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

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Update Information

This is the eleventh edition of the *Model Documentation Report: Industrial Sector Demand Module of the National Energy Modeling System (NEMS)*. It reflects changes made to the module over the past year for the *Annual Energy Outlook 2006*. These changes include:

- Updated base-year (2002) manufacturing unit energy consumption estimates based on the Energy Information Administration's (EIA) *2002 Manufacturing Energy Consumption Survey*.
- Updated base-year (2002) unit energy consumption estimates for the non-manufacturing sectors based on information from the U.S. Department of Agriculture, the U.S. Census Bureau, and the EIA.
- Incorporated the technology characterizations developed in 2005 by FOCIS Associates for the manufacturing sectors.
- Updated boiler characterizations based on a 2005 ORNL/EEA report
- Extended the model time horizon to 2030.

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1. Introduction

Purpose of this Report

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

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

Model Summary

The NEMS Industrial Demand Model is a dynamic accounting model, bringing together the disparate industries and uses of energy in those industries, and putting them together in an understandable and cohesive framework. The Industrial Model generates long-term (up to the year 2030) projections of industrial sector energy demand as a component of the NEMS integrated modeling system. From the NEMS system, the Industrial Model receives fuel prices, employment data, and the value of industrial shipments. Based on the values of these variables, the Industrial Model passes back to the NEMS system estimates of 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. For the *Annual Energy Outlook 2006* (*AEO2006*), revisions were made to the process and assembly component of the bulk chemical industry to account for differing energy consumption patterns and growth rates. A minor change was made to the pulp and paper industry to reflect greater use of market pulp in the future. The manufacturing industries are modeled through the use of a detailed process flow or end use accounting procedure. The nonmanufacturing industries are represented in less detail. The industrial model projects energy consumption at the four Census region levels; energy consumption at the Census division level is allocated by using data from the *State Energy Data Report 2001*.[1] The national-level values reported in *Annual Energy Review 2004* were allocated to the Census Divisions using the *State Energy Data Report 2001*.[2]

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

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[1] Issued December 2004, http://www.eia.doe.gov/emeu/states/_seds.html

[2] In 2002, EIA comprehensively reviewed and revised how it collects, estimates, and reports fuel use for facilities producing electricity. For a detailed discussion, see Energy Information Administration, *Annual Energy Review 2001*, DOE/EIA-0384 (2001), November 2002, Appendix H, “Estimating and Presenting Power Sector Fuel Use in EIA Publications and Analyses,” web site http://tonto.eia.doe.gov/FTPROOT/multifuel/038401.pdf. The specific impacts on reported industrial energy consumption are discussed in Energy Information Administration, *Annual Energy Outlook 2003*, pp. 32-34, Energy Information Administration, *Annual Energy Outlook 2003*, DOE/EIA-0383(2003) (January 2003), web site http://www.eia.doe.gov/oiaf/archive/aeo03/pdf/0383(2003).pdf.

produces byproducts that are consumed in the BSC component. For the manufacturing industries, the PA component is separated into the major production processes or end uses.

Archival Media

The model is archived as part of the National Energy Modeling System production runs used to generate the *AEO2006*.

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Organization of this Report

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

The Appendices to this report provide supporting documentation for the Industrial Model. Appendix A is a bibliography of data sources and background materials used in the model development process. Appendix B provides the input data. Appendix C is the model abstract.

2. Model Purpose

Model Objectives

The NEMS Industrial Demand Model was designed to project industrial energy consumption by fuel type and industry as defined in the North American Industrial Classification System (NAICS).[3] The Industrial Model generates long-term (up to the year 2030) projections of industrial sector energy demand as a component of the NEMS integrated modeling system. From the NEMS system, the Industrial Model receives fuel prices, employment data, and the value of shipments, which are expressed in 2000 dollars, for industrial activity. Based on the values of these variables, the Industrial Model passes back to the NEMS system estimates of fuel consumption for 17 main fuels, including feedstocks and renewables, (Table 1) for each of 15 industry groups. The Industrial Model projects 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 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* (*AEO*) and other applications that examine long-term energy-economy interactions.

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

To a lesser extent, the Industrial Model can endogenously analyze specific technology programs or energy standards. The model distinguishes among the energy-intensive manufacturing industries, the non-energy-intensive manufacturing industries, and the non-manufacturing industries.

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

The Unit Energy Consumption (UEC) is defined as the energy use per ton of throughput at a process step or as energy use per dollar of shipments for the end use industries. The “Existing UEC” is the current average installed intensity (as of 2002). The “New 2002 UEC” is the intensity expected to prevail for a new installation in 2002. Similarly, the “New 2030 UEC’ is the intensity expected to prevail for a new installation in 2030. 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. 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.

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[3] Executive Office of the President, Office of Management and Budget, *North American Industry Classification System, United States, 2002*. Washington, DC, 2002.

Interaction with Other NEMS Modules

Table 1shows the Industrial Model inputs from and outputs to other NEMS modules. Note that all inter-module interactions must pass through the integrating module. For the industrial module, the Macroeconomic Activity Module (MAM) is the most important. MAM supplies industry value of shipments and employment for the industrial module's subsectors. Ultimately, these two drivers are major factors influencing industrial energy consumption over time. The second most important factor is the set of energy prices provided by the various supply modules.

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 Integration Module
Electricity prices	Electricity Market Module
Natural gas prices	Natural Gas Transmission and Distribution Module
Steam coal prices Metallurgical coal prices	Coal Market Module
Distillate oil prices Residual oil prices LPG prices Motor gasoline prices Petrochemical feedstock prices Asphalt and road oil prices Other petroleum prices	Petroleum Market Module
Value of shipments Employment	Macroeconomic Activity Module
Refinery consumption of: Natural gas Steam coal Distillate oil Residual oil LPG Still gas Petroleum coke Other petroleum Purchased Electricity	Petroleum Market Module
Lease and Plant Natural Gas Consumption	Natural Gas Transmission and Distribution Module
Energy consumption for Gas-to-Liquids conversion	Oil and Gas Supply Module
Energy consumption for Coal-to-Liquids conversion	Petroleum Market Module

Table 1. Interaction With Other NEMS Modules

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

3. Model Rationale

Theoretical Approach

Introduction

The NEMS Industrial Model can be characterized as a dynamic accounting model, combining economic and engineering data and knowledge. Its architecture brings together the disparate industries, and uses of energy in those industries, and combines them in an understandable and cohesive framework. This explicit understanding of the current uses of energy in the industrial sector is used as the framework from which to base the dynamics of the model.

One of the overriding characteristics in the industrial sector is the heterogeneity of industries, products, equipment, technologies, processes, and energy uses. Adding to this heterogeneity is that the industrial sector includes not only manufacturing, but also agriculture, mining, and construction. These disparate industries range widely from highly energy-intensive activities to non-energy-intensive activities. Energy-intensive industries are modeled at a disaggregate level so that projected changes in composition of the products produced will be automatically taken into account when computing energy consumption. Industrial modeling approaches other than NEMS have either combined very different activities together across industries or users, or they have been so disaggregate as to require extensive resources for data development and for running the model when the composition of products produced is projected to change.

Modeling Approach

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

- The industrial model incorporates three major industry categories, consisting of energy-intensive manufacturing industries, non-energy-intensive manufacturing industries, and nonmanufacturing industries. The level and type of modeling and the attention to detail is different for each.
- Each industry is modeled as three separate but interrelated components, consisting of boilers/steam/cogeneration (BSC), buildings (BLD) and process/assembly (PA) activities.
- The model uses a vintaged capital stock accounting framework that models energy use in new additions to the stock and in the existing stock. The existing stock is retired based on retirement rates for each industry.
- The manufacturing industries are modeled with a structure that explicitly describes the major process flows or major consuming uses in the industry.
- The industrial model uses "technology bundles" to characterize technical change. These bundles are defined for each production process step or end use.
- Technology improvement for each technology bundle for each production process step or end use is based upon engineering judgments.
- The model structure accommodates several industrial sector activities including: fuel switching, cogeneration, renewables consumption, recycling and byproduct consumption. The principal model calculations are performed at the four Census region level and aggregated to a national total.

