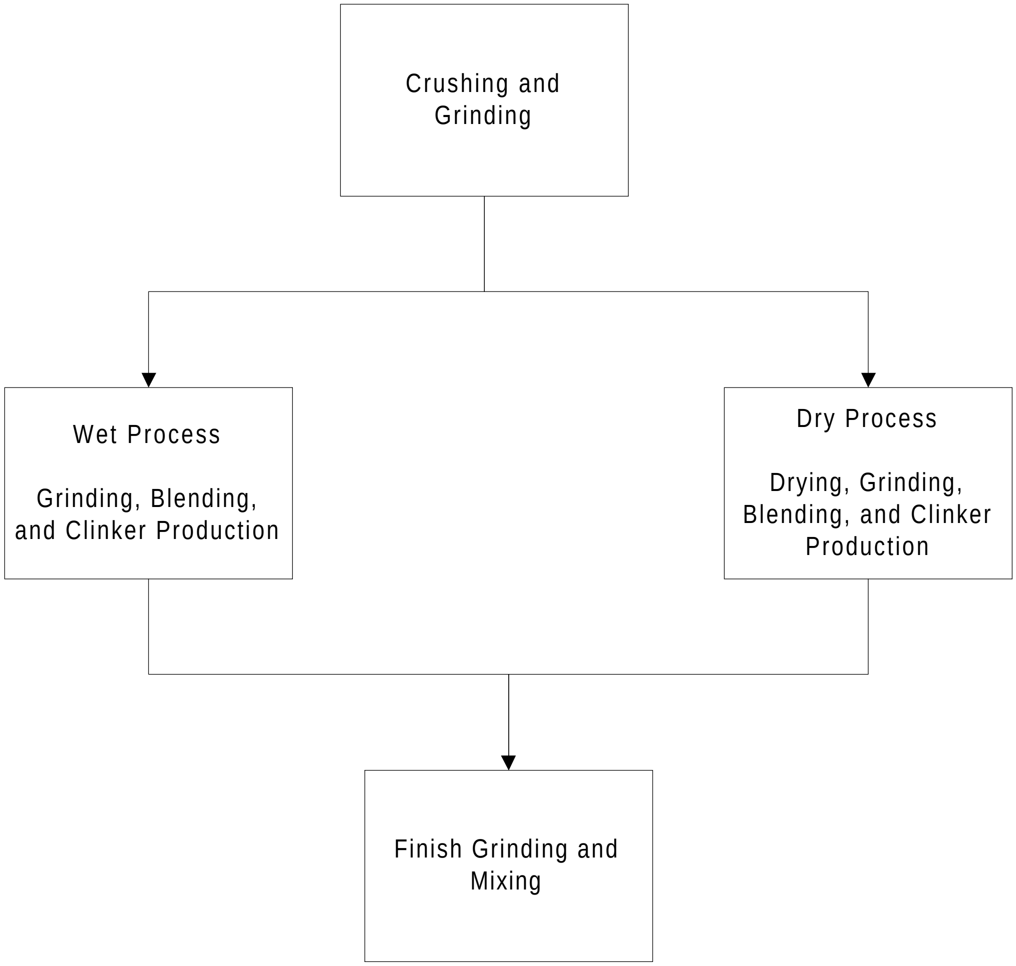
The cement industry produced 85 million tons of cement in 1994. Since cement is the primary binding ingredient in concrete mixtures, it is used in virtually all types of construction. As a result, the U.S. demand for cement is highly sensitive to the levels of construction activity. The wet process accounted for 23 percent of production, while the dry process accounted for about 77 percent.

The hydraulic cement industry exhibits one of the highest unit energy consumption values (MMBtu/dollar value of output) in the U.S. industrial sector. The industry consumed approximately 327 trillion Btu of energy in 1994 as identified in the *1994 Manufacturing Consumption Survey*. This accounts for 35 percent of the energy consumed in the stone, clay and glass industry. Direct fuel, used in clinker-producing kilns, accounted for 95 percent of the total energy consumption, with the remaining 5 percent attributed to electricity. The electricity consumed is used to operate crushing and grinding equipment, materials handling equipment, machine drives and pumps and fans.

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

The UEC values for each process in the hydraulic cement industry are shown in Table C6, Appendix C. 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 C11 in Appendix C.

Figure 6. Cement Industry Process Flow



<u>Blast Furnace and Basic Steel Products Industry (SIC 331)</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 not part of the SIC 33 (it is part of mining). Iron ore and coal are the basic raw materials which are used to produce iron. A simplified description of a very complex industry is provided below.

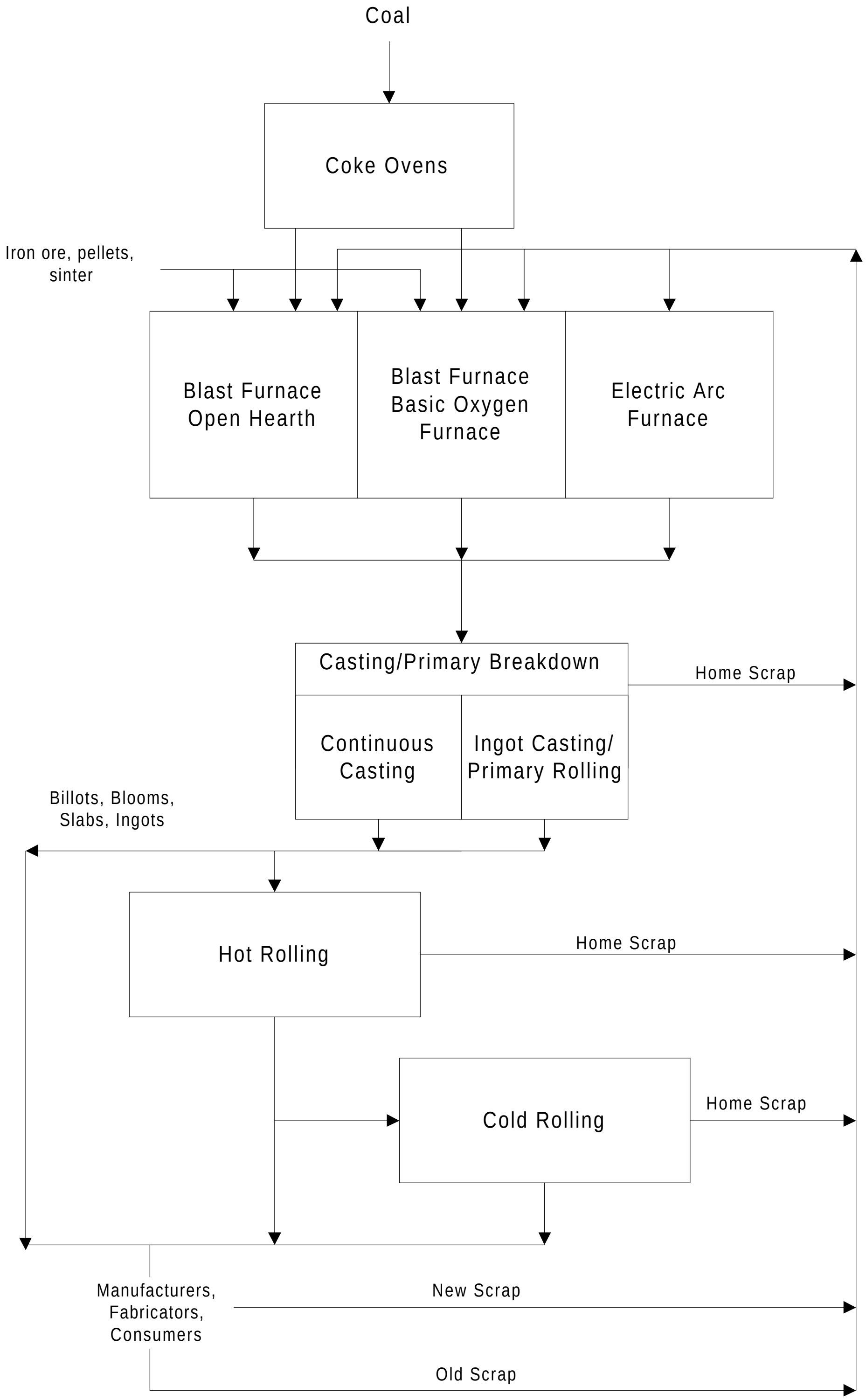
Iron is produced in the Blast Furnace (BF), which is then charged into a Basic Oxygen Furnace (BOF) or Open Hearth (OH) to produce raw steel. The OH is now obsolete. The Electric Arc Furnace (EAF) is utilized to produce raw steel from an all scrap charge, sometimes supplemented with direct reduced iron (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 1994, the U.S. steel industry produced over 100 million tons of raw steel utilizing the BF/BOF and the EAF. Taking process yields into account, the total shipments were approximately 95 million tons. The EAF accounted for almost 40 percent of the raw steel production. Continuous casting was the predominant casting process whereas ingot casting is declining. .

Table C7 in Appendix C summarizes UEC estimates by process step and energy type for the steel industry. The largest category for energy use is coal, followed by liquid and gas fuels. Coke ovens and blast furnace also generate a significant amount of byproduct fuels, which are used throughout the steel plant. The regional distribution of steel-making technologies is presented in Table C11, Appendix C.

Figure 7. Iron and Steel Industry Process Flow



Primary Aluminum Industry (SIC 3334, 3353)

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

The primary aluminum industry modeled in the Industrial Model generally accounts for the energy used in SIC 3334 (alumina refineries and primary aluminum smelters) and SIC 3353 (aluminum sheet, plate, and foil). The primary industry produced approximately 5.1 million tons of aluminum products in 1994.

The UEC estimates developed for the process steps are presented in Table C8 in Appendix C. . The primary form of energy used is electricity. The regional distribution of smelters in the primary aluminum Industry is presented in Table C11 in Appendix C.

Non-Energy-Intensive Industries

The remaining industries, non-manufacturing and non-energy-intensive manufacturing, do not have process steps. They are represented as having a UEC for each fuel. These UECs are presented in Table C9 for non-manufacturing and in Table C10 for non-energy-intensive manufacturing in Appendix C.

Technology Possibility Curves and Relative Energy Intensities

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

Unit energy consumption values for the state-of-the-art (SOA) and advanced technologies were estimated. SOA technologies are the latest proven technologies that are available at the time there is a commitment made to build a new plant. These values were then compared to the unit energy consumption values for 1994 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 1994 average energy use (see Table C12, Appendix C).

The savings shown in the appendix for the listed technologies represent savings over "average" 1994 energy use and SOA energy use. The latter increases are due to the gradual commercialization of advanced technologies. Advanced technologies are ones which are still under development and will be available at some time in the future. Where a range is shown for the savings, it was assumed that the lower end of the savings range would start to be realized in the beginning of the time frame, the midpoint of the savings would be realized at the end of the time frame, and the upper end of the savings range would not be realized until 10 or more years after the time frame shown. An energy savings range is most often given when multiple technologies will be becoming available in the future for the same process step or product line. The savings range represents engineering judgment of the most likely achievable savings. In these instances, it is uncertain which specific technologies will be implemented, but it is reasonably certain that at least one of these technologies or a similar technology is likely to be successful. It is also recognized that in some instances thermodynamic limits are being approached which will prevent further significant improvements in energy savings.