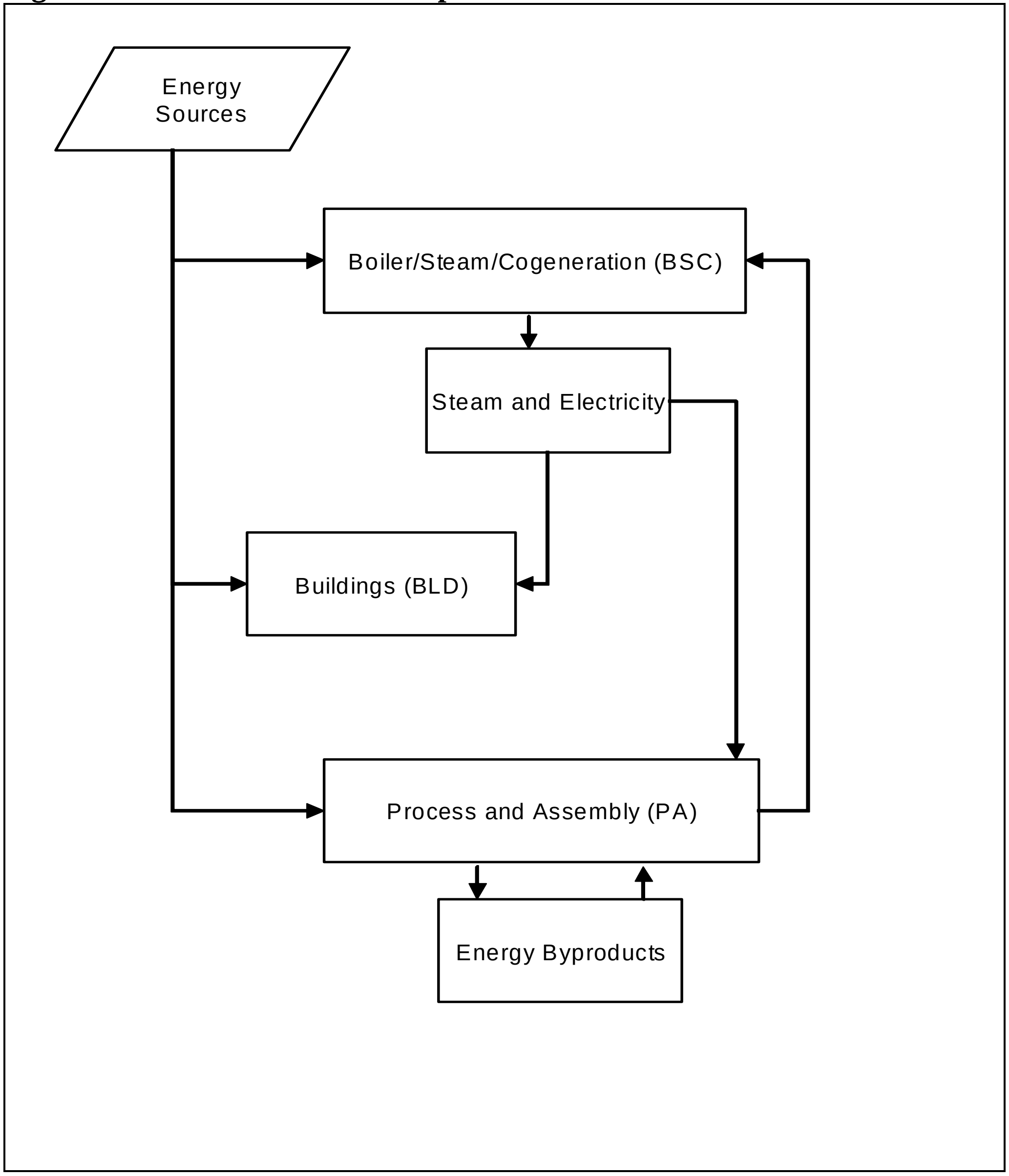
Fundamental Assumptions

The industrial sector consists of numerous heterogeneous industries. The Industrial Model classifies these industries into three general groups: energy-intensive industries, non-energy-intensive industries, and non-manufacturing industries. There are eight energy-intensive manufacturing industries; seven of these are modeled in the industrial model. These are as follows: food products (NAICS 311); paper and allied products (NAICS 322); bulk chemicals (parts of NAICS 325); glass and glass products (NAICS 3272); cement (NAICS 32731); iron and steel (NAICS 331111); and aluminum (NAICS 3313). Also within the manufacturing group are metal-based durables (NAICS 332-336) and the balance of manufacturing (all NAICS manufacturing sectors that are not included elsewhere). A minor change was made to the pulp and paper industry to reflect greater use of market pulp in the future. The eighth energy-intensive industry, petroleum refining (NAICS 32411) is modeled in detail in the Petroleum Market Model, a separate module of NEMS, and the projected energy consumption is included in the manufacturing total. The projections of lease and plant fuel and cogeneration consumption for Oil and Gas (NAICS 211) are modeled in the Oil and Gas Supply Module and included in the Industrial Sector energy consumption totals.

The flow of energy among the three industrial model components follows the arrows in Figure 1. The BSC component satisfies the steam demand from the PA and BLD components. For the manufacturing industries, the PA component is broken down into the major production processes or end uses. Energy consumption in the NEMS Industrial Model is primarily a function of the level of industrial economic activity. Industrial economic activity in the NEMS system is measured by the dollar value of shipments produced by each industry group. The value of shipments by NAICS classification is provided to the Industrial Model by the NEMS Macroeconomic Activity Module. As the level of industrial economic activity increases, energy consumption typically increases, but at a slower rate than the growth in economic activity.

The amount of energy consumption reported by the Industrial Model is also a function of the vintage of the capital stock that produces the shipments. It is assumed that new capital stock will consist of state-of-the-art technologies that are relatively more energy efficient than the average efficiency of the existing capital stock. Consequently, the amount of energy required to produce a unit of output using new capital stock is less than that required by the existing capital stock. The energy intensity of the new capital stock relative to 2002 capital stock is reflected in the parameter of the Technology Possibility Curve (TPC) estimated for each process step or end use. These curves are based on engineering judgments about the likely future path of energy intensity changes.

Figure 1. Industrial Model Components



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. It is assumed that 50 percent of the improvement that can be incorporated in new capacity additions could be captured by retrofitting existing capacity. The net effect is that over time the amount of energy required to produce a unit of output declines. Although total energy consumption in the industrial sector is projected to increase, overall energy intensity is projected to decrease.

Energy consumption in the buildings component is assumed to grow at the same rate as the average growth rate of employment and output in that industry.[4] This formulation has been used to account for the countervailing movements in manufacturing employment and value of shipments. Manufacturing

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

employment falls over the projection, which alone would imply falling building energy use. But, since shipments tend to grow fairly rapidly, that implies that conditioned floor space is increasing (although the relevant data are not available). Energy consumption in the BSC is assumed to be a function of the steam demand of the other two components.

Industry Disaggregation

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

Table 2. Industry Categories

Energy-Intensive Manufacturing	Nonmanufacturing Industries
Food Products (NAICS 311)	Agriculture, Crops (NAICS 111)
Paper and Allied Products (NAICS 322)	Agriculture, Other (NAICS 112-115)
Bulk Chemicals Inorganic (NAICS 32512 to 32518) Organic (NAICS 32511, 32519) Resins (NAICS 3252) Agricultural (NAICS 3253)	Coal Mining (NAICS 2121)
	Oil and Gas Mining (NAICS 211)
	Other Mining (NAICS 2122-2123)
Glass and Glass Products (NAICS 3272)	Construction (NAICS 233-235)
Cement (NAICS 32731)	
Iron and Steel (NAICS 3311)	
Aluminum (NAICS 3313)	
Nonenergy-Intensive Manufacturing	
Metal-Based Durables (NAICS 332-336)	
Balance of Manufacturing (all remaining manufacturing NAICS, excluding Petroleum refining (32410))	

NAICS = North American Industrial Classification System

Source: Office of Management and Budget, *North American Industry Classification System*, United States, 2002 (Springfield, VA, National Technical Information Service, 2002).

Energy Sources Modeled

The NEMS Industrial Model estimates energy consumption by 15 industries for 14 fuels. The fuels modeled in the Industrial Model are:

- Electricity
- Natural Gas
- Steam Coal

- Distillate Oil
- Residual Oil
- LPG for heat and power
- Motor Gasoline
- Petroleum Coke
- Renewables (biomass and hydropower)
- Natural Gas Feedstock
- Coking Coal (including net imports)
- LPG Feedstock
- Petrochemical Feedstocks
- Asphalt and Road Oil

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

Key Computations

The key computations of the Industrial Model are the Unit Energy Consumption (UEC) estimates made for each NAICS industry group. UEC is defined as the amount of energy required to produce one dollar's worth of shipments. The distinction between existing and new capital equipment is maintained with a vintage-based accounting procedure. In practice, the fuel use in similar capital equipment is the same across vintages. For example, an electric arc furnace primarily consumes electricity no matter whether it is an old electric arc furnace or a new one.

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

Buildings Component UEC

Buildings are estimated to account for 9 percent of allocated heat and power energy consumption in manufacturing industries.[5] Estimates of 2002 manufacturing sector building UEC's are presented in Table B1 and Table B2. Energy consumption in manufacturing buildings is assumed to grow at the average of the growth rates of employment and shipments in that industry. This assumption appears to be reasonable since lighting and heating, ventilation, and air conditioning (HVAC) are used primarily for the convenience of humans rather than machines. However, since value of shipments tend to grow, it is likely that conditioned floor space also grows. This combination attempts to account for the contrasting trends in employment and shipments growth rates.

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[5] Computed from Energy Information Administration, *2002 Manufacturing Energy Consumption Survey*, (www.eia.doe.gov/emeu/mecs/MECS2002/data02/shelltables.html), March 2005. Note that byproduct and non-energy use of combustible fuels are excluded from the computation because they are not allocated in the MECS tables.

Process and Assembly Component UEC

The process and assembly component (PA) accounted for the largest share, 57 percent, of direct energy consumption for heat and power in 2002. Of the PA total, natural gas accounted for 48 percent and electricity accounted for 43 percent.

Estimation of the PA component UECs depends on the particular industry. For the manufacturing industries, engineering data relating energy consumption to the product flow through the process steps or end uses are used. In addition, engineering judgment is used to characterize autonomous change in the manufacturing industries through the use of Technology Possibility Curves (TPCs). The energy intensity of the new capital stock relative to 2002 capital stock is reflected in the parameter of the TPC estimated for each process step or end use. These curves are based on engineering judgment of the likely future path of energy intensity changes. The non-manufacturing industries do not use process steps or end-uses due to data limitations.

Fuel shares for process and assembly energy use in eight manufacturing industries[6] are adjusted for changes in relative fuel prices. These industries are food, paper, chemicals, glass, cement, steel, metal-based durables, and other manufacturing. In each industry, two logit fuel-sharing equations are applied to revise the initial fuel shares obtained from the process-assembly component. The resharing does not affect the industry's total energy use--only the fuel shares. The methodology adjusts total fuel shares across all process stages and vintages of equipment to account for aggregate market response to changes in relative fuel prices.

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

$$NewShr_i = \left(\frac{DefltShr_i * e^{(\beta_i - \beta_i * Prcrat_i)}}{\sum_{i=1}^{n} DefltShr_i * e^{(\beta_i - \beta i_i * Prcrat_i)}} \right) \tag{1}$$

where:

$NEWSHR_i$ = New fuel-group share for fuel *i*,
$DEFLTSHR_i$ = Default fuel-group share for fuel *i*, and
$Prcrat_i$ = Ratio of current year price to 2002 price for fuel *i*

The user-specified coefficients β_j are 0.05 for the *AEO2006*.

The form of the equation results in unchanged fuel shares when the price indices are all 1, or unchanged from their 2002 levels. The implied own-price elasticity of demand is about -0.1 for the assumed values of β_j and for the boiler shares typically observed.

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

Manufacturing Industry UEC Estimation

For the nine manufacturing industry groups, energy consumption for the PA component is modeled according to the process flows or end uses in that industry. The industries are food products, paper and allied products, bulk chemicals (including inorganic, organic, resins, and agricultural chemicals), glass and glass products, cement, iron and steel, aluminum, metal-based durables, and the balance of manufacturing (excluding petroleum refining that is modeled in the Petroleum Market Model of 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 were analyzed according to one of the following methodologies:

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

Methodology 2. Develop 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 products, bulk chemicals, metal-based durables, and the balance of manufacturing). A motor stock model calculates the electricity consumption for the machine drive end-use for these four industries.

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

Fossil Fuels;
Electricity (valued at 3,412 Btu/kWh);
Steam; and
Non-fuel energy sources.

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

Food Products (NAICS 311)

The food products industry accounted for 11 percent ($437 billion) of manufacturing value of shipments in 2002. The food products industry consumed approximately 1,123 trillion Btu of energy in 2002.[7] Energy use in the food products industry for the PA Component was estimated on the basis of end-use in four major categories:

Process Heating;
Process Cooling;
Machine Drive;
Other.

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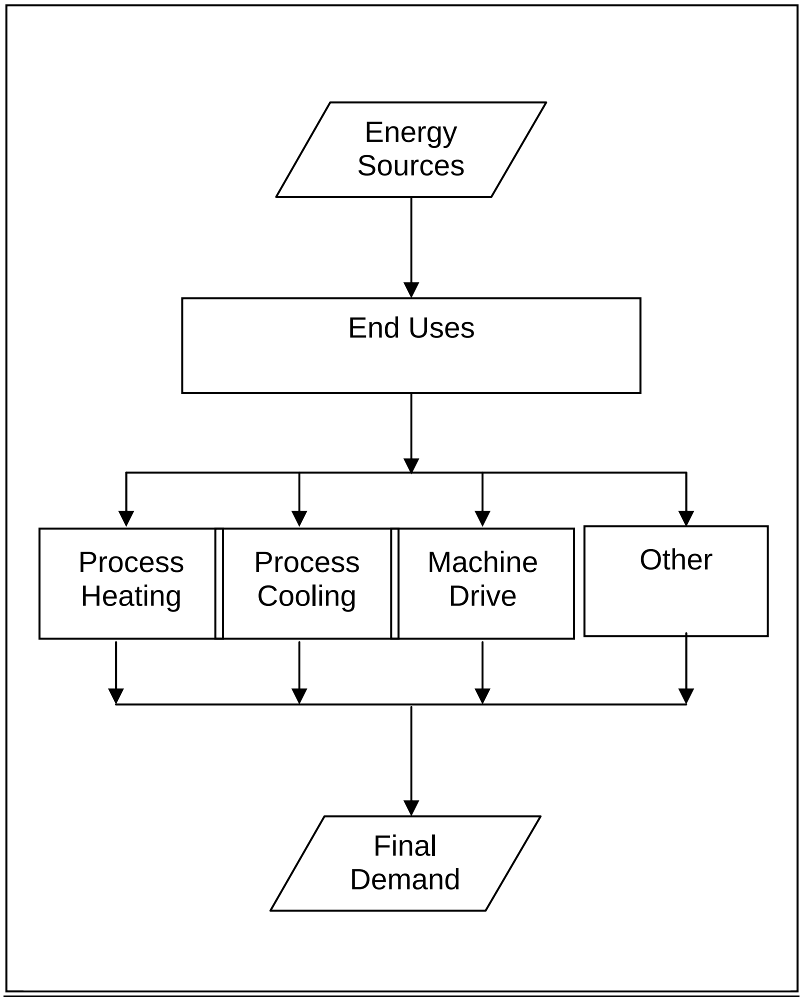
[7] Energy Information Administration (EIA), *2002 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.htm, March 2005. Note that the industrial model's energy consumption projection for 2002 may vary slightly from the MECS2002 values due to the inclusion of data from the electricity data forms and model discrepancy.

Figure 2 portrays the PA component's end-use energy flow for the food products industry. A motor stock model, which is described later in this document, calculates electricity consumption for the machine drive end-use. The UECs estimated for the remaining end-uses in this industry are provided in Table B3. The dominant end-use was direct heat, which accounted for 74 percent of the total PA energy consumption.

Figure 2. Food Industry End Uses

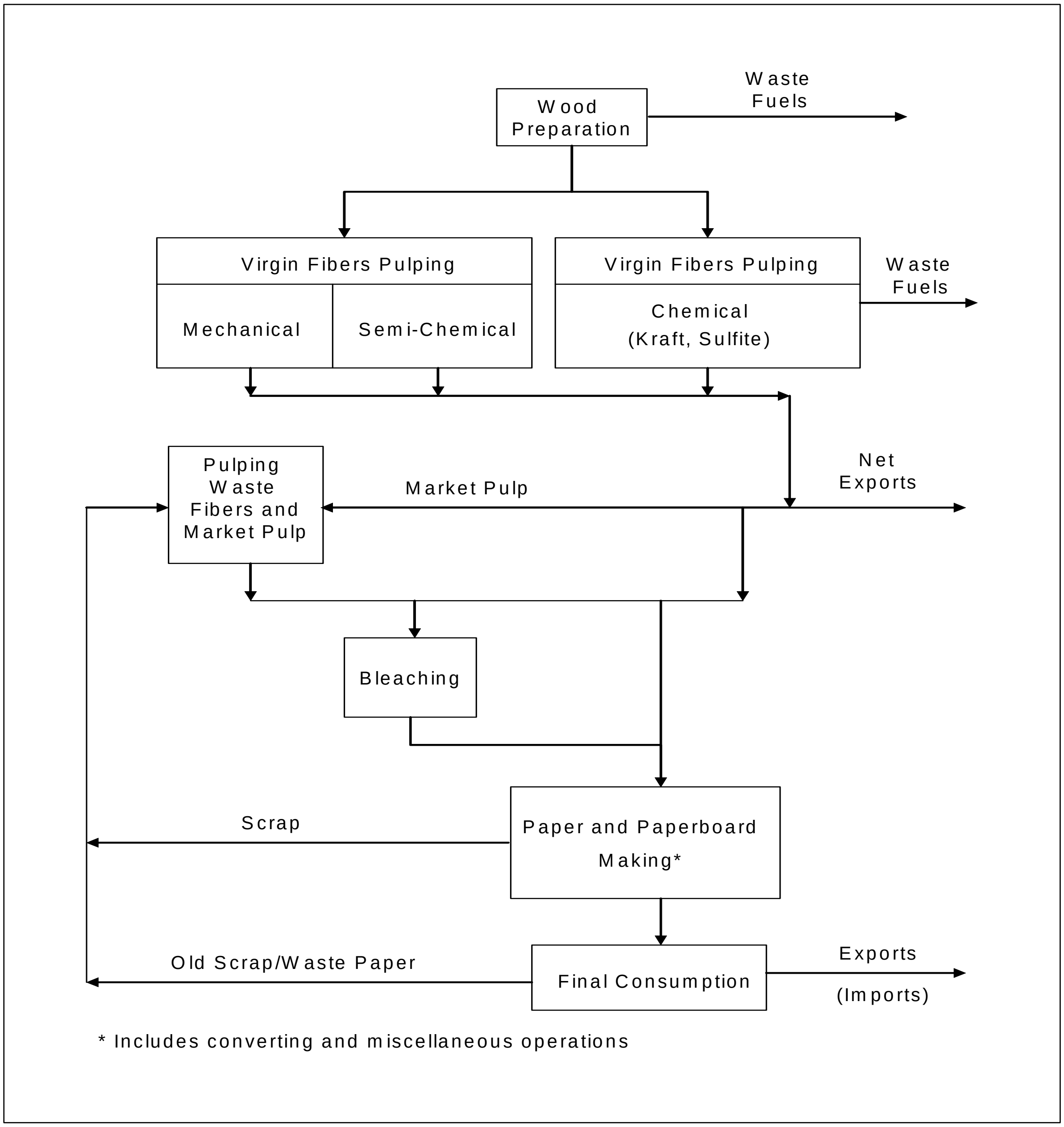


Paper and Allied Products (NAICS 322)

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

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.