The improvement for new plants assumes the plant has been built with the SOA technologies available for that process. SOA technologies are the latest proven technologies that are available at the time there is a commitment made to build the plant. A second and often more important set of substantial improvements are often realized when **advanced technologies** become available for a certain process. Often one sees a number of technologies being developed and it is difficult to ascertain which specific technologies will be successful. Some judgment is necessary as to the potential for energy savings and the likelihood for such savings to be achieved. All the energy improvement values are based on 1994 energy usage.

Additionally, even SOA technologies and advanced technologies can at times be expected to show improvements once developed as the process is improved, optimal residence times and temperatures are found, and better energy recovery techniques are installed. Depending on the process, these are factored into the projections as slow improvements ranging from zero to about 0.5 percent/year. Old plants, however, are assumed to be able to economically justify some retrofits and for other reasons listed above, to show slow improvements over time in their unit energy use. Based on engineering judgment, it is assumed that by 2020, old processes (1994 stock) still operating can achieve up to 50 percent of the energy savings of SOA technology. Thus, if SOA technology has an REI of 0.80, old processes in the year 2020 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 are given in Table C12.)   The list of SOA and advanced technologies considered in the analysis is presented in Table C13, Appendix C.

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.

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

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. Otherwise, the default values for the intensity decline rate is used, $BCSC_{v,fuel,step}$. For the non-manufacturing industries, the default values, i.e., when TPCPrat is below the threshold, for $BCSC_{v,fuel,step}$ are zero.

Above the TPCPrat threshold, the following relationships hold:

$$
\begin{aligned}
X &= TPCPrat^{TPCBeta} \\
TPCPriceFactor &= 4 * \frac{X}{(1 + X)} \\
TPCRate_v &= TPCPriceFactor * BCSC_{v,fuel,step}
\end{aligned}
\tag{3}
$$

where:	$TPCPrat$	=	Ratio of current year average industrial energy price to 2000 price, equal to 1 for years prior to 2001;
	$TPCBeta$	=	Parameter of logistic function, currently specified as 5;
	$TPCPriceFactor$	=	TPC price factor, ranging from 0 (no price effect) to 4;
	$TPCRate_v$	=	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 for each fuel *f* and step *s*.

After the TPC calculations are done, another set of calculations that characterize price-induced energy conservation (as opposed to energy reductions resulting from technology changes) are performed. Industrial processes involve the discharge of waste at elevated temperatures (e.g., liquids, air, solids). Some portion of the unrecovered heat would be both technically and economically recoverable if energy prices increase. The approach assumes that the design engineer's goal is to maintain a constant dollar value of the unrecovered heat. This leads to an equilibrium condition:

$$
\begin{aligned}
&P_2 * HeatLoss_2 = P_1 * HeatLoss_1 \\
&\Rightarrow \quad \frac{HeatLoss_2}{HeatLoss_1} = \frac{P_1}{P_2}
\end{aligned}
\tag{4}
$$

where: P_1 and P_2 = Energy price in period 1 and period 2, and
$HeatLoss_1$ and $HeatLoss_2$ = Unrecovered heat in period 1 and period 2.

The above relationship can be put into the TPC-UEC framework by determining the practical minimum energy to carry out reactions as a fraction of the total energy actually used, FUnew. (The unrecovered heat values are given in Table C14 in Appendix C.)

$$UEC_1 = (FUnew * UEC_1) + (FUloss_1 * UEC_1) \tag{5}$$

Note that the term (FUnew * UEC_1) is a constant and that the remaining product term represents the unrecovered heat in the first period (with price = P_1). Multiplying the second product term by product throughput yields $HeatLoss_1$.

$$UEC_1 = CONSTANT + \frac{HeatLoss_1}{Throughput} \tag{6}$$

A similar equation holds for period 2 with price = P_2. Manipulation of the above three equations yields the following expression for the UEC_2 that results from the price-induced energy conservation.

$$UEC_2 = (FUnew * UEC_1) + (FUloss_1 * UEC_1) * \frac{P_1}{P_2} \tag{7}$$

While unrecovered heat, and the UEC, is inversely related to price in the two periods, it is unlikely that all facilities will adopt uniform policies regarding heat recovery. Consequently, a market penetration factor is assumed for old an new vintage. (Currently, these are assumed to be 0.2 for old vintage and 0.4 for new vintage.) This result can be thought of as representing per unit energy saving (UES) and is easier to calculate in the model.

$$UES_{2,v} = (FUnew * UEC_{1,v}) + (FUloss_1 * UEC_{1,v}) * \frac{P_1}{P_2} * MarkPen_v \tag{8}$$

where: $UES_{2,v}$ = Unit energy savings in period *2* for vintage *v*, and
$MarkPen_v$ = Market penetration of price-induced energy conservation for vintage *v*.

The final calculation then is to adjust by the base UEC by the UES for each vintage.

$$ENPINT_{v,f,s} = ENPINT_{v,f,s} - UES_v \tag{9}$$

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 39 percent of total manufacturing heat and power energy consumption.[7] Within the BSC component, natural gas accounts for 68 percent and coal 22 percent.

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

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

$$ShareFuel_i = \frac{(P_i^{\alpha_i}\beta_i)}{\sum_{i=1}^{3} P_i^{\alpha_i}(\beta_i)} \tag{10}$$

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 1994 fuel shares using the relative prices that prevailed in 1994. (The values in the equation are presented in Table C15.) 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 1994 MECS and exclude waste and byproducts.

The α_i sensitivity parameters are posited to be a positive function of energy prices. For years after 2000, the ratio of the current year's average industrial energy price to the average price in 2000 is computed, SwitchPrat.

Above the SwitchPrat threshold, the following relationships hold:

$$\begin{aligned} X &= SwitchPrat^{SwitchBeta} \\ SwitchPriceFactor &= 4 * \frac{X}{(1 + X)} \\ \alpha_{iPrice} &= SwitchPriceFactor * \alpha_i \end{aligned} \tag{11}$$

[7]Computed from Energy Information Administration, *Manufacturing Consumption of Energy 1994*, DOE/EIA-0512(94) (Washington, DC, December 1997), Table A8. Note that byproduct and non-energy use of combustible fuels are excluded from the computation.

where:	*SwitchPrat*	=	Ratio of current year average industrial energy price to 2000 price, equal to 1 for years prior to 2001;
	SwitchBeta	=	Parameter of logistic function, currently specified as 4;
	SwitchPriceFactor	=	Fuel switching price factor, ranging from 0 (no price effect) to 4;
	α_{iPrice}	=	Fuel switching sensitivity parameters after accounting for energy price increases;
	α_i	=	Default fuel switching sensitivity parameters.

Cogeneration capacity, generation, and fuel use 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 867 survey. The most recent data is for 1997, with planned additions (units under construction) through 2000. The non-public Form 867 data file, containing proprietary data, is processed outside the model to separate industrial cogeneration from commercial sector cogeneration, cogeneration from refineries and enhanced oil recovery operations, and non-traditional cogeneration. Non-traditional cogenerators are primarily merchant power plants selling to the grid and often supplying relatively small amounts of thermal energy. The remainder, or traditional industrial cogeneration portion, is approximately 40 percent of the total cogeneration generating capacity. The cogeneration capacity and generation is distinguished by region, industry, prime mover, and primary fuel type.

The modeling of unplanned cogeneration begins with the model year 2001, under the assumption that planned units under construction cover additions through 2000. 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 determined with a new modeling approach developed for the Annual Energy Outlook 2000. The new approach is based on assessing capacity that could be added to generate the industrial steam requirements that are not already met by existing cogeneration. We assume that the cogenerated electricity can be used to either reduce purchased electricity or sold to the grid. Consequently, the driving assumption is that the technical potential for traditional cogeneration is primarily based on supplying thermal requirements. For simplicity, the approach is considered to be based on gas turbine cogeneration plants, although the characteristics of the cogeneration plants assumed could be set by the user to simulate different technologies for different size ranges.

The steps to the approach are outlined as follows:

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

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

b. Classify non-cogenerated steam uses into four 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 (see Appendix Table C18). 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 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.

c. 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 segment

a. Select a candidate cogeneration system 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 5 cogeneration systems are used (see Appendix Table C17):

- Net electric generation capacity in kilowatts
- Total installed cost, in 1997 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

For each load segment, we select the largest system with a steam output capacity less than or equal to the output of the average-sized boiler.

b. Determine the investment payback period needed to recover the prototypical cogeneration investment for each load segment. The analysis considers the annual cash flow from the investment to be equal to the value of the cogeneration 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, 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 10 percent of the industrial electricity rate. 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 (see Appendix Table C19). 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 is 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, we have 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 1994 and is assumed to retire at a fixed rate each year. Middle vintage capital is that which is added from 1994 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-1994 capital stock. The retirement rates used in the Industrial Model for the various industries are listed in Table C12 in Appendix C.

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 2000, the ratio of the current year's average industrial energy price to the average price in 2000 is computed, RetirePrat. For non-manufacturing industries, if RetirePrat is above a threshold, the retirement rate is changed from 0 to a small positive value, currently 0.02.[8] Further, the retirement rate is an increasing function of RetirePrat. For the manufacturing industries, the default retirement rates increase with RetirePrat.

Above the RetirePrat threshold, the following relationships hold:

$$X = RetirePrat^{RetireBeta}$$

$$RetirePriceFactor = 2 * \frac{X}{(1 + X)} \tag{12}$$

$$RetireRate_s = RetirePriceFactor * ProdRetr_s$$

where:	*RetirePrat*	=	Ratio of current year average industrial energy price to 2000 price, equal to 1 for years prior to 2001;
	RetireBeta	=	Parameter of logistic function, currently specified as 5;
	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

[8]There is no information concerning the retirement rates for non-manufacturing industries.

the industrial sector are pulping liquor, a byproduct of the chemical pulp process in the paper industry, and wood.

Recycling

With projected higher landfill costs, regulatory emphasis on recycling, and potential cost savings, recycling of post-consumer scrap is likely to grow. Projecting such growth, however, is highly dependent on assessing how regulations will be developed, the growth of the economy, and quality related issues dealing with recycled materials. Assumptions for recycling in the Paper and Allied Products and Blast Furnace and Basic Steel Products industries are shown in Table C16 in Appendix C.

Legislative Implications

The Energy Policy Act of 1992 (EPACT) and the Clean Air Act Amendments of 1990 (CAA) contain several implications for the industrial model. These implications fall into three categories: coke oven standards; efficiency standards for boilers, furnaces, and electric motors; and industrial process technologies. The industrial model assumes the leakage standards for coke oven doors do not reduce the efficiency of producing coke, or increase unit energy consumption. The industrial model uses heat rates of 1.25 (80 percent efficiency) and 1.22 (82 percent efficiency) for gas and oil burners respectively. These efficiencies meet the EPACT standards. The standards for electric motors call for an increase of 10 percent efficiency. The industrial model incorporates a 10 percent savings for SOA motors increasing to 20 percent savings in 2015. Given the time lag in the legislation and the expected lifetime of electric motors, no further adjustments are necessary to meet the EPACT standards for electric motors. The industrial model incorporates the necessary reductions in unit energy consumption for the energy-intensive industries.