Figure 3. Paper Manufacturing Industry Process Flow



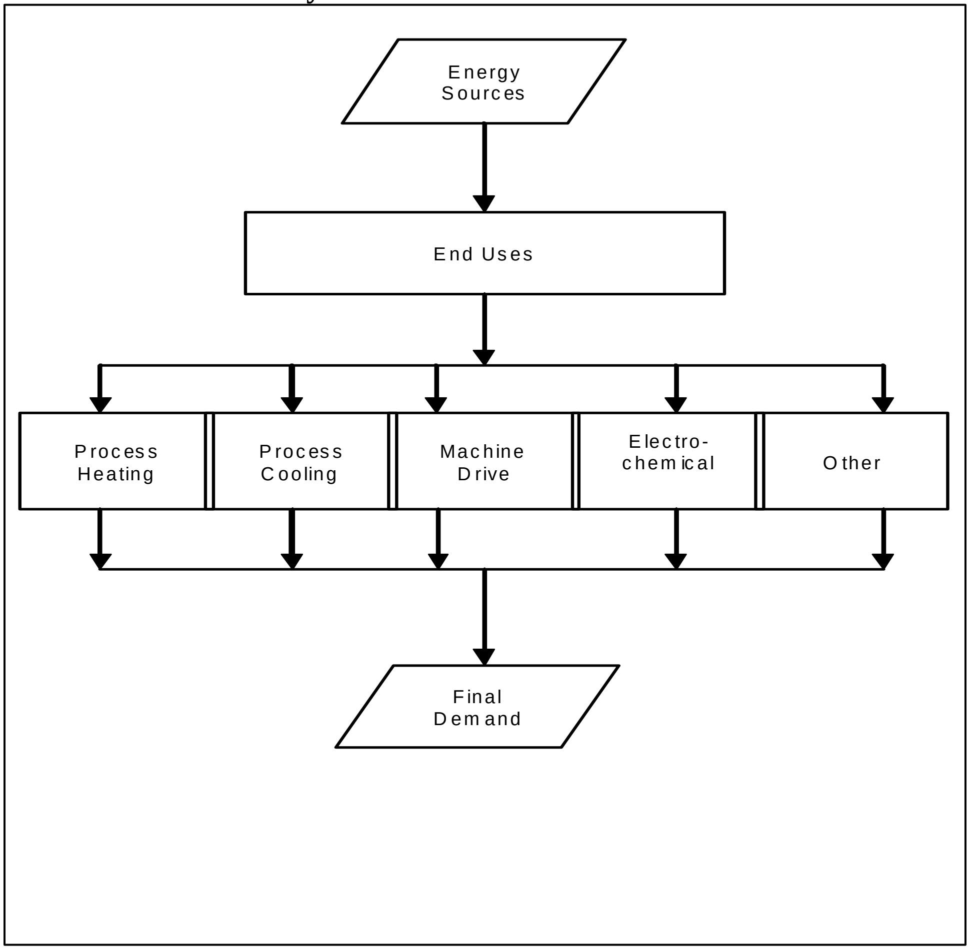
* Includes converting and miscellaneous operations

In 2002, 91 million tons of paper and paperboard products were produced. The major paper products include wood-free printing paper, groundwood printing paper, newsprint paper, tissue paper and packaging paper. The major paper board products include kraft paperboard, corrugating medium and recycled paperboard. Of the total pulp production, 49 percent was produced with the kraft chemical process, 3 percent from semi-chemical, 5 percent from mechanical (groundwood) and 43 percent from waste fibers. The unit energy use estimates for this industry are provided in Table B4. The largest component of this energy (including steam) use is in the paper and paper board making process step and kraft pulping step, accounting for 42 percent and 35 percent, respectively. Use of recycled paper as the feedstock for the waste fiber pulping step is taken into account. The regional distribution for each technology is shown in Table B12. Future additions to pulping capacity are assume to reflect a slight relative increase in waste pulping via increased use of market pulp. This assumption reflects recent trends in additional imports of market pulp.

Bulk Chemical Industry (parts of NAICS 325)

The bulk chemical sector is very complex. Industrial inorganics and industrial organics are the basic chemicals, while plastics, agricultural chemicals, and other chemicals are either intermediates or final products. The bulk chemical industry is estimated to consume 24 percent (6.0 quadrillion Btu) of the total energy consumed in the manufacturing sector, while accounting for less than 5 percent ($196 billion) of manufacturing value of shipments.[8] This industry is a major energy feedstock user and a major cogenerator of electricity.

Figure 4. Bulk Chemical Industry End Uses



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[8] This MECS2002 value does not include 1.2 quadrillion Btu of petrochemical feedstocks which are not assigned directly to the chemical industry.

The complexity of the bulk chemical industry, with its wide variety of products and use of energy as both a fuel and feedstock, has led to an end-use modeling approach. A motor stock model, which is described later in this document, calculates electricity consumption for the machine drive end-use. The end-uses for the industry are shown in Figure 4.

The process and assembly component of the four subsectors of the bulk chemical industry are modeled separately. Table 3 displays the subsector names, NAICS code, and projected value of shipments growth rate in *AEO2006*. While the growth rate for total bulk chemicals is 0.5 percent, the growth rates of the subsectors vary greatly, from a decline of 0.5 percent to a 0.9 percent increase.

Table 3. Bulk Chemical Industry Subsectors and Value of Shipments

Subsector	NAICS	Growth Rate (2004-2030)
Inorganic chemicals	32512 to 32518	-0.5%
Organic chemicals	32511, 32519	0.6%
Resins/Synthetics	3252	0.9%
Agricultural Chemicals	3253	0.1%
Bulk Chemicals	All Above	0.5%

There are very noticeable differences among the subsectors (Table B5). For example, the agricultural chemicals subsector has a very high UEC for natural gas feedstocks, while the other subsectors do not. Within the industrial model, disaggregation of the bulk chemical industry is done by changing the number of end uses from 5 to 20 (i.e., 5 end uses by 4 subsectors).

Glass and Glass Products Industry (NAICS 3272)

The energy use profile has been developed for the total glass and glass products industry, NAICS 3272. This definition includes glass products made from purchased glass. The glass making process contains four process steps: batch preparation, melting/refining, forming and post-forming. Figure 5 provides an overview of the process steps involved in the glass and glass products industry. While scrap (cullet) and virgin materials are shown separately, this is done to separate energy requirements for scrap versus virgin material melting. In reality, glass makers generally mix cullet with the virgin material. In 2002, the glass and glass product industry produced approximately 17 million tons of glass products.

The glass and glass products industry consumed approximately 201 trillion Btu of energy in 2002.[9] This accounts for about 20 percent of the total energy consumed in the stone, clay and glass industry. The fuel consumed is predominantly for direct fuel use; because there is very little steam demand. This direct fuel is used mainly in furnaces for melting. Table B6 shows the unit energy consumption values for each process step.

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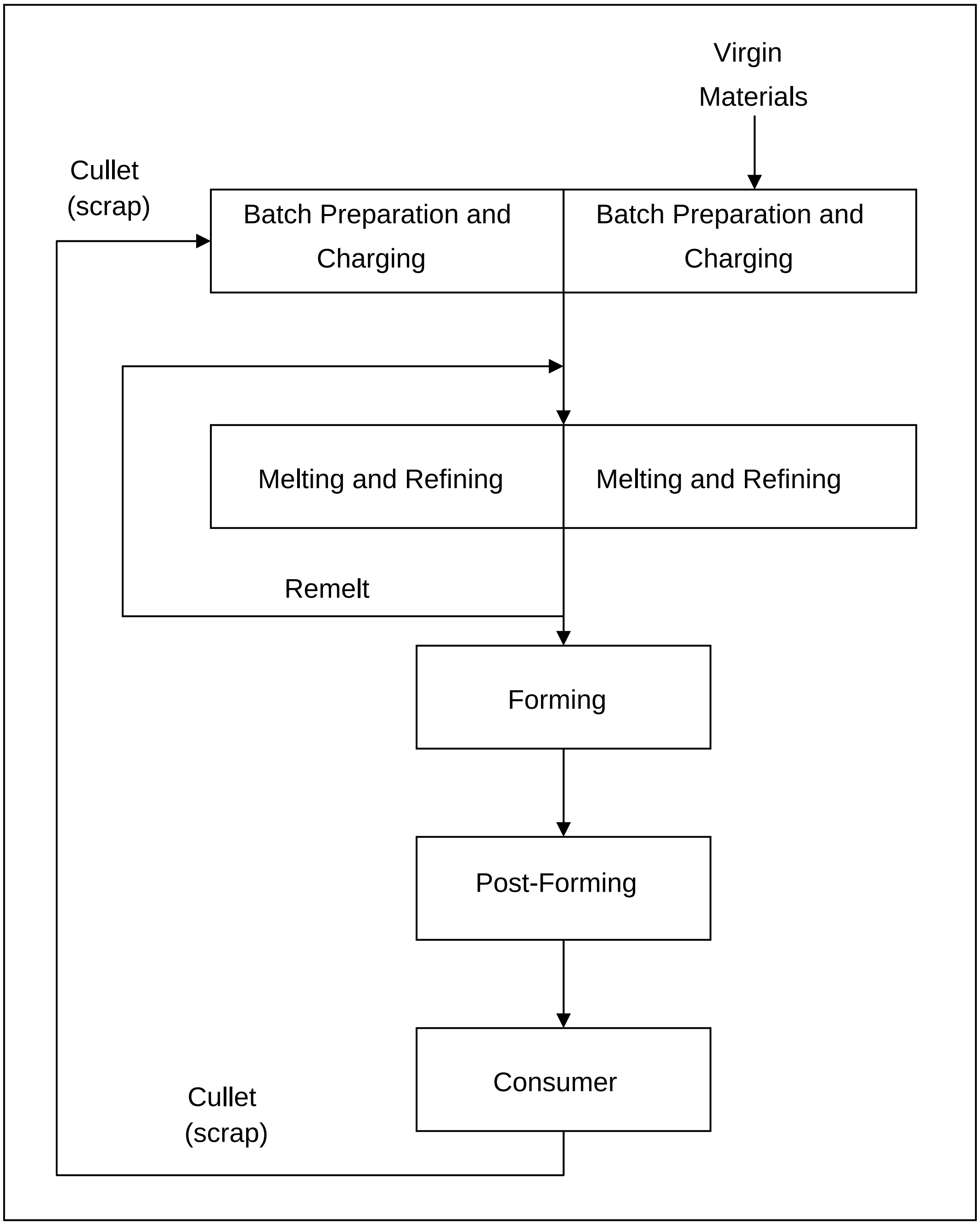
[9] Energy Information Administration (EIA), *2002 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.htm, March 2005. Note that the industrial model's energy consumption projection for 2002 may vary slightly from the MECS2002 values due to the inclusion of data from the electricity data forms and model discrepancy.