Several programs included in the Climate Change Action Plan (CCAP) target the industrial sector. Note that the potential impacts of the Climate Wise Program are also included in the CCAP impacts. The intent of these programs is to reduce greenhouse gas emissions by lowering industrial energy consumption. The Department of Energy (DOE) program offices estimated that implementation of these programs would reduce industrial electricity consumption by 79 billion kilowatthours and fossil energy consumption by 359 trillion Btu by 2010. However, since the energy savings associated with the voluntary programs in the CCAP largely duplicate savings that would have occurred in their absence, estimated CCAP energy savings were reduced for industrial modeling purposes. The *Annual Energy Outlook 2000* (*AEO2000*) assumes that CCAP reduces electricity consumption by 25 billion kilowatt-hours and fossil energy consumption by 65 trillion Btu. The fossil energy is assumed to be 85 percent natural gas and 15 percent steam coal. In this situation, industrial carbon emissions would be reduced by about 5 million metric tons (1 percent) in 2010.

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 dissaggregate 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 2000 are presented in Appendix Tables C17, C18, and C19.

Benchmarking

The Industrial Model energy demand forecasts are benchmarked to actual 1990 through 1997 State Energy Data System (SEDS) values to ensure that the model forecasts for these years coincide with the SEDS consumption data. The benchmark factors are based on the ratio of the SEDS value of consumption for each fuel to the consumption calculated by the model at the census division level. Additional calibration for the years 1998-2000 are performed to conform with the *Short-Term Integrated Forecasting System*.

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

Table 3. Outline of NEMS Industrial Module

Industrial Module Solution Outline

I. First Year: Initialize Data

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

II. Industry Processing:

Loop through each of 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

A. RDBIN: Read memory management file with previous year's data for this industry, region
B. CALPROD: Compute revised productive capacity and throughput by process/assembly step and vintage; implement retirement and vintaging assumptions.
C. CALCSC: Conservation Supply Curve: Evaluate changes in UECs based on Technological Possibility Curves (TPCs) or econometric estimates, depending on the industry.
   1. CALCSC1: Calculate UECs for non-energy-intensive industries.
   2. CALCSC3: Apply ADL TPC Approach.
D. CALBYPROD: Calculate consumption of byproduct fuels
E. CALPATOT: Compute consumption of energy in the process assembly component
   1. INDPALOG: Optionally, adjust fuel shares for process-assembly industries using a 2-stage logit equation. First year, read spreadsheet file (INDPALOG.WK1) with logit coefficients
      a. CALPALOG: evaluate logit shares for a given industry and a given set of fuels, given changes in energy prices since the base year.
F. CALBTOT: Compute consumption of energy in the buildings component
G. CALGEN: Compute electricity generation for sale and internal use by prime mover and fuel. Calculates steam for cogeneration and estimates penetration of new builds
   1. SteamSeg Assign fraction of steam load in current load segment for current industry
   2. DanCog Read cogen assumptions spreadsheet
   3. EvalCogen Evaluate investment payback of a cogen system in a given year
H. CALSTOT: Compute Energy consumption in the Boiler-Steam-Cogeneration (BSC) component
I. WRBIN: Write memory management file with data on this industry, region
J. INDTOTAL: Accumulate total energy consumption for the industry

III. National Sums:

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

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

A. SEDS Benchmarking:
   1. SEDS years (through 1995): calculate regional benchmark factors as the ratio of actual consumption to model consumption for each fuel in four Census regions.
   2. Post SEDS Years (1996-on): Optionally, multiply model consumption by the SEDS benchmark factors.
B. Disaggregate energy consumption from 4 Census regions to 9 Census Divisions using shares from SEDS
C. Calibrate regional energy consumption to match the latest year of national-level history data (from the STEO file).
D. STEO Benchmarking:
   1. STEO years: calculate national benchmark factors as the ratio of model consumption for each fuel to the STEO forecast for each fuel.
   2. Post-STEO years: Optionally, over the period 1998 to 2000, multiply model consumption by the STEO benchmark factors.
E. Assign final results to NEMS variables

$$PRCX_{elec,r} = \frac{\sum_{d=1}^{NUM_r} DPRCX_{elec,r} \ x \ QSELIN_{d,1994}}{\sum_{d=1}^{NUM_r} QSELIN_{d,1994}} \tag{13}$$

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
$QSELIN_{d,1994}$	=	SEDS consumption of electricity in Census division d in 1994.

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

ISEAM

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

Subroutine RCNTRL

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

Subroutine REXOG

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

Subroutine IEDATA

IEDATA stands for Industrial Enprod Data where enprod is the name of the 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.

The routines are as follows:

<u>IRHEADER</u>

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

The ratio of physical output to 1994 value of output for five of the energy-intensive industries is calculated (food and bulk chemical industries are excluded). This constant ratio is applied to value of output in subsequent years.

$$PHDRAT_i = \frac{PHYSICAL_i}{PRODVX_{i,r}} \tag{14}$$

where:

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

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

$$PRODX_{i,r} = PHDRAT_i \ x \ PRODVX_{i,r} \tag{15}$$

where:

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

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

$$PRODX_{i,r} = PRODVX_{i,r} \tag{16}$$

where:

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

<u>IRSTEPDEF</u>

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

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

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

Let:

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

Then, we have the following:

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

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

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

Physical throughput is obtained for two vintages, old and new. Old vintage is considered to be any capital installed in 1994 or earlier. Middle vintage includes installations from 1995 to the lag of the current forecast year. New vintage includes any capital installed in the current forecast year.

The following subroutines collect data from the input files:

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

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

IRBSFUEL

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

IRCOGEN

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

IRSTEPBYP

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

IRSTEPDAT

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

MECS94

This subroutine is called to update the prodflows for 1994.

CWAFUD

Calls a data file, Consumption With Advance Fuel Use Data (CWAFUD), to update the initial ENPROD data file with 1994 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:

$$PRODSUM_{s,l} = PRODFLOW_{old,s,l} \times PRODX_{i,r} \tag{17}$$

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:

$$PRODSUM_{s,l} = PRODFLOW_{old,s,l} \ x \ PRODCUR_{total,IP} \tag{18}$$

where:

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

$PRODFLOW_{old,s,l}$ = Down-step throughput to process step *s* linked by link *l* for old vintage, and

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

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

$$PRODCUR_{total,s} = \sum_{l=1}^{NTMAX_s} PRODSUM_{s,l} \tag{19}$$

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 2000, the ratio of the current year's average industrial energy price to the average price in 2000 is computed, TPCPrat. If TPCPrat is above a threshold, the TPC is changed from 0 to a small positive value, currently 0.005. Further, the TPC is an increasing function of TPCPrat.

Above the TPCPrat threshold, the following relationships hold:

$$X = TPCPrat^{TPCBeta}$$

$$TPCPriceFactor = 2 * \frac{X}{(1 + X)} \tag{20}$$

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

where:	*TPCPrat*	=	Ratio of current year average industrial energy price to 2000 price, equal to 1 for years prior to 2001;
	TPCBeta	=	Parameter of logistic function, currently specified as 5;
	TPCPriceFactor	=	TPC price factor, ranging from 0 (no price effect) to 2;
	$TPCRate_v$	=	TPC multiplier on TPC rate due to energy price increases for vintage *v*;
	BYPCSC	=	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.

$$BYPINT_{v,f,s} = (BYPINTLag_{v,f,s}) * (1 + TPCRate_v) \tag{21}$$

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 energy savings 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.

$$BYPINT_{mid,f,s} = \left(\frac{(PRODLag_{mid,s} * BYPINTLag_{mid,f,s}) + (PRODLag_{new,s} * BYPINTLag_{new,f,s})}{PRODLag_{mid,s} + PRODLag_{new,s}} \right)^{TPCRate_{old}} \quad (22)$$

where:

$PRODLAG_{new,s}$	=	Prior year production from new capacity at process step *s*,
$PRODLAG_{mid,s}$	=	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.

$$BYPQTY_{v,f,s} = PRODCUR_{v,s} \ x \ BYPINT_{v,f,s} \quad (23)$$

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.

$$ENBYPM_{f,v} = \sum_{s=1}^{MPASTP} BYPQTY_{v,f,s} \quad (24)$$

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.

$$ENPQTY_{v,f,s} = PRODCUR_{v,s} \times ENPINT_{v,f,s} \tag{25}$$

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:[9]

- 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,

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

- petroleum coke,
- asphalt and road oil,
- petrochemical feedstocks,
- other petroleum feedstocks, and
- other petroleum.

Intermediate fuels include the following:

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

Renewable fuels include the following 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.

$$ENPMQTY_f = \sum_{s=1}^{MPASTP} ENPQTY_{total,f,s} \tag{26}$$

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.

$$ENPMQTY_{coke} = ENPIQTY_{coke} - \left[PRODCUR_{total,co} \ x \ \frac{24.8}{10^6} \right] \tag{27}$$

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 CALBTOT

CALBTOT calculates the total energy consumption for buildings. The energy consumption for buildings is calculated for two building uses, lighting and HVAC. Total energy consumption is determined for electricity, natural gas, and steam with a weighted average of the industry employment UEC and the industry output UEC.

$$\begin{aligned} ENBQTY_{e,f} = {} & (EWeight * [EMPLX_{i,r} * ENBINT_{e,f}] \ + \\ & OWeight * [ProdVX_{i,r} * ONBINT_{e,f}]) \ * \ BldPFac \end{aligned} \tag{28}$$

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:

$$BldPFac = BldPRat^{BldElas} \tag{29}$$

where:

BldPRat = Ratio of current year average industrial energy price to 2000 price, equal to 1 for years prior to 2001; and

BldElas= Assumed elasticity, currently -0.2.

Subroutine CALGEN

Subroutine CALGEN determines electricity generation from cogeneration by prime mover and fuel. The prime movers are steam turbines, combustion turbines, and internal combustion. The subroutine estimates market penetration of new cogeneration capacity as a function of steam load, steam already met through cogeneration, and cost and performance factors affecting cogeneration economics. CALGEN calls subroutine DanCog 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-867 data.[10]

CALGEN begins by computing total steam demand as the sum of steam use in buildings and steam use from the process and assembly component::[11]

$$STEMCUR = ENBQTY_{hvac,steam} + ENPIQTY_{steam} \tag{30}$$

[10]Two subroutines not shown here perform the calculations required to move between the division-level data based on the EIA-867 and the region-level data that are required for model computation. These subroutines are CAL_EI867 and CALCGSH. Existing cogeneration capacity is determined in subroutine INDCGN using the average utilization rates for the last data year from the EIA-867.

[11]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.

where:

$STEMCUR$ = Total steam demand,

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

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

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

$$NonCogSteam = STEMCUR - CogSteam97_{inddir,indreg} \quad (31)$$

where $NonCogSteam$ = Non-cogenerated steam based on existing cogeneration capacity

$STEMCUR$ = Total steam demand, and

$CogSteam97_{inddir,indreg}$ = Steam met by existing cogenerators as of the last data year.

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

$$AggSteamLoad_{loadsegment} = NonCogSteam * SteamSeg_{inddir,loadsegment} , \quad (32)$$

where $AggSteamLoad_{loadsegment}$ = Aggregate steam load for a load segment

$SteamSeg_{inddir,loadsegment}$ = the fraction of total steam in each of four boiler firing ranges (expressed in million Btu/hour) of 10-50, 50-100, 100-250, and greater than 250.

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 btus per hour:

$$AveHourlyLoad_{loadsegment} = AggSteamLoad_{loadsegment} / .008760 \quad (33)$$

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):

$$TechPot_{loadsegment} = AveHourlyLoad_{loadsegment} * PowerSteam_{isys} \tag{34}$$

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)

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):

$$EconPot_{loadsegment} = TechPot_{loadsegment} * EconFrac_{loadsegment} \tag{35}$$

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:

$$CapAddMW_{loadsegment} = EconPot_{loadsegment} * PenetrationRate \tag{36}$$

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 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.

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).

$$BIO = Max(0, \frac{BioAvail_{indreg,year} - BioAvail_{indreg,year-1}}{HeatRate}) \quad (37)$$

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 (currently assumed to be 25,000).

The available biomass generation is then added to the previous year's cogeneration.

$$SICGEN_{indreg,year,inddir,biomass,pm,3} = SICGEN_{indreg,year-1,inddir,biomass,pm,3} + BIO \quad (38)$$

where:

$SICGEN_{indreg,year,inddir,biomass,gt,3}$ = Total biomass cogeneration by region, year, industry, and prime mover; and

$SICGEN_{indreg,year-1,inddir,biomass,gt,3}$ = Previous year's cogeneration by region, industry, and prime mover.

Capacity for electric generation is determined from total generation of electricity and a capacity utilization rate based on EIA-867 survey data, combined with the increased generation from new plant additions as calculated above. Generation and capacity are aggregated by prime mover from data specified at the census division level. The capacity values are used only for reporting purposes and not used within the industrial module. Capacity by prime mover is calculated using shares computed based on EIA-867 survey data. Electricity generation for own use is calculated by using the own use share of electricity generation from the EIA-867 survey data.

Electricity generation for own use is then calculated from the following equation.

$$ELOWN_{pm} = ELGEN_{pm} \; x \; (1 - GRDSHRG_{inddir,indreg}) \quad (39)$$

where:

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

Electricity generation for sales to the grid is calculated similarly.

Subroutine EvalCogen

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

$$SteamLoad_{loadsegment} = AveBoilSize_{loadsegment} * EboilEff_{loadsegment} \tag{40}$$

where

$SteamLoad_{loadsegment}$	=	Steam output of average boiler in the load segment, in millions of Btus an hour
$AveBoilSize_{loadsegment}$	=	Firing capacity of average boiler in the load segment
$EboilEff_{loadsegment}$	=	Assumed boiler efficiency

First, a candidate cogeneration system is selected for each load segment with thermal output that matches the steam output of the average-sized boiler in the load segment. The system selected is the largest one with a thermal output less than the average steam load in the load segment. To do this, the user-supplied characteristics for *nsys* (5) 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 1997 dollars per kilowatthour-electric
$CapFac_{isys}$	=	System capacity factor
$CHeatRate_{isys}$	=	Total fuel use per kilowatthour-electric generated (Btus/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)
	=	$CogSizeKW_{isys} * .003412 / PowerSteam_{isys}$

Thus, for each load segment, the largest system, *isys*, with a steam output capacity less than or equal to the average load in a load segment is designated:

$$CogSys_{loadsegment} = isys,$$

where the following relation holds:

$$SteamOutput_{isys} <= SteamLoad_{loadsegment} < SteamOutput_{isys+1} \qquad (41)$$

where

$SteamOutput_{isys}$	=	Steam output of the candidate cogeneration systems
$SteamLoad_{loadsegment}$	=	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 2000). 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:

$$FuelCost_{loadsegment} = FuelUse_{isys} * CogFuelPrice \qquad (42)$$

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

$$ExistFuelUse_{loadsegment} = SteamOutput_{isys} * 8.76 * CapFac_{isys} / EboilEff_{loadsegment} \qquad (43)$$

$$ExistFuelCost_{loadsegment} = ExistFuelUse_{loadsegment} * CogFuelPrice \qquad (44)$$

Determine incremental fuel cost and the value of cogenerated electricity:

$$IncrFuelCost_{loadsegment} = FuelCost_{loadsegment} - ExistFuelCost_{loadsegment} \qquad (45)$$

$$ElecValue_{loadsegment} = ElecSizeMWH_{isys} * CogElecPrice * .003412 \qquad (46)$$

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

$$OperProfit_{loadsegment} = ElecValue_{loadsegment} - IncrFuelCost_{loadsegment} \qquad (47)$$

Determine the investment capital cost and the investment payback period

$$Investment_{loadsegment} = CogSizeKW_{isys} * CogCapCostKW_{isys} \tag{48}$$
$$CpayBack_{loadsegment} = Investment_{loadsegment} / OperProfit_{loadsegment} \tag{49}$$

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:

$$EconFrac_{\ loadsegment} = Acceptance(\ AcceptFrac,\ 13,\ Cpayback_{\ loadsegment}\ ) \tag{50}$$

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. Fuel consumption is also allocated between cogeneration and non-cogeneration boilers. Generation by prime mover is determined in CALGEN as is the net steam demand. The methodology is initiated by calculating the system fuel required for the generation by each prime mover. The fuel consumption is then allocated to electricity generation using an incremental heat rate. The remaining fuel consumption is allocated to steam generation from cogeneration units. The latter allows the amount of steam generated with this fuel to be calculated using assumed boiler efficiencies. This steam, cogsteam, is subtracted from the net steam demand, StemCur, to determine the amount of steam that must be produced with non-cogeneration boilers.

$$FuelSys_{pm,fuel} = SicGen_{region,year,inddir,fuel,pm} * \frac{GenEqpHtRt_{pm}}{10^6} \tag{51}$$

where:

$FuelSys_{pm,fuel}$	=	Total fuel consumption for cogeneration by prime mover *pm*,

$SicGen_{region,year,inddir,fuel,pm}$ = Electricity generation by region, year, industry, fuel and prime mover, and

$GenEqpHtRt_{pm}$ = Heat rate for each prime mover.

The fuel consumption allocated to electricity generation is calculated using an incremental heat rate for electricity only.[12]

$$FuelElec_{pm,fuel} = SicGen_{region,year,inddir,fuel,pm} * \frac{IncrHeatRate}{10^6} \tag{52}$$

where:

$FuelElec_{pm,fuel}$ = Allocated fuel consumption for electricity generation by cogeneration prime mover *pm*,

$SicGen_{region,year,inddir,fuel,pm}$ = Electricity generation by region, year, industry, fuel and prime mover, and

$IncrHeatRate$ = Incremental heat rate for electricity only.

Consequently, the fuel allocated to process steam generated from cogeneration is just the difference.

$$FuelCogSteam_{pm,fuel} = FuelSys_{pm,fuel} - FuelElec_{pm,fuel} \tag{53}$$

The next steps are to calculate the amount of process steam generated by the allocated fuel and to determine the amount of steam that must be generated by non-cogeneration boilers.[13]

$$\begin{aligned} CogSteam &= FuelCogSteam_{pm,fuel} * BEff_{fuel} \\ NonCogSteam &= StemCur - CogSteam \end{aligned} \tag{54}$$

where: $BEff_{fuel}$ = Assumed boiler efficiency by fuel, and

$NonCogSteam$ = Steam to be cogenerated by non-cogeneration boilers.

---

[12]The variable $FuelElec_{pm,fuel}$ is allocated between own use and sales to the grid using the historical share of sales to the grid in variable $OthFuel_{pm,fuel,k}$, where *k* represents own use or sales to the grid. In subroutine INDCGN, $OthFuel_{pm,fuel,k}$ is copied into variable DivFuel; DivFuel is finally copied into variable CGINDQ in subroutine WEXOG for reporting the results to NEMS.

[13]A complication arise here because biomass is heavily used in cogeneration. Since the biomass is a byproduct of the production process, it reduces the purchased fuel requirements. Consequently, the amount of biomass available for non-cogeneration steam boilers is subtracted from NonCogSteam.

The fuels consumed in non-cogeneration boilers is added to the system fuel consumed by cogeneration to yield total fuel consumption in the BSC component.

$$EnSQty_{fuel} = FuelSys_{pm,fuel} + \frac{(CogSteam_{pm,fuel} * BSShr_{fuel})}{BEff_{fuel}} \tag{55}$$

Subroutine INDTOTAL

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

$$QTYMAIN_{f,r} = ENPMQTY_f + ENBQTY_{total,f} + ENSQTY_f + BYPBSCM_f \tag{56}$$

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.

$$QTYMAIN_{elec,r} = ENPMQTY_{elec} + ENBQTY_{total,elec} - ELOWN \tag{57}$$

where:

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

Subroutine NATTOTAL

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

$$TQMAIN_{f,r} = \sum_{i=1}^{INDMAX} QTYMAIN_{f,r} \tag{58}$$

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.[14] All other industries have similar equations.

$$FOODCON_{f} = \sum_{f=1}^{NUM_{fg}} QTYMAIN_{f,total} \tag{59}$$

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

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

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

Subroutine INDCGN

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

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

$$CAPGW_{cdiv,fuel,sales} = CAP867_{cdiv,year,ind,fuel} \ x \ SHARE_{pm,cdiv,year,ind,fuel} \ x \ IGRIDSHR_{cdiv,year,ind} \tag{60}$$

where:

$CAPGW_{\mathrm{cdiv,fuel,sales}}$	=	Existing or planned capacity for cogeneration of electricity for sales to the grid for census division and fuel,
$CAP867_{cdiv,year,ind,fuel}$	=	EIA-867 capacity by census division, year, industry, and fuel,
$SHARE_{pm,cdiv,yr,ind,fuel}$	=	EIA-867 share of fuel by prime mover PM, census division, year, and industry,
$IGRIDSHR_{cdiv,yr,ind}$	=	EIA-867 sales-to-the-grid share of capacity in census division, year, and industry

The capacity for own use is calculated similarly.

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

$$GENGWH_{cdiv,fuel,sales} = \sum_{cdiv=1,9} \sum_{fuel=1,6} \sum_{pm=1,3} \sum_{ind=1,15} SICGEN_{cdiv,yr,ind,fuel,pm,sales} \tag{61}$$

where:

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

Generation for sales to the grid is calculated similarly.

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

$$DIVFUEL_{cdiv,fuel,sales} = OTHFUEL_{cdiv,fuel,sales} \tag{62}$$

where:

$DIVFUEL_{cdiv,fuel,sales}$ = Industrial variable holding aggregate total industrial cogeneration fuel consumption by division, fuel, and sales to the grid and own use

$OTHFUEL_{\mathrm{cdiv,fuel,sales}}$ = Variable holding the cogeneration fuel consumption calculated based on EIA-867 aggregate total generation by fuel, prime mover, and census division, multiplied by appropriate heat rates,

where:

$$OTHFUEL_{cdiv,fuel,sales} = \sum_{cdiv=1,9} \sum_{pm=1,3} SICGEN_{cdiv,yr,ind,pm,sales} \ x \ RATE_{pm} \tag{63}$$

where:

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

Industrial cogeneration fuel consumption for own use is calculated similarly.

Subroutine WEXOG

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

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

$$BMAIN_{fuel,region} = TQMAIN_{fuel,region} + QELRF_{region} \tag{64}$$

The equation for total industrial natural gas consumption is:

$$BMAIN_{fuel,region} = TQMAIN_{fuel,region} + QNGRF_{region} + CGOGQ_{sales,region} + CGOGQ_{own,region} + NONTRAD_{region,fuel} \tag{65}$$

where:

$BMAIN_{ng,r}$ = Consumption of natural gas in Census region *r*,

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

$QNGRF_{r,y}$ = Natural gas consumed by petroleum refining industry in Census division *r* in year *y*, and

$CGOGQ_{sales,region}$= Consumption of natural gas from cogeneration of electricity for sales to the grid in enhanced oil recovery in Census region and year.