Figure 5. Glass Industry Process Flows

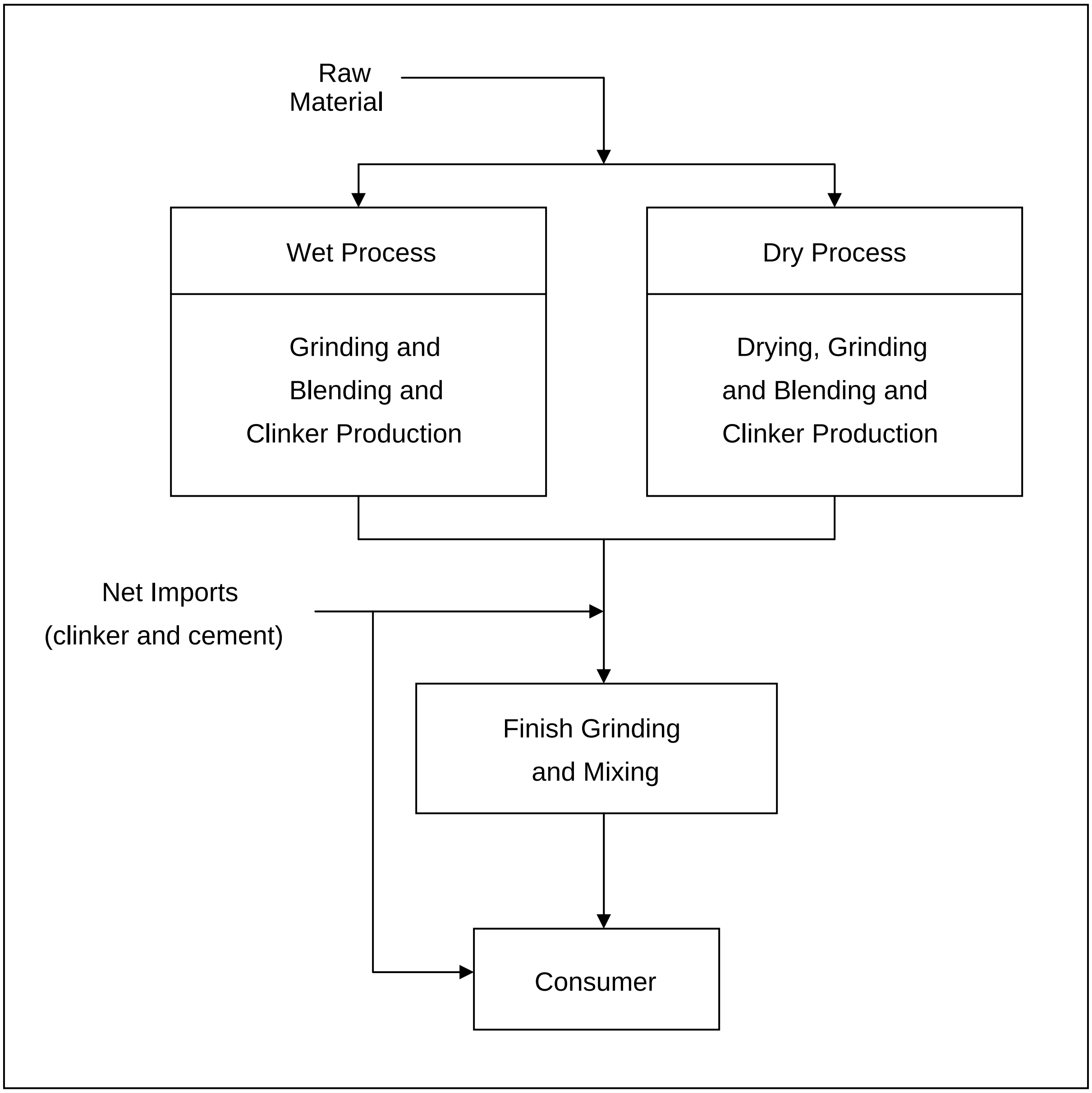


Cement Industry (NAICS 32731)

The cement industry uses raw materials from quarrying and mining operations that are sent through crushing and grinding mills and then converted to clinker in the clinker producing step. This clinker is then ground to produce cement. The industry produces cement by two major processes: the long-wet process and the dry process. The wet process accounted for 25 percent of production, while the dry process accounted for about 75 percent in 2002. 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 cement industry.

The cement industry produced 99 million tons of cement in 2002. 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.

Figure 6. Cement Industry Process Flow



The cement industry exhibits one of the highest unit energy consumption values (MMBtu/dollar value of shipments) in the U.S. industrial sector. The industry consumed approximately 411 trillion Btu of energy in 2002.[10] Direct fuel, used in clinker-producing kilns, accounted for 88 percent of the total PA energy consumption.

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[10] Energy Information Administration (EIA), *2002 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.htm, March 2005. Note that the industrial model's

Even with older plants and longer kilns, the wet process shows somewhat smaller electric energy consumption largely because of the use of energy efficient wet raw material grinding and lack of preheaters/precalciners found in dry plants. However total energy use is greater in wet plants due to less efficient use of sensible energy in the kiln off-gases

The UEC values for each process in the cement industry are shown in Table B7. As noted previously, it is assumed that all new cement capacity will be based on the dry process. The regional distribution of cement production processes is presented in Table B12.

Iron and Steel Industry (NAICS 331111)

The iron and steel industry includes the following six major process steps:

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

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

For the Industrial Model, a process flow was developed to classify the above six process steps into the five process steps around which unit energy consumption values were estimated. Figure 7 shows the process flow diagram used for the analysis. The agglomeration step was not considered because it is part of mining. Iron ore and coal are the basic raw materials that 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 2002, the U.S. steel industry produced 101 million tons of raw steel utilizing BF, BOF and EAF. Taking process yields into account, the total shipments were approximately 100 million tons. EAF accounted for 50 percent of the raw steel production. Continuous casting was the predominant casting process whereas ingot casting is declining.

Table B8 summarizes UEC estimates by process step and energy type for the steel industry. The largest category for energy use is coal, followed by liquid and gas fuels. Coke ovens and blast furnaces also produce a significant amount of byproduct fuels, which are used throughout the steel plant. The regional distribution of steel-making technologies is presented in Table B12.

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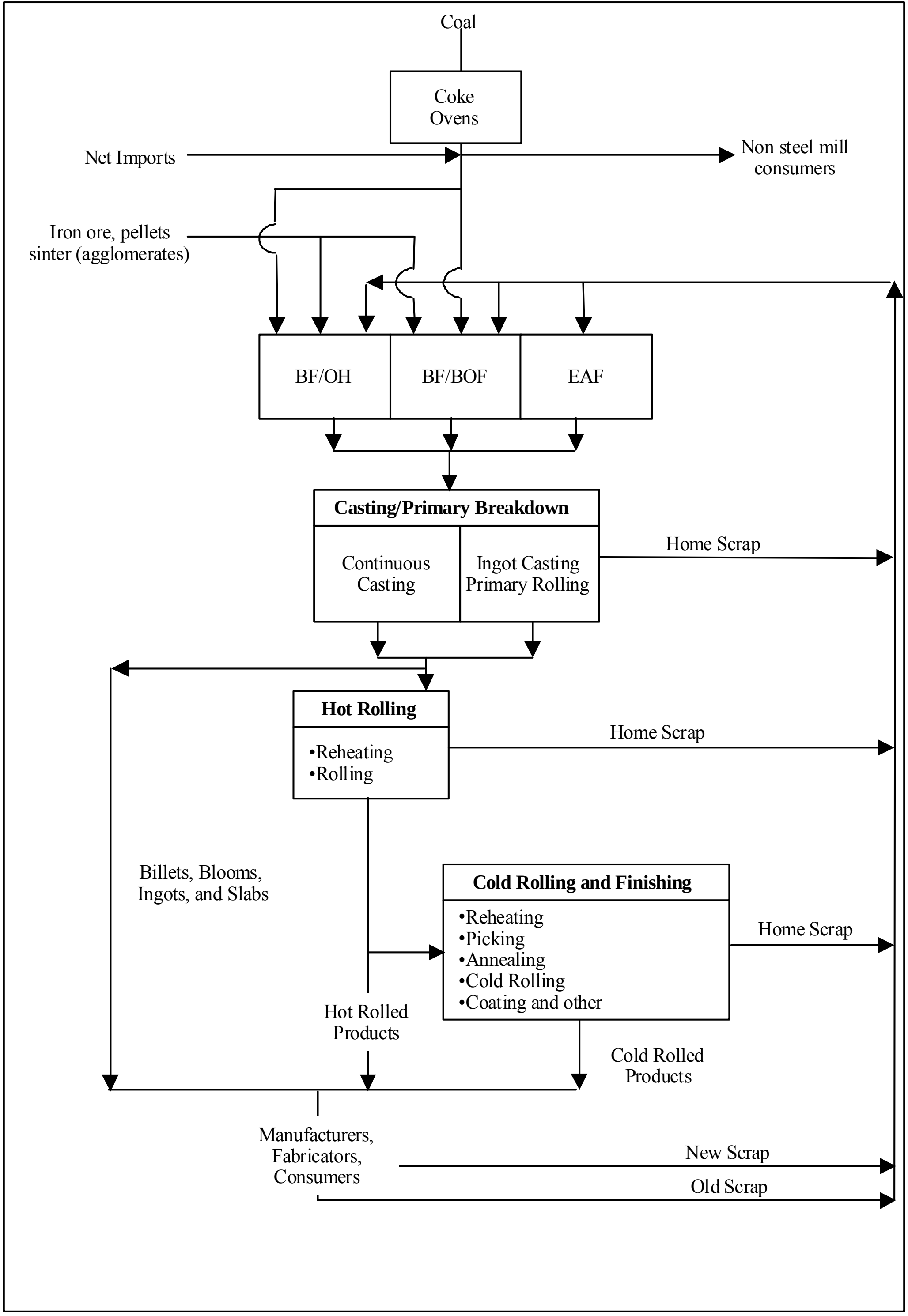
energy consumption projection for 2002 may vary slightly from the MECS2002 values due to the inclusion of data from the electricity data forms and model discrepancy.