$CGOGQ_{own,region}$ = Consumption of natural gas from cogeneration of electricity for own use in enhanced oil recovery by Census region year.

Total industrial consumption for other fuels is calculated similarly.

SEDS benchmark factors are calculated as follows:

$$SEDSBF_{fuel,region} = \frac{SEDS4_{fuel,region}}{BMAIN_{fuel,region}} \tag{66}$$

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:

$$BENCH_{fuel,region} = SEDSBF_{fuel,region} \; x \; BMAIN_{fuel,region} \tag{67}$$

STEO benchmark factors are calculated as follows:

$$STEOBF_{fuel} = \frac{STEO_{fuel,year}}{\sum_{fuel} \sum_{region} BENCH_{fuel,region}} \tag{68}$$

where:

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

$STEO_{fuel,year}$ = Total third quarter STEO consumption by fuel for each forecast year.

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

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

$$BENCH_{fuel,region} = STEOBF_{fuel} \text{ x } BENCH_{fuel,region} \tag{69}$$

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.

$$DSRENW_{f,d} = \frac{OUTIND_{13,d} + OUTIND_{11,d}}{\sum_{d=1}^{NUM_r} (OUTIND_{13,d} + OUTIND_{11,d})} \tag{70}$$

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.

$$BENCHFAC_{bm,d} = \frac{BIOFUELS_d}{\sum_{f=2}^{3} DQRENW_{f,d}} \tag{71}$$

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

$$DQRENW_{f,d} = TQRENW_{f,region} \ x \ DSRENW_d \tag{72}$$

where:

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

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

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

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

$$CCAPCL_{total} = CCAPFOS_1 + .1 * (CCAPFOS_2 - CCAPFOS_1) * NGYRS \tag{73}$$

where:

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

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

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

Electricity savings are calculated similarly.

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

$$QELIN_{cdiv,year} = BENCH_{elec,region} \text{ x } SEDSHR_{elec,region,cdiv} \tag{74}$$

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.

$$QGFIN_{cdiv,year} = \left[BENCH_{ngas,region} \text{ x } SEDSHR_{ngas,region,region}\right] \text{ x } \left[\frac{TQMAIN_{cng,region} + TQMAIN_{fds,region}}{BMAIN_{ngas,region}}\right] \tag{75}$$

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

$$QGIIN_{cdiv,year} = QNGIN_{ngas,cdiv} - QGFIN_{cdiv,year} \tag{76}$$

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.

$$QBMIN_{d,y} = \left[\sum_{f=2}^{3} DQRENW_{f,d}\right] + \left[\sum_{u=1}^{2} CGOGQ_{d,y,bm,u}\right] + QBMRF_{d,y} \tag{77}$$

where:

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

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

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

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

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

$$QTRIN_{d,y} = QHOIN_{d,y} + QBMIN_{d,y} + QGEIN_{d,y} + QSTIN_{d,y} + QPVIN_{d,y} + QWIIN_{d,y} + QMSIN_{d,y} \tag{78}$$

where:

$QTRIN_{d,y}$ = Industrial consumption of total renewables in Census division *d* in year *y*,

$QHOIN_{d,y}$ = Industrial consumption of hydropower in Census division *d* in year *y*,

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

$QGEIN_{d,y}$ = Industrial consumption of geothermal in Census division *d* in year *y*,

$QSTIN_{d,y}$ = Industrial consumption of solar thermal in Census division *d* in year *y*,

$QPVIN_{d,y}$ = Industrial consumption of photovoltaic in Census division d in year y,

$QWIIN_{d,y}$ = Industrial consumption of wind in Census division d in year y, and

$QMSIN_{d,y}$ = Industrial consumption of municipal solid waste in Census division d in year y.

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

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

$$CGINDCAP_{d,y,f,u,pl} = CAPGW_{d,f,u,pl} \tag{79}$$

where:

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

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

Total consumption is calculated below.

$$CGINDQ_{d,y,f,u} = DIVFUEL_{d,f,u} \tag{80}$$

where:

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

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

Subroutine RDBIN

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

MODCAL

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

Subroutine CALPROD

CALPROD determines the throughput for production flows for the process and assembly component. Existing old and middle vintage production is 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 2000, the ratio of the current year's average industrial energy price to the average price in 2000 is computed, RetirePrat. For non-manufacturing industries, if RetirePrat is above a threshold, the retirement rate is changed from 0 to a small positive value, currently 0.02.[15] Further, the retirement rate is an increasing function of RetirePrat. For the manufacturing industries, the default retirement rates increase with RetirePrat.

Above the RetirePrat threshold, the following relationships hold:

$$X = RetirePrat^{RetireBeta}$$

$$RetirePriceFactor = 2 * \frac{X}{(1 + X)} \qquad (81)$$

$$RetireRate_s = RetirePriceFactor * ProdRetr_s$$

where:	*RetirePrat*	=	Ratio of current year average industrial energy price to 2000 price, equal to 1 for years prior to 2001;
	RetireBeta	=	Parameter of logistic function, currently specified as 5;
	RetirePriceFactor	=	TPC price factor, ranging from 0 (no price effect) to 2;

[15]There is no information concerning the retirement rates for non-manufacturing industries.

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

$ProdRetr_s$ = Default retirement rate for step s.

$$PRODCUR_{old,s} = \left[PRODCUR_{old,s} + IDLCAP_{old,s}\right] x \ (1 - RetireRate_s) \tag{82}$$

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 due to energy price increases for step s.

$$PRODCUR_{mid,s} = (PRODCUR_{mid,s} + PRODCUR_{new,s}) \ x \ (1 - RetireRate_s) \tag{83}$$

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 due to 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.

$$PRODX_{i,r} = PHDRAT \ x \ PRODVX_{i,r} \tag{84}$$

where:

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

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

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

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

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

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

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

$$PRODCUR_{total,s} = PRODFLOW_{old,s,l} \times PRODX_{i,r} \tag{85}$$

where:

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

$PRODFLOW_{old,s,l}$ = Down-step throughput to process step *s* by link *l* for old vintage, and

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

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

$$PRODCUR_{new,s} = PRODCUR_{total,s} - PRODCUR_{old,s} - PRODCUR_{mid,s} \tag{86}$$

where:

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

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

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

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

Middle vintage production is unaltered.

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

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

The balance equation is:

$$JOINTNEW + EXISTCAP - DOWN\ STEP\ REQD = 0 \tag{87}$$

where:

$JOINTNEW$ = Idle production for process step s for old vintage,

$EXISTCAP$ = Existing production at process step s for old vintage,

$DOWN\_STEP\_REQD$ = Existing production at process step s for mid vintage, and

Solving for the unknown, we write:

$$JOINTNEW = DOWN\ STEP\ REQD - EXISTCAP \tag{88}$$

The step's share of new capacity is:

$$PRODCUR_{new,is} = JOINTSHR_{is} \ x \ JOINTNEW \tag{89}$$

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

$$\begin{aligned} &[PFold_{i,j}] \ x \ [PRODCUR \ OLD_j] \ + \\ &[PFmid_{i,j}] \ x \ [PRODCUR \ MID_j] \ + \\ &[PFnew_{i,j}] \ x \ [PRODCUR \ NEW_j] \ + \\ &\qquad JOINTNEW = 0 \end{aligned} \tag{90}$$

where:

$PFold_{i,j}$	=	Production flow rate corresponding to industrial processes installed in 1994 plants for the ith primary step and the jth downstep
$PFmid_{i,j}$	=	Production flow rates corresponding to industrial production capacity installed in post 1994 plants for the ith primary step and the jth downstep
$PFnew_{i,j}$	=	Production flow rates of all new industrial capacity added within a given year to meet exogenous output and retirement of existing capital stock requirements for the ith primary step and the jth downstep

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

Subroutine CALCSC1

All the non-energy-intensive industries’ UECs are updated in CALCSC1. 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.

$$ENPINT_{v,f,s} = ENPINTLAG_{v,f,s} * (1 + TPCRate_v) \tag{91}$$

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, $BCSC_{v,fuel,step}$. For the non-manufacturing industries, the default values, i.e., when TPCPrat is below the threshold, for $BCSC_{v,fuel,step}$ are zero.

Above the TPCPrat threshold, the following relationships hold:

$$X = TPCPrat^{TPCBeta}$$

$$TPCPriceFactor = 4 * \frac{X}{(1 + X)} \tag{92}$$

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

where:			
	$TPCPrat$	=	Ratio of current year average industrial energy price to 2000 price, equal to 1 for years prior to 2001;
	$TPCBeta$	=	Parameter of logistic function, currently specified as 5;
	$TPCPriceFactor$	=	TPC price factor, ranging from 0 (no price effect) to 4;
	$TPCRate_v$	=	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 for each fuel *f* and step *s*.

Subroutine CALCSC3

CALCSC3 computes UECs for the energy-intensive 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.

$$ENPINT_{v,f,s} = ENPINTLAG_{v,f,s} * (1 + TPCRate_v) \tag{93}$$

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:

$$X = TPCPrat^{TPCBeta}$$
$$TPCPriceFactor = 3 * \frac{X}{(1 + X)} \qquad (94)$$
$$TPCRate_v = TPCPriceFactor * BCSC_{v,fuel,step}$$

where: *TPCPrat* = Ratio of current year average industrial energy price to 2000 price, equal to 1 for years prior to 2001;

TPCBeta = Parameter of logistic function, currently specified as 5;

TPCPriceFactor = TPC price factor, ranging from 0 (no price effect) to 3;

$TPCRate_v$ = 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 for each fuel *f* and step *s*.

After the TPC calculations are done, another set of calculations that characterize price-induced energy conservation (as opposed to energy reductions resulting from technology changes) are performed. Industrial processes involve the discharge of waste at elevated temperatures (e.g., liquids, air, solids). Some portion of the unrecovered heat would be both technically and economically recoverable if energy prices increase. The approach assumes that the design engineer's goal is to maintain a constant dollar value of the unrecovered heat. This leads to an equilibrium condition:

$$P_2 * HeatLoss_2 = P_1 * HeatLoss_1$$
$$\Rightarrow \frac{HeatLoss_2}{HeatLoss_1} = \frac{P_1}{P_2} \qquad (95)$$

where: P_1 and P_2 = Energy price in period 1 and period 2, and
$HeatLoss_1$ and $HeatLoss_2$ = Unrecovered heat in period 1 and period 2.

The above relationship can be put into the TPC-UEC framework by determining the practical minimum energy to carry out reactions as a fraction of the total energy actually used, FUnew.

$$UEC_1 = (FUnew * UEC_1) + (FUloss_1 * UEC_1) \tag{96}$$

Note that the term ($FUnew * UEC_1$) is a constant and that the remaining product term represents the unrecovered heat in the first period (with price = P_1). Multiplying the second product term by product throughput yields $HeatLoss_1$.

$$UEC_1 = CONSTANT + \frac{HeatLoss_1}{Throughput} \tag{97}$$

A similar equation holds for period 2 with price = P_2. Manipulation of the above three equations yields the following expression for the UEC_2 that results from the price-induced energy conservation.

$$UEC_2 = (FUnew * UEC_1) + (FUloss_1 * UEC_1) * \frac{P_1}{P_2} \tag{98}$$

While unrecovered heat, and the UEC, is inversely related to price in the two periods, it is unlikely that all facilities will adopt uniform policies regarding heat recovery. Consequently, a market penetration factor is assumed for old an new vintage. (Currently, these are assumed to be 0.2 for old vintage and 0.4 for new vintage.) This result can be thought of as representing per unit energy saving (UES) and is easier to calculate in the model.

$$UES_{2,v} = (FUnew * UEC_{1,v}) + (FUloss_1 * UEC_{1,v}) * \frac{P_1}{P_2} * MarkPen_v \tag{99}$$

where:	$UES_{2,v}$	=	Unit energy savings in period *2* for vintage *v*, and
	$MarkPen_v$	=	Market penetration of price-induced energy conservation for vintage *v*.