Figure 7. Steel Industry Process Flows



Aluminum Industry (NAICS 3313)

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

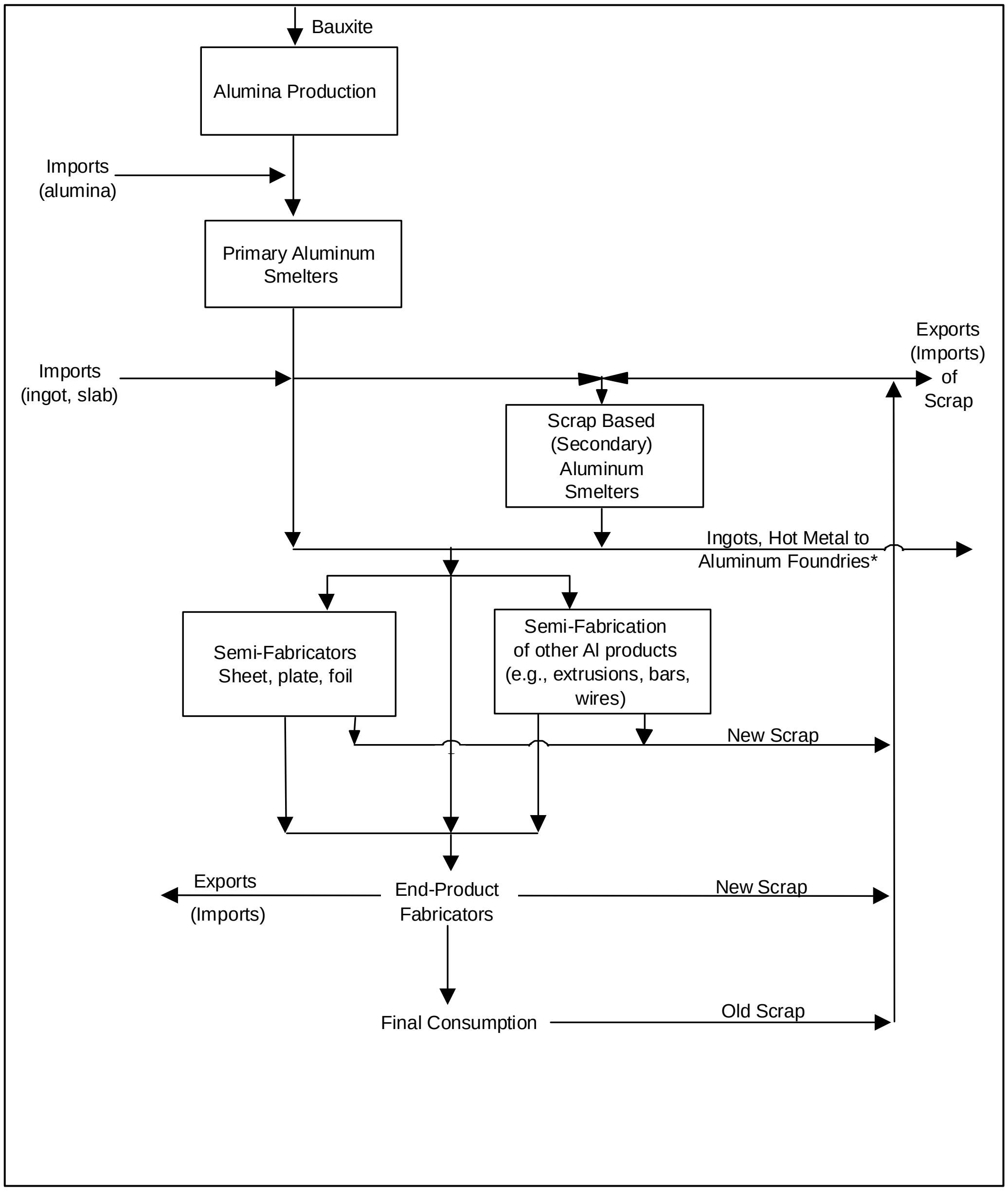
Alumina Refining (NAICS 331311)
Primary Aluminum Production (NAICS 331312)
Secondary Smelting and Alloying of Aluminum (NAICS 331314)
Aluminum Sheet, Plate, Foil Manufacturing (NAICS 331315)
Other Aluminum Semi-fabrication found in NAICS 3316 and
Semi-fabrication of flat products found in NAICS 331319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

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

The primary sector produced approximately 3.0 million tons of aluminum in 2002. The secondary (scrap-based) sector recovered 3.1 million tons, exceeding primary production for the first time. Domestic aluminum production plus aluminum semi-finished imports resulted in about 7.2 million tons of mill products like sheet, plate, and foil, cable, and wire.

The UEC estimates developed for the process steps are presented in Table B9. The principal form of energy used is electricity. The regional distribution of smelters in the aluminum Industry is presented in Table B12.

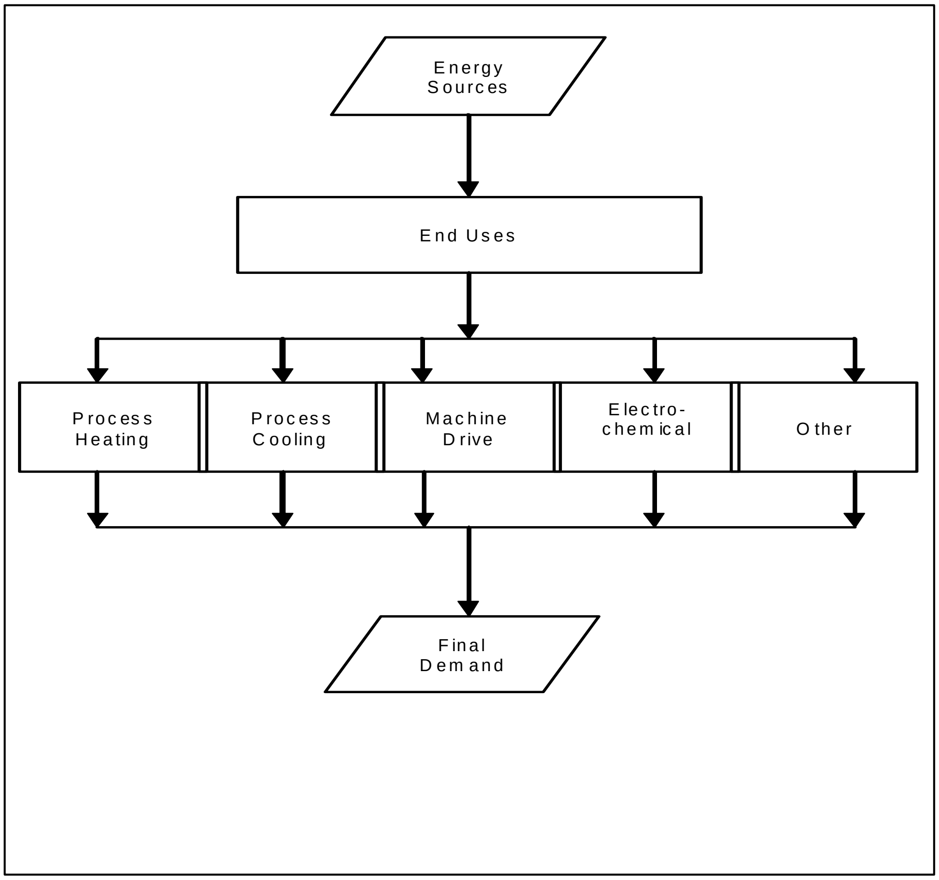
Figure 8. Aluminum Industry Process Flow



Metal-Based Durables Industry (NAICS 332-336)

This industry group consists of industries engaged in the manufacture of fabricated metals, industrial machinery and equipment, electronic and other electric equipment, transportation equipment, and instruments. Typical processes found in this group include remelting operations followed by casting or molding, shaping, heat treating processes, coating, and joining and assembly. Given this diversity of processes, the industry group's energy is characterized by the generic end uses in MECS 2002. These end uses are shown in Figure 9.

Figure 9. Metal-Based Durables Industry End Uses



In 2002, the metal-based durables industry consumed 1.4 quadrillion Btu of energy.[11] A motor stock model, which is described later in this document, calculates electricity consumption for the machine drive end-use. Unit energy consumption values for the other end uses in the PA component for the metal-based durables industry are given in Table B10.

Balance of Manufacturing Industry (all other manufacturing NAICS)

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

In 2002, the balance of manufacturing industry consumed 2.8 quadrillion Btu of energy.[12] A motor stock model, which is described later in this document, calculates electricity consumption for the machine drive

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[11] Energy Information Administration (EIA), *2002 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.htm, March 2005. Note that the industrial model's energy consumption projection for 2002 may vary slightly from the MECS2002 values due to the inclusion of data from the electricity data forms and model discrepancy.

[12] Energy Information Administration (EIA), *2002 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.htm, March 2005. Note that the industrial model's energy consumption projection for 2002 may vary slightly from the MECS2002 values due to the inclusion of data from the electricity data forms and model discrepancy.

end-use. Unit energy consumption parameters for the other end uses in the PA component of the balance of manufacturing industry group are given in Table B10.

Non-Manufacturing Industries

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

Energy consumption data for the two agriculture sectors (crops and other agriculture) are largely based on information contained in the Farm Production Expenditures Summary conducted by the U.S. Department of Agriculture.[13] Expenditures for four energy sources were collected for crop farms and livestock farms. These data were converted from dollar expenditures to energy quantities using prices from the Department of Agriculture and the EIA.

The mining industry is divided into three sectors in the Industrial Demand Model – coal mining, oil and gas, and other mining. The quantities of seven energy types consumed by 29 mining sectors were collected as part of the 2002 Economic Census of Mining by the U.S. Census Bureau.[14] The data for the 29 sectors were aggregated into the three sectors included in the Industrial Demand Model and the physical quantities were converted to Btu for use in NEMS.

There is only one construction sector included in the Industrial Demand Model. Detailed statistics for the 31 construction subsectors included in the 2002 Economic Census were aggregated. Expenditure amounts for five energy sources were collected by the U.S. Census Bureau.[15] These expenditures were converted from dollars to energy quantities using EIA prices.

These three sources are considered to be the most complete and consistent data available for each of the three non-manufacturing sectors. These data, supplemented by available EIA data, are used to derive total energy consumption for the non-manufacturing industrial sectors. The additional EIA data sources include the *State Energy Data System 2001*,[16] the *2002 Manufacturing Energy Consumption Survey*,[17] and *Fuel Oil and Kerosene Sales 2002*.[18] The source data relate to total energy consumption and provide no information on the processes or end-uses for which the energy is consumed. Therefore, the UECs for the non-manufacturing sectors relate energy consumption for each fuel type to value of shipments. These UECs are presented in Table B11 for non-manufacturing.

Technology Possibility Curves, Unit Energy Consumption, and Relative Energy Intensities

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

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[13] U.S. Department of Agriculture, National Agricultural Statistical Service, *Farm Production Expenditures 2003 Summary*, July 2004 http://usda.mannlib.cornell.edu/reports/nassr/price/zpe-bb/fpex0704.pdf.

[14] U.S. Department of Commerce, Census Bureau, *Economic Census 2002: Mining Industry Series*, various dates during 2004 and 2005, http://www.census.gov/econ/census02/guide.

[15] U.S. Department of Commerce, Census Bureau, *Economic Census 2002: Construction Industry Series*, various dates during 2004 and 2005 http://www.census.gov/econ/census02/guide/INDRPT23.HTM.

[16] Energy Information Administration, *State Energy Data System 2001* (Washington, DC, August 2004).

[17] Energy Information Administration (EIA), *2002 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.html, March 2005.

[18] Energy Information Administration, *Fuel Oil and Kerosene Sales 2002*, DOE/EIA-0535(02) (Washington, DC, November 2003).

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 2002 to develop an index of relative energy intensity (REI). Relative energy intensity is defined as the ratio of energy use in a new or advanced process compared to 2002 average energy use (Table B13).

The improvement for new plants assumes the plant has been built with the SOA technologies available for that process. A second and often more important set of substantial improvements is often realized when advanced technologies become available for a certain process. Often one sees a number of 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 2002 energy usage.

Additionally, even SOA technologies and advanced technologies can at times be expected to show improvements once developed as the process is improved, optimal residence times and temperatures are found, and better energy recovery techniques are installed. Depending on the process, these are factored into the projections as slow improvements ranging from zero to about 0.5 percent/year. Old plants are assumed to be able to economically justify some retrofits and for other reasons listed above, to show slow improvements over time in their unit energy use. Based on engineering judgment, it is assumed that by 2030, old processes (2002 stock) still operating can achieve up to 50 percent of the energy savings of SOA technology due to retrofits and other reasons listed above. Thus, if SOA technology has an REI of 0.80, old processes in the year 2030 will have an REI of 0.90. As a convenience for modeling purposes, the rate of change between the initial point and final point is defined as the technology possibility curve (TPC) and used to interpolate for the intervening points. The TPCs for the reference case are given in Table B13. For scenario analysis, a set of TPCs that reflect more rapid technology changes are also given in Appendix B. The TPCs for the high technology case are given in Table B14. The list of SOA and advanced technologies considered in the analysis is presented in Table B15.

Advanced technologies are ones that are still under development and will be available at some time in the future. It is uncertain which specific technologies will be implemented, but it can be assumed with reasonable certainty that at least one of these technologies or a similar technology will be successful. It is also recognized that in some instances thermodynamic limits are being approached, which will prevent further significant improvements in energy savings.

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

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

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 fuel price is higher than it was in 2002. Otherwise, the default value for the intensity decline rate is used, $BCSC_{v,fuel,step}$.

$$X = TPCPrat^{TPCBeta}$$

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

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

where:

TPCPrat = Ratio of current year average industrial energy price to 2002 price;
TPCBeta = Parameter of logistic function, currently specified as 4;
TPCPriceFactor = TPC price factor, ranging from 0 (no price effect) to 2 for ENPINT
$TPCRate_v$ = Intensity decline rate after accounting for changes due to energy price increase*s* for vintage *v*; and
$BCSC_{v,fuel,step}$ = Default intensity rate for old and new vintage *v* for each fuel *f* and step s.

Motor Model

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

The data for the basic motor stock model were derived from *United States Industrial Electric Motor Systems Market Opportunities Assessment*,[19] a report produced for the U.S. Department of Energy's Office of Industrial Technologies (Table B16).

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

1. For each failed motor, evaluate whether the motor is repaired or replaced. The cost and performance characteristics for the motor options are from the MotorMaster+ version 4.0 software (Table B17).

    a. Determine the cost differential for replacing the motor. This is the difference between the cost of the new motor meeting the EPACT92 minimum efficiency standards and the cost of repairing the motor.

    b. Determine the annual electricity expenditure savings from replacing the motor. This calculation requires the rated motor horsepower, the average motor part-load, the conversion factor from horsepower to kilowatts, the annual operating hours for the motor, the industrial electricity price, the efficiency rating for an EPACT92 minimum efficiency motor, and the efficiency rating for a repaired motor. For purposes of the analysis, the electricity price is assumed to remain constant at the level in the year the choice is made.

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

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

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

   a. Given the payback for each motor size group in each industry, estimate the fraction of replacement motors purchased. This analysis begins with an assumed distribution of required investment payback periods, deemed the payback acceptance curve. Rather than an actual curve, a lookup table is used (Table B18). In the table, for each integer payback period from 0 to 4 years, a fraction of new motors is specified. This quantifies the notion that the shorter the payback, the greater the fraction of firms that would choose the higher efficiency option, in this case replacing a failed motor.

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

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

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

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

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

4. For each of the new motors purchased up to 500 horsepower, evaluate whether EPACT92 minimum efficiency motors or premium motors are chosen. The cost and performance characteristics for the motor options are also from the MotorMaster+ version 4.0 software (Table B17).

   a. Determine the cost differential for the premium motor option. This is the difference between the cost of the premium motor and the cost of the EPACT92 minimum efficiency motor.

   b. Determine the annual electricity expenditure savings from the premium motor. This calculation requires the rated motor horsepower, the average motor part-load, the conversion factor from horsepower to kilowatts, the annual operating hours for the motor, the industrial electricity price, the efficiency rating for an EPACT92 minimum efficiency motor, and the efficiency rating for a premium efficiency motor. For purposes of the analysis, the electricity price is assumed to remain constant at the level in the year the choice is made.

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

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

   a. Given the payback for each motor size group in each industry, estimate the fraction of premium efficiency new motors purchased. This analysis begins with an assumed distribution of required investment payback periods, deemed the payback acceptance curve. Rather than an actual curve, a lookup table is used (Table B18). In the table, for each integer payback period from 0 to 4 years, a fraction of premium motors is specified. This quantifies the notion that the shorter the payback, the greater the fraction of firms that would purchase the higher efficiency motor.

   b. Determine the number of EPACT92 minimum efficiency motors purchased. This is the difference between the total number of motors purchased and the number of premium efficiency motors purchased.

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

   a. Determine the average electricity consumption for the motor stock as a weighted average of the electricity consumption for new premium efficiency motors, new EPACT92 minimum efficiency motors, rewound motors, and surviving motors.

   b. Determine the average efficiency for the motor stock as a weighted average of the efficiency for new premium efficiency motors, new EPACT92 minimum efficiency motors, rewound motors, and surviving motors.

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

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

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

Boiler, Steam, Cogeneration Component

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

The boiler component is estimated to consume 29 percent of manufacturing heat and power energy consumption, excluding byproduct fuels.[20] Within the BSC component, natural gas accounts for 69 percent and coal 25 percent of consumption.

The steam demand and byproducts from the PA and BLD components are passed to the BSC component, which allocates the steam demand to conventional boilers and to cogeneration. The allocation is based upon an estimate of useful thermal energy supplied by cogeneration plants. Energy for cogeneration is subtracted from total indirect fuel use as reported in MECS (given in Table B19) to obtain conventional boiler fuel use and the associated steam. Assumed average boiler efficiency and a fuel sharing equation are used to estimate the required energy consumption to meet the steam from conventional boilers.

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[20] Computed from Energy Information Administration (EIA), *2002 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.html, March 2005, Table 5.8. Note that byproduct and non-energy use of combustible fuels are excluded from the computation.

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

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

where the fuels are coal, petroleum, and natural gas. The P_i are the fuel prices; α_i are sensitivity parameters; and the β_i are calibrated to reproduce the 2002 fuel shares using the relative prices that prevailed in 2002. 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 2002 MECS and exclude waste and byproducts.

The α_i sensitivity parameters are posited to be a positive function of average energy prices of industrial boiler fuels (coal, residual fuel, and natural gas). For years after 2002, the ratio of the current year's average boiler fuel price to the corresponding average price in 2002 is computed, SwitchPrat. If SwitchPrat is greater than 1.0, the following relationships hold:

$$\begin{aligned} X &= SwitchPrat^{SwitchBeta} \\ SwitchPriceFactor &= 4 * \frac{X}{(1+X)} \\ \alpha_{iPrice} &= SwitchPriceFactor * \alpha^{i} \end{aligned} \tag{5}$$

where:

$SwitchPrat$ = Ratio of current year average industrial energy price to 2002 price;
$SwitchBeta$ = Parameter of logistic function, currently specified as 4;
$SwitchPriceFactor$ = Fuel switching price factor, ranging from 0 (no price effect) to 4 for boiler shares;
α_{iPrice} = Fuel switching sensitivity parameters after accounting for energy price increases; and
α_i = Default fuel switching sensitivity parameters.