The final calculation then is to adjust by the base UEC by the UES for each vintage.

$$ENPINT_{v,f,s} = ENPINT_{v,f,s} - UES_v \tag{100}$$

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.

$$ENPINT_{mid,f,s} = \frac{SUMPINT_{f,s}}{CUMPROD_{new,s}} \tag{101}$$

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

$$ShareFuel_i = \frac{(P_i^{\alpha_i}\beta_i)}{\sum_{i=1}^{3} P_i^{\alpha_i}(\beta_i)} \qquad (102)$$

where the fuels are coal, petroleum, and natural gas. Base year boiler shares for distillate, residual oil, and liquid petroleum gas are calculated explicitly in order to obtain exact estimates of these fuel shares from the aggregate petroleum fuel share calculation. The P_i are the fuel prices; α_i are sensitivity parameters, the default value is -0.25; and the β_i are calibrated to reproduce the 1994 fuel shares using the relative prices that prevailed in 1994. 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 1994 MECS and exclude waste and byproducts.

The α_i sensitivity parameters are posited to be a positive function of energy prices. For years after 2000, the ratio of the current year's average industrial energy price to the average price in 2000 is computed, SwitchPrat.

Above the SwitchPrat threshold, the following relationships hold:

$$X = SwitchPrat^{SwitchBeta}$$

$$SwitchPriceFactor = 4 * \frac{X}{(1 + X)} \qquad (103)$$

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

where:

where:	*SwitchPrat*	=	Ratio of current year average industrial energy price to 2000 price, equal to 1 for years prior to 2001;
	SwitchBeta	=	Parameter of logistic function, currently specified as 4;
	SwitchPriceFactor	=	Fuel switching price factor, ranging from 0 (no price effect) to 4;
	α_{iPrice}	=	Fuel switching sensitivity parameters after accounting for energy price increases;
	α_i	=	Default fuel switching sensitivity parameters.

Appendix A. Bibliography

Data Sources

Decision Analysis Corporation of Virginia, *Energy Consumption in U.S. Agriculture*, (prepared for EIA) 1989.

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

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

Decision Analysis Corporation and Arthur D. Little Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*, (prepared for EIA) 1998.

Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Update on Selected Process Flows and Energy Use*, (prepared for EIA) 1994.

Energy Information Administration. *Annual Energy Outlook 2000*. DOE/EIA-0383(2000), December 1999.

Energy Information Administration. *Manufacturing Energy Consumption Survey: Consumption of Energy 1994*, DOE/EIA-0512(94), December 1997.

Energy Information Administration. *State Energy Data Report, Consumption Estimates 1960-1997*, DOE/EIA-0214(97), September 1999.

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 Commerce, Bureau of Economic Analysis, *Business Statistics 1963-1991*, Washington, DC.

U. S. Department of Commerce, Office of Business Analysis, *National Energy Accounts*, PB89-187918, February 1989.

U.S. Department of the Interior, Bureau of Mines, *1990 Minerals Yearbook*, Volume II.

Background Material

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.

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. 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:
September 1999.

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

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

Official Model Representatives:
T. Crawford Honeycutt
(202)586-1420
choneycu@eia.doe.gov
Office of Integrated Analysis and Forecasting
Energy Demand Analysis Branch
1000 Independence Avenue, SW
EI-84, Room 2F-094
Washington, DC 20585

Documentation:
Model Documentation Report: Industrial Sector Model of the National Energy Modeling System, January 2000.

Archive Media and Installation Manual(s):
The model has been archived on IBM RISC 6000 magnetic tape storage as part of the National Energy Modeling System production runs used to generate the *Annual Energy Outlook 2000*.

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, 1994 through 2020.

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 does not include a detailed process flow.

Non-DOE Input Sources:
Historical Dollar Value of Output in the Industrial Sector

DOE Input Sources:
Form EI-867: Survey of Independent Power Producers
- Electricity generation, total and by prime mover
- Electricity generation for own use and sales
- Capacity utilization

Manufacturing Energy Consumption Survey 1994, December 1997
State Energy Data System 1997, September 1999

Computing Environment:
- Hardware Used: IBM RISC 6000
- Operating System: AIX 4.2.1
- Language/Software Used: XL FORTRAN 90 Compiler/6000, Ver 4.0
- Estimated Run Time: 1.1 minutes for a 1994-2020 run in non-iterating NEMS mode on an IBM RISC 6000.
- Special Features: None.

Appendix C. Data Inputs

Table C1. Building Component UEC (Trillion Btu/Thousand Employees)					
		Building Use and Energy Source			
		Lighting	HVAC		
SIC	Industry	Electric UEC	Electric UEC	Natural Gas UEC	Steam UEC
20	Food & Kindred Products	0.007	0.009	0.014	0.045
26	Paper & Allied Products	0.013	0.016	0.023	0.008
281, 282, 286, 287	Bulk Chemicals	0.016	0.030	0.680	0.006
3211, 3221, 3229	Glass and Glass Products	0.013	0.019	0.044	0.004
3241	Hydraulic Cement	0.029	0.029	0.029	0.057
331	Blast Furnaces & Basic Steel	0.012	0.018	0.067	0.011
3334, 3353	Primary Aluminum	0.019	0.027	0.006	0.005
34, 35, 36, 37, 38	Metal Based Durables	0.008	0.013	0.015	0.002
All Remaining Manufacturing SIC's	Other Non-Intensive MFG Fabricated Metals	0.007	0.010	0.013	0.004

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

Table C2. Food and Kindred Products Industry National UECs, 1994 (Thousand Btu/1987$ Output, Unless Otherwise Indicated)								
End Use	Output (Billion$)	Electric	Nat Gas	Resid	Distillate	LPG	Coal	Steam
Direct Heat	379.0	0	0.506	0.008	0.005	0.005	0.027	0
Hot Water/Steam	379.0	0	0	0	0	0	0	1.406
Refrigeration	379.0	0.135	0	0	0	0	0	0
Other Electric	379.0	0.350	0	0	0	0	0	0

Table C3. Pulp and Paper Industry National UECs, 1994 (Million Btu/Ton of Flow, Unless Otherwise Indicated)									
Process Step	Flow (MMtons)	Electric	Nat Gas	Resid	Distillat e	LPG	Coal	Steam	Byproduct
Wood Preparation	109.1	0.270	0	0	0	0	0	0	3.566
Pulping									
Waste	40.4	1.300	0	0	0	0	0	1.400	0
Mech	5.9	5.400	0	0	0	0	0	0.500	0
Semi-chem	4.1	1.500	0	0	0	0	0	5.300	0
Kraft	54.5	1.500	1.422	0.386	0.021	0.020	0.051	11.300	16.183
Bleaching	48.5	0.300	0	0	0	0	0	5.600	0
Papermaking	98.6	1.500	0.299	0.081	0.005	0.004	0.011	6.000	0

Table C4. Bulk Chemical Industry National UECs, 1994 (Thousand Btu/1987$ Output, Unless Otherwise Indicated)									
End-Use	Output (Billion$)	Electric	Nat Gas	Resid	Distillate	LPG	Coal	Steam	Pet Feed
Direct Heat	145.6	0	4.665	0.060	0.020	0.013	0.033	0	0
Steam/Hot Water	145.6	0	0	0	0	0	0	8.654	0
Electrolytic	145.6	0.830	0	0	0	0	0	0	0
Other Electric	145.6	3.975	0	0	0	0	0	0	0
Feedstocks	145.6	0	4.632	0	0	10.516	0	0	8.497

Table C5. Glass and Glass Products Industry National UECs, 1994 (Million Btu/Ton of Flow, Unless Otherwise Indicated)						
Process Step	Flow (MMtons)	Electric	Nat Gas	Resid	Distillate	LPG
Virgin						
Batch Prep	13.5	0.19	0	0	0	0
Melting/Refining	13.5	0.46	5.177	0.137	0.018	0.018
Forming	13.5	0.61	1.597	0.042	0.006	0.005
Post-Forming	13.5	0.23	1.877	0.050	0.007	0.006

Table C6. Hydraulic Cement Industry National UECs, 1994 (Million Btu/Ton of Flow, Unless Otherwise Indicated)									
Process Step	Flow (MMtons)	Electric	Nat Gas	Resid	Distillate	Other Petrol.	LPG	Coal	Steam
Dry Process	57.8	0.23	0.310	0.014	0.032	0.774	0.005	2.755	0
Wet Process	17.7	0.21	0.421	0.019	0.043	1.051	0.007	3.739	0.09
Finish Grinding	84.8	0.22	0	0	0	0	0	0	0

Table C7. Blast Furnace and Basic Steel Products Industry National UECs, 1994 (Million Btu/Ton of Flow, Unless Otherwise Indicated)								
Process Step	Flow (MMtons)	Electric	Nat Gas	Resid	Coal	Coke	Steam	Byproduct
Coke Ovens	22.7	0.1	0.03	0	38.9	NA	0.8	3.14
Iron & Steelmaking								
BOF	61	0.2	1.41	0.15	0.36	9.85	1.28	1.32
EAF	39.6	1.59	0.574	0.001	0	0	0	0
Casting								
Ingot	10.5	0.3	1.66	0	0	0	0.03	0
Continuous	90	0.09	0.3	0	0	0	0.01	0.09
Hot Rolling	96.7	0.35	1.5	0.02	0	0	0.02	0.3
Cold Rolling	36.7	0.79	1.5	0	0	0	1.61	0

Table C8. Aluminum Industry National UECs, 1994 (Million Btu/Ton of Flow, Unless Otherwise Indicated)					
Process Step	Flow (MMtons)	Electric	Nat Gas	Distillate	Steam
Primary	3.6	49	4.091	0.008	0.2
Semi-Fab	5.1	2.9	10.179	0.020	0.2

Table C9. Non-Manufacturing Sector PA Component National UECs, 1994 (Thousand Btu/1987$ Output, Unless Otherwise Indicated)										
Industry	Output (Billion $)	Electric	Nat Gas	Resid	Distillate	LPG	Motor Gasoline	Coal	Steam	Other Petrol*
Agri-Crops	97.6	0.959	0.318	0	4.004	0.553	0.657	0.002	0.139	0.115
Agri-Other	139.7	0.254	0.095	0	1.059	0.146	0.173	0	0.033	0.032
Coal mining	28.6	1.566	0.030	0.288	2.013	0	0.129	0.296	0	0
Oil and Gas	79.9	1.396	3.361	0.073	0.526	0	0.127	0	0	0.099
Other Mining	24.3	4.638	0.006	0.393	2.629	0	0.01	2.219	0	0
Construction	389.3	0.284	0.438	0.288	0.439	0.077	0.270	0	0	3.013

*Other Petroleum is miscellaneous petroleum products except in the construction industry where it consists of asphalt and road oil.

Table C10. Non-Energy-Intensive Manufacturing Sector PA Component National UECs, 1994 (Thousand Btu/1987$ Output, Unless Otherwise Indicated)									
Industry	Output (Billion$)	Electric	Nat Gas	Resid	Distillate	LPG	Coal	Steam	Other
Metal-Based Durables	1159.3	0.281	0.254	0.001	0.005	0.003	0.002	0.217	0.03
Other Manufacturing	796.6	0.719	0.778	0.038	0.013	0.104	0.019	0.928	0.341

Table C11. Regional Technology Shares						
	Census Region					
Industry	Technology	NE	MW	SO	WE	US
Paper and Allied Products						
	Kraft (incl. Sulfite)	6.0%	5.0%	72.0%	17.0%	100%
	Semi-Chemical	11.0%	30.0%	48.0%	11.0%	100%
	Mechanical	19.0%	14.0%	47.0%	20.0%	100%
	Waste Fiber	18.0%	31.0%	34.0%	17.0%	100%
Hydraulic Cement						
	Wet Process	17.3%	26.6%	43.0%	13.1%	100%
	Dry Process	9.2%	28.9%	35.0%	26.8%	100%
Blast Furnace and Basic Steel Products						
	Electric Arc Furnace	23.6%	36.1%	31.6%	8.7%	100%
	Basic Oxygen Furnace	10.5%	69.5%	20.0%	0.0%	100%
	Open Hearth	34.5%	0.0%	36.2%	29.3%	100%
	Coke Oven	23.9%	50.4%	23.5%	2.1%	100%
Primary Aluminum						
	Smelters	7.0%	15.7%	43.3%	34.1%	100%

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

Table C12. Coefficients for Technology Possibility Curves

	Old Facilities		New Facilities			
Industry/ Process Unit	REI 2020	TPC[a]	REI 1994	REI 2020	TPC[a]	Retirement Rate
Food						
Direct Fuel	0.897	-0.004	0.90	0.80	-0.004	1.7
Hot Water/Steam	0.922	-0.003	0.90	0.80	-0.004	1.7
Refrigeration	0.947	-0.002	0.90	0.80	-0.004	1.7

Table C12. Coefficients for Technology Possibility Curves

Industry/ Process Unit	Old Facilities		New Facilities			Retirement Rate
	REI 2020	TPC[a]	REI 1994	REI 2020	TPC[a]	
Other Electric	0.947	-0.002	0.90	0.80	-0.004	1.7
Pulp & Paper						
Wood Preparation	0.950	-0.003	0.840	0.831	-0.0004	2.3
Waste Pulping	0.974	-0.001	0.930	0.885	-0.002	2.3
Mechanical Pulping	0.944	-0.003	0.840	0.822	-0.0009	2.3
Semi-Chemical	0.894	-0.006	0.730	0.697	-0.002	2.3
Kraft, Sulfite	0.903	-0.005	0.730	0.600	-0.008	2.3
Bleaching	0.910	-0.005	0.750	0.683	-0.004	2.3
Paper Making	0.910	-0.005	0.750	0.560	-0.012	2.3
Bulk Chemicals						
Direct Fuel	0.897	-0.004	0.90	0.80	-0.004	1.9
Hot Water/Steam	0.922	-0.003	0.90	0.80	-0.004	1.9
Electrolytic	0.980	-0.0008	0.90	0.80	-0.004	1.9
Other Electric	0.947	-0.002	0.90	0.80	-0.004	1.9
Glass[b]						
Batch Preparation	0.957	-0.002	0.882	0.882	0	1.3
Melting/Refining	0.892	-0.006	0.850	0.448	-0.027	1.3
Forming	0.952	-0.003	0.818	0.744	-0.004	1.3
Post Forming	0.921	-0.004	0.780	0.760	-0.001	1.3
Cement						
Dry Process	0.982	-0.0009	0.790	0.657	-0.008	1.2
Wet Process[c]	0.954	-0.002	NA	NA	NA	1.2
Finish Grinding	0.943	-0.003	0.813	0.641	-0.010	1.2

Table C12. Coefficients for Technology Possibility Curves

Industry/ Process Unit	Old Facilities REI 2020	Old Facilities TPC[a]	New Facilities REI 1994	New Facilities REI 2020	New Facilities TPC[a]	Retirement Rate
Steel						
Coke Oven[c]	1.00	0	0.840	0.817	-0.001	1.5
BF/Basic Oxygen Furnace	1.00	0	1.00	0.982	-0.0008	1.0
Electric Arc Furnace	1.00	0	0.960	0.960	0	1.5
Ingot Casting[c]	1.00	0	NA	NA	NA	2.9
Continuous Casting	1.00	0	1.00	1.00	0	2.9
Hot Rolling	0.698	-0.019	0.500	0.401	-0.009	2.9
Cold Rolling	0.877	-0.007	0.840	0.488	-0.023	2.9
Aluminum						
Primary Aluminum	0.936	-0.003	0.910	0.812	-0.005	2.1
Semi-Fabrication	0.855	-0.008	0.610	0.506	-0.008	2.1

[a]TPC is the annual rate of change between 1994 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: Decision Analysis Corporation and Arthur D. Little, Inc., *NEMS Industrial Model: Update on Energy Use and Industrial Characteristics.* Unpublished report prepared for Energy Information Administration, July 1998 and Office of Integrated Analysis and Forecasting.

Table C13. Advanced and State-of-the-Art Technologies

Sector	Major Process Step	Technology	Improvement in Subprocess Step	Alt Process Step
Pulp/Paper (S-O-A)	Wood Preparation	Whole Tree Debarking/Chipping*	1	
		Chip Screening Equipment*	1	
Pulp/Paper (S-O-A)	Chemical Pulping Technologies (Kraft, Sulfite)	Continuous Digesters	1	
		Batch Digesters	1	
		Radar Displacement Heating	1	

Table C13. Advanced and State-of-the-Art Technologies				
		Sunds Defibrator Cold Blow and Extended Delignification		1
		EKONO's White Liquor Impregnation		1
		Anthraquinone Pulping		1
		Alkaline Sulfite Anthraquinone (ASOQ) and Neutral Sulfite Anthraquinone (NSAQ) Pulping		1
		Tampella Recovery System	1	
		Advanced Black Liquor Evaporator	1	
		Process Controls System	1	
Pulp/Paper (S-O-A)	Mechanical and Semi-Mechanical Technologies	Pressurized Groundwood (PGW)		1
		PGW-Plus		1
		Thermo-Refiner Mechanical Pulping	1	
		Heat Recovery in TMP*	1	
		Cyclotherm System for Heat Recovery*	1	
		Chemimechanical Pulping	1	
		Chemi-Thermomechanical Pulping (CTMP)	1	
		Process Control System	1	
Pulp/Paper (S-O-A)	Semi-Chemical Technologies	See Chemical and Mechanical S-O-A technologies above		
Pulp/Paper (S-O-A)	Waste Paper Pulping Technologies	Advanced Pulping	1	
		Advanced Deinking	1	
Pulp/Paper (S-O-A)	Bleaching Oxygen Predelignification Technologies	Oxygen Bleaching		1
		Displacement Bleaching	1	
		Bio-bleaching		1
Pulp/Paper (S-O-A)	Papermaking Technologies	Extended Nip Press*	1	
		Hot Pressing	1	
		IR Moisture Profiling*	1	

Table C13. Advanced and State-of-the-Art Technologies				
		Reduced Air Requirement*	1	
		Waste Heat Recovery*	1	
		Process Control System*	1	
Pulp/Paper (Adv Tech)	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. We assumed REIs to decrease by 0.5% per year.		
Pulp/Paper (Adv Tech)	Chemical (Kraft/Sulfite) Technologies			
		Non-Sulfur Chemimechanical (NSCM) Pulping		1
		Advanced Alcohol Pulping		1
		Biological Pulping		1
		Ontario Paper Co. (OPCO) Process		1
		Black Liquor Concentration*	1	
		Black Liquor Heat Recovery *	1	
		Black Liquor Gasification*	1	
Pulp/Paper (Adv Tech)	Mechanical Technologies			
		Advanced Chemical/Thermal Treatment	1	
		Non-Sulfur Chemimechanical (NSCM)		1
		OPCO Process		1
Pulp/Paper (Adv Tech)	Semi-Chemical Technologies	Technology Introduction:		
		OPCO Process		1
		NSCM Process	1	
		Waste Pulping - Improvements in steam use, computer control, etc., assumed to decrease REI by 0.2% per year.	1	

Table C13. Advanced and State-of-the-Art Technologies				
Pulp/Paper (Adv Tech)	Bleaching Technologies	Technology Introduction:		
		Ozone Bleaching		1
		NO2/O2 Bleaching		1
		Biobleaching		1
Pulp/Paper (Adv Tech)	Papermaking Technologies	Technology Introduction: 2005-2015		
		High-Consistency Forming*	1	
		Advances in Wet Pressing*	1	
		Press Drying*	1	
		Impulse Drying*	1	
		Air Radio-Frequency-Assisted (ARFA) Drying*	1	
Glass (S-O-A)	Batch Preparation Technologies	Computerized Weighing, Mixing, and Charging	1	
Glass (S-O-A)	Melting/Refining Technologies			
		Chemical Boosting	1	
		Oxygen Enriched Combustion Air*	1	
		Automatic Tap Charging Transformers for Electric Melters	1	
		Sealed-in Burner Systems*	1	
		Dual-Depth Melter	1	
		Chimney Block Regenerator Refractories	1	
		Reduction of Regenerator Air Leakage*	1	
		Recuperative Burners*	1	
Glass (S-O-A)	Forming/Post-Forming Technologies	Emhart Type 540 Forehearth	1	
		EH-F 400 Series Forehearth	1	
		Forehearth High-Pressure Gas Firing System	1	
		Lightweighting	1	
Glass (Advanced)	Batch Preparation Technologies	No advanced technologies identified		

Table C13. Advanced and State-of-the-Art Technologies				
Glass (Advanced)	Melting/Refining Technologies	Technology Introduction: 1995-2010		
		Direct Coal Firing	1	
		Submerged Burner Combustion	1	
		Coal-Fired Hot Gas Generation*	1	
		Advanced Glass Melter		1
		Batch Liquefaction	1	
		Molybdenum-Lined Electric Melter		1
		Ultrasonic Bath Agitation/Refining*	1	
		Excess Heat Extraction from Regenerators	1	
		Thermochemical Recuperator	1	
		Sol-Gel Process		1
		Furnace Insulation Materials*	1	
		Pressure Swing Adsorption Oxygen Generator*	1	
		Hollow Fiber Membrane Air Separation Process*	1	
Glass (Advanced)	Forming/Post-Forming Technologies	Technology Introduction: 1995-2010		
		Mold Design*	1	
		Mold Cooling Systems	1	
		Automatic Gob Control	1	
		Improved Glass Strengthening Techniques*	1	
		Improved Protective Coatings*	1	
Cement (S-O-A)	Dry Process Technologies	Roller Mills*	1	
		High-Efficiency Classifiers*	1	
		Grinding Media and Mill Linings*	1	
		Waste Heat Drying*	1	
		Kiln Feed Slurry Dewatering*	1	
		Dry-Preheater/Precalciner Kilns	1	
		Kiln Radiation and Infiltration Losses*	1	
		Kiln Internal Efficiency Enhancement*	1	

Table C13. Advanced and State-of-the-Art Technologies				
		Waste Fuels*	1	
		Controlled Particle Size Distribution Cement	1	
		High-Pressure Roller Press	1	
		Finish Mill Internals, Configuration, and Operation	1	
		Grinding Aids*	1	
Cement (S-O-A)	Imports-Finish Grinding Technologies	High-Efficiency Classifiers*	1	
		Controlled Particle Size Distribution Cement*	1	
		High Pressure Roller Press		1
		Roller Mills*		1
		Finish Mill Internals, Configuration, and Operation	1	
		Grinding Aids*	1	
Cement (Advanced)	Dry Process Technologies	Technology Introduction: 1997-2013		
		Autogenous Mills	1	
		Differential Grinding	1	
		Sensors and Controls*	1	
		Fluidized-Bed Drying	1	
		Stationary Clinkering Systems	1	
		All-Electric Kilns		1
		Sensors for On-Line Analysis*	1	
		Advanced Kiln Control*	1	
		Catalyzed, Low-Temperature Calcination		1
		Alkali Specification Modification*	1	
		Cone Crushers*	1	
		Advanced (Non-Mechanical) Comminution	1	
		Modifying Fineness Specifications*	1	
		Blended Cements*	1	
		Advanced Waste Combustion	1	
Cement (Advanced)	Imports-Finish Grinding			

Table C13. Advanced and State-of-the-Art Technologies				
		Sensors and Controls*	1	
		Cone Crushers*	1	
		Advanced (Non-Mechanical) Comminution		1
		Modifying Fineness Specifications*	1	
		Blended Cements*	1	
I&S (S-O-A)	Cokemaking Technologies	Dry Quenching of Coke*		1
		Carbonization Control	1	
		Programmed Heating	1	
		Wet Quenching of Coke with Energy Recovery*	1	
		Sensible Heat Recovery of Off-Gases*	1	
I&S (S-O-A)	Ironmaking Technologies	Blast Furnace		
		Coal Injection*	1	
		Water-Cooling	1	
		Movable Throat Armor*	1	
		Top Gas Pressure Recovery*	1	
		Hot Stove Waste Heat Recovery*	1	
		Insulation of Cold Blast Main*	1	
		Recovery of BF Gas Released During Charging	1	
		Slag Waste Heat Recovery*	1	
		Paul Wurth Top*	1	
		External Desulfurization - injection of calcium carbide or mag-coke as a desulfurizing reagent*	1	
		Midrex/HBI		1
I&S (S-O-A)	Steelmaking Technologies	Basic Oxygen Furnace		
		Gas Recovery in Combination with Sensible Heat Recovery*	1	
		Two working vessels concept*	1	
		Combined Top and Bottom Oxygen Blowing*	1	
		In-Process Control (Dynamic) of Temp and Carbon Content*	1	

Table C13. Advanced and State-of-the-Art Technologies				
		Electric Arc Furnace		
		DC Arc Furnaces*	1	
		Ultra-High Power (UHP)*	1	
		Computerization*	1	
		Bottom Tap Vessels*	1	
		Water-Cooled Furnace Panels and Top*	1	
		Water-Cooled Electrode Sections*	1	
		Oxy-Fuel Burners*	1	
		Long Arc Foamy Slag Practice*	1	
		Material Handling Practices*	1	
		Induction Furnaces*		1
		Energy Optimizing Furnaces*		1
		Scrap-Preheating*	1	
		Ladle Drying and Preheating*	1	
		Injection Steelmaking (ladle metallurgy)	1	
		Vacuum Arc Decarburization*		
		Argon Stirring	1	
		Specialty Steelmaking Processes		
		Electroslag Remelting (ESR)*		1
		Argon-Oxygen Decarburization (AOD)*		1
		Vacuum Induction Melting (VIM)*		1
		Electron Beam Melting (EBM)*		1
		Vacuum Arc Remelting (VAR)*		1
I&S (S-O-A)	Steelcasting Technologies	Modern Casters*		1
		Thin Slab Casting		1
		Slab Heat Recovery*	1	
		Soaking Pit Utilization and Pit Vacant Time*	1	

Table C13. Advanced and State-of-the-Art Technologies				
I&S (S-O-A)	Steelforming (Rolling) Technologies	Hot Charging	1	
		Preheating Furnaces		
		Improved Insulation*	1	
		Waste Heat Recovery and Air Preheating*	1	
		Waste Heat Recovery and Fuel Gas Preheating*	1	
		Increased Length of the Preheating Furnace	1	
		Waste Heat Boilers	1	
		Evaporative Cooling of Furnace Skids	1	
		Direct Rolling		
		Leveling Furnace*	1	
		The Coil Box*	1	
		Covered Delay Table*	1	
		Pickling - Insulated Floats*	1	
		Annealing		
		Air Preheating*	1	
		Fuel Gas Preheating	1	
		Combustion Control*	1	
		Continuous Annealing		1
		Continuous Cold Rolling		1
I&S (Advanced Technologies)	Ironmaking Technologies	PLASMARED		1
		COREX		1
		Direct Iron Ore Smelting (AISI)		1
		HiSmelt		1
		Fastmet		1
		Iron Carbide Route		1

Table C13. Advanced and State-of-the-Art Technologies				
		Iron Ore Reduction/Steelmaking (AISI)		1
I&S (Advanced Technologies)	Direct Steelmaking Technologies	PLASMAMELT		1
		INRED		1
		ELRED		1
		Foster Wheeler-Tetronics Expanded Processive Plasma Process		1
I&S (Advanced Technologies)	Steelmaking Technologies	Scrap Preheating*	1	
		Energy Optimizing Furnace (EOF)		1
		Modern Electric Arc Furnace with Continuous Charging/Scrap Preheating	1	
		Modern Basic Oxygen Furnace	1	
		Injection of Carbonaceous Fuels		
		Increased Scrap Use		
		Ladle Drying and Preheating*	1	
		Injection Steelmaking	1	
I&S (Advanced Technologies)	Steelcasting Technologies	Horizontal Continuous Caster*		1
		Near Net Shapecasting*		1
		Direct Strip Casting*		1
		Ultra Thin Strip Casting*		1
		Spray Casting		1
I&S (Advanced Technologies)	Hot/Cold Rolling	Direct Rolling	1	
		Continuous Cold Rolling and Finishing	1	
		In-Line Melting/Rolling	1	
		Advanced Coating	1	

Table C13. Advanced and State-of-the-Art Technologies				
Aluminum (S-O-A)	Alumina Refining Technologies	Advanced Digesters	1	
		Heat Recovery*	1	
Aluminum (S-O-A)	Primary Aluminum Technologies	Advanced Cells	1	
		New Cathodes*	1	
Aluminum (S-O-A)	Semi-Fabrication Technologies	Continuous-Strip Casting		1
		Electromagnetic Casting	1	
Aluminum (S-O-A)	Secondary Aluminum Technologies	Induction Melting		1
		Advanced Melting		1
Aluminum (Advanced)	Alumina Refining Technologies	Retrofit of S-O-A Technologies	1	
Aluminum (Advanced)	Primary Aluminum Technologies	Technology Introduction:		
		Carbothermic Reduction		1
		Inert Anodes*	1	
		Bipolar Cell Technology		1
		Wettable Cathodes*	1	
Aluminum (Advanced)	Semi-Fabrication Technologies	Technology Introduction		
		New Melting Technology*		
		Preheaters*	1	

Table C13. Advanced and State-of-the-Art Technologies				
Aluminum (Advanced)	Secondary Aluminum Technologies	Technology Introduction		
		New Melting Technology (submerged radiant burners)	1	
		Preheaters*	1	
		Heat Recovery Technology	1	
TOTAL			164	61
Note: 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. A discussion of relative energy intensities for new iron/steelmaking technologies is found in Appendix M of the 1993 report to DAC/EIA.				
Source: Arthur D. Little, Inc. *Aggressive Technology Strategy for the NEMS Model*. Unpublished Report Prepared for the Energy Information Administration (September 1998).				

Table C14. Unrecovered Heat Assumptions

Industry	Vintage	FUnew Steam	FUnew Fuel
Food	Old	0.48	0.57
Food	New	0.53	0.63
Pulp and Paper	Old	0.55	0.59
Pulp and Paper	New	0.69	0.74
Bulk Chemicals	Old	0.72	0.76
Bulk Chemicals	New	0.80	0.84
Glass	Old	0.79	0.65
Glass	New	0.94	0.77
Cement	Old	0.66	0.54
Cement	New	0.94	0.77
Steel	Old	0.55	0.60
Steel	New	0.69	0.75
Aluminum	Old	0.60	0.65
Aluminum	New	0.69	0.75

Source: Decision Analysis Corporation and Arthur D. Little Inc., *NEMS Industrial Model: Technology DataBase*. Unpublished Report Prepared for Energy Information Administration, (Vienna, VA, 1997).

Table C15. Logit Function Parameters for Estimating Boiler Fuel Shares

Industry	Alpha	Natural Gas	Steam Coal	Oil
Food	-0.25	0.62	0.16	0.23
Paper and Allied Products	-0.25	0.56	0.31	0.13
Bulk Chemicals	-0.25	0.57	0.18	0.25
Glass and Glass Products	-0.25	0.91	0.0	0.09
Cement	-0.25	0.96	0.02	0.02
Steel	-0.25	0.47	0.15	0.38
Aluminum	-0.25	0.97	0.0	0.03
Based Durables	-0.25	0.73	0.18	0.10
Other Non-Int MFG	-0.25	0.91	0.05	0.04

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

Table C16. 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).

Table C17. Characteristics of Candidate Cogeneration Systems					
	Systems Considered				
	1	2	3	4	5
Electric Capacity (kW)	1000	2500	5000	10000	40000
Total Installed Cost (97 $/kW)	1600	1400	1200	1000	950
Capacity Factor	0.8	0.8	0.8	0.8	0.8
Overall Efficiency	0.7	0.7	0.7	0.75	0.8
Total Heat Rate (Btus/kWh)	14,217	13,132	11,263	10,515	9,749
Incremental Heat Rate (Btus/kWh)	6,042	5,907	5,673	4,922	4,265
Steam Output (mmBtu/hour)	6.5	14.5	22.4	44.7	175.5
Power-Steam Ratio	.52	.59	.76	.76	.78

Sources: Energy Information Administration, Office of Integrated Analysis and Forecasting. Installation costs and performance factors summarized from two books from the Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET): Gas-Turbine-Based CHP in Industry and Small Scale Cogeneration. Some characteristics, such as heat rates of gas-turbines, are summarized from data provided from Solar Turbines (owned by Caterpillar) and Allison Gas Turbines.

Table C18. Boiler population characteristics used for cogeneration system sizing and steam load segmentation

Distribution of Boilers by Firing Capacity and Industry	**10-50 mmbtu/hr**	**50-100 mmbtu/hr**	**100-250 mmbtu/hr**	**> 250 mmbtu/hr**
Food	35.9%	25.1%	25.5%	13.5%
Pulp and Paper	10.1%	10.9%	24.9%	54.1%
Chemicals	25.7%	15.7%	28.8%	29.8%
Primary Metals	28.2%	12.3%	21.9%	37.7%
Other Manuf	51.4%	24.7%	19.0%	5.0%
Average Boiler Size (mmbtu/hr)	28.42	84.24	141.73	466.08

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

Table C19. Payback Acceptance Rate Assumptions for Cogeneration Market Penetration

Paypack Period in Years	Acceptance Rate
0	100.00%
1	88.50%
2	64.00%
3	39.50%
4	20.50%
5	9.75%
6	5.50%
7	3.75%
8	2.50%
9	1.63%
10	0.88%
11	0.25%
12	0.00%

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