Cogeneration capacity, generation, fuel use, and thermal output are determined from exogenous data and simulated new additions as determined from an engineering and economic evaluation. Existing cogeneration capacity and planned additions are derived from EIA's Form 860B (and predecessor) survey. The most recent data used is for 2004, with planned additions (units under construction) through 2006.[21]

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[21] EIA has comprehensively reviewed and revised how it collects, estimates, and reports fuel use for facilities producing electricity. For a detailed discussion, see Energy Information Administration, *Annual Energy Review 2001*, DOE/EIA-0384 (2001), November 2002, Appendix H, "Estimating and Presenting Power Sector Fuel Use in EIA Publications and Analyses," web site www.eia.doe.gov/emeu/ site http://tonto.eia.doe.gov/FTPROOT/multifuel/038401.pdf.

The data is processed outside the model to separate industrial cogeneration from commercial sector cogeneration, cogeneration from refineries and enhanced oil recovery operations, and offsite cogeneration. Offsite cogenerators are primarily merchant power plants selling to the grid and often supplying relatively small amounts of thermal energy. The remainder, or onsite industrial cogeneration portion, was approximately 60 percent of the total cogeneration capacity in 2002. The cogeneration data is available on a plant basis and identifies the capacity, generation, useful thermal energy, energy use by fuel, and the shares of that energy for electricity and thermal. The data is aggregated by Census region, industry, and fuel type for input to the model.

The modeling of unplanned cogeneration begins with model year 2004, under the assumption that planned units under construction cover only some of the additions expected through 2006. In addition, it is assumed that any existing cogeneration capacity will remain in service throughout the projection, 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. Biomass cogeneration is assumed to be added as increments of biomass waste products are produced, primarily in the pulp and paper industry. The amount of biomass cogeneration added is equal to the quantity of new biomass available (in Btu), divided by the total heat rate assumed from biomass steam turbine cogeneration.

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

The steps to the approach are outlined as follows:

1. 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 six size ranges, or load segments, based on an exogenous data set providing the boiler size distribution for each industry and assuming that steam loads are distributed in the same proportions as boiler capacity (Table B20). 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).

2. Evaluate a gas turbine system prototype for each size range

   a. A candidate cogeneration system is established for each load segment with thermal output that matches the steam output of the average-sized boiler in each load segment. To do this, the user-supplied characteristics for eight cogeneration systems are used (Table B21):

      i. Net electric generation capacity in kilowatts

      ii. Total installed cost, in 2003 dollars per kilowatt hour-electric

    iii. System capacity factor

    iv. Total fuel use per kilowatt hour

    v. Fraction of input energy converted to useful heat and power

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

    i. Fraction of input energy converted to electric energy, or electric energy efficiency

    ii. Electric generation from the cogeneration plant in megawatt hours

    iii. Cogeneration system fuel use per year in billion Btu

    iv. Power-Steam Ratio

    v. Steam output of the cogeneration system

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

3. Assess Market Penetration Based on Payback and Payback Acceptance Curve

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

    b. Given the payback for the prototype system evaluated, estimate the fraction of total technical potential that is considered economical. To do this, we start with an assumption about the distribution of required investment payback periods deemed the payback acceptance curve. Rather than using an actual curve, we use a table of assumptions that, when plotted, is referred to as a payback acceptance curve (Table B22). In the table, for each integer payback period from 0 to 12 years, we assume that some fraction of cogeneration investments would be considered acceptable. This quantifies the notion that the shorter the payback, the greater the fraction of firms that would be willing to invest. It can also capture the effect that market barriers have in discouraging cogeneration investment.

    c. Given the total economic potential for cogeneration, estimate the amount of capacity that would be added in the current model year. The annual capacity additions can be estimated based on some pattern on market penetration over time. For simplicity, it is assumed that the economic potential would penetrate over a 20-year time period. Thus, 5 percent of the economic potential is 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 25-year projection 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 projection 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 vintage information are very sketchy.) The industrial model capital stock is grouped into three vintages: old, middle, and new. The old vintage consists of capital in production in 2002 and is assumed to retire at a fixed rate each year. Middle vintage capital is that which is added from 2002 through the Year-1, where Year is the current projection year. New capital is added in the projection years when existing production is less than the output projected by the NEMS Regional Macroeconomic Model. Capital additions during the projection horizon are retired in subsequent years at the same rate as the pre-2003 capital stock. The retirement rates used in the Industrial Model for the various industries are listed in Table B13.

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 2002, the ratio of the current year's average industrial energy price to the average price in 2002 is computed as RetirePrat.

If RetirePrat is greater than 1.0, the following relationships hold:

$$\begin{aligned} &X = RetirePrat^{RetireBeta} \\ &RetirePriceFactor = 4 * \frac{X}{(1+X)} \\ &RetireRate_s = RetirePriceFactor * ProdRetr_s \end{aligned} \tag{6}$$

where:

$RetirePrat$ = Ratio of current year average industrial energy price to 2002 price;
$RetireBeta$ = Parameter of logistic function, currently specified as 2 for capital stock retirement;
$RetirePriceFactor$ = TPC price factor, ranging from 0 (no price effect) to 2;
$RetireRate_s$ = Retirement rate after accounting for energy price increases for step s; and
$ProdRetr_s$ = Default retirement rate for step s.

Renewable Fuels

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

Recycling

With projected higher landfill costs, regulatory emphasis on recycling, and potential cost savings, recycling of post-consumer scrap is likely to grow. Projecting such growth, however, is highly dependent on assessing how regulations will be developed, the growth of the economy, and quality related issues dealing with recycled materials.

Legislative Requirements

The Energy Policy Act of 1992 (EPACT92) and the Clean Air Act Amendments of 1990 (CAAA90) contain several implications for the industrial model. These implications fall into three categories: coke oven standards; efficiency standards for boilers, furnaces, and electric motors; and industrial process technologies. The industrial model assumes the leakage standards for coke oven doors do not reduce the efficiency of producing coke, or increase unit energy consumption. The industrial model uses heat rates of 1.25 (80 percent efficiency) and 1.22 (82 percent efficiency) for gas and oil burners respectively. These efficiencies meet the EPACT92 standards. The EPACT92 electric motor standards set minimum efficiency levels for all motors up to 200 horsepower purchased after 2002. All of the motors available in the motor model are at least as efficient as the EPACT92 standards. The industrial model incorporates the necessary reductions in unit energy consumption for the energy-intensive industries.

Section 108 of the Energy Policy Act of 2005 (EPACT2005) requires that Federally funded projects involving cement or concrete increase the amount of recovered mineral component (e.g., fly ash or blast furnace slag) used in the cement. Such use of mineral components is a standard industry practice, and increasing the amount could reduce both the quantity of energy used for cement clinker production and the level of process-related CO_2 emissions. Because the proportion of mineral component is not specified in the legislation, this provision is not included in the *AEO2006*. When regulations are promulgated, their estimated impact could be modeled in NEMS.

Section 1321 of EPACT2005 extends the Section 29 PTC for nonconventional fuel to facilities producing coke or coke gas. The credit is available for plants placed in service before 1993 and between 1998 and 2010. Each plant can claim the credit for 4 years; however, the total credit is limited to an annual average of 4000 barrels of oil equivalent (BOE) per day. The value of the credit is currently $3.00 per BOE, and will be adjusted for inflation in the future. Because the bulk of the credits will go to plants already operating or under construction, there is likely to be little impact on coke plant capacity.

Cogeneration

The cogeneration assessment requires three basic sets of assumptions: 1) cost and performance characteristics of prototypical plants in various size ranges; 2) data to disaggregate steam loads by industry into several size ranges, or load segments; and 3) market penetration assumptions to quantify the relationship between the economics of cogeneration and its adoption over time. These assumptions are introduced into the model through a spreadsheet file. The cogeneration assumptions used for the *AEO2006* are presented in Table B18, Table B20, and Table B22.

Benchmarking

The Industrial Model energy demand projections are benchmarked to values presented in *Annual Energy Review 2004*. The national-level values reported in *Annual Energy Review 2004* were allocated to the Census Divisions using the *State Energy Data Report 2001*. The benchmark factors are based on the ratio of the SEDS value of consumption for each fuel to the consumption calculated by the model at the Census division level. EIA has comprehensively reviewed and revised how it collects, estimates, and reports fuel use for facilities producing electricity.[22] The specific impacts on reported industrial energy consumption are discussed in Energy Information Administration, *Annual Energy Outlook 2003*, pp. 32-34.[23] Additional calibration for the years 2002-2005 are performed to conform with the *Short-Term Energy Outlook*.

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[22] For a detailed discussion, see Energy Information Administration, *Annual Energy Review 2001*, DOE/EIA-0384 (2001), November 2002, Appendix H, "Estimating and Presenting Power Sector Fuel Use in EIA Publications and Analyses," web site site http://tonto.eia.doe.gov/FTPROOT/multifuel/038401.pdf.

[23] Energy Information Administration, *Annual Energy Outlook 2003*, DOE/EIA-0383(2003) (January 2003), web site http://www.eia.doe.gov/oiaf/archive/aeo03/pdf/0383(2003).pdf.

4. Model Structure

Outline of Model

Table 4 presents the solution outline for the NEMS Industrial Demand Model. The following section provides an overview of the solution outline for the model.

Table 4. Outline of the Model

First Year: Initialize Data

A.RCNTL: Read Control Options
B.IRCOGEN: Read cogeneration data files (called from IND)
C.MecsLess860B: Calculate 2002 boiler fuel by subtracting Form 906 cogeneration fuel from 2002 MECS indirect fuels.
D.REXOG: Assign exogenous macroeconomic and energy price variables that come from NEMS.
E.IEDATA: Read ENPROD file with industry production parameters, base year industrial output, UECs, elasticities and other coefficients; Much of the data originally read from ENPROD is now read from two files, ITECH.txt and Prodflow.txt via subroutines UECTPC and MECS2002, respectively.
F.MECS2002: Read PRODFLOW.TXT containing process/assemplty step definitions and flow rates from most recent MECS data (2002)
G.UECTPC: Read ITECH.txt file with MECS-based UEC rates and the TPC assumptions
H.IRSTEO:Read Short Term Energy Outlook File with last available history data and national projections for the next two years.

Industry Processing:

Loop through each of 15 industry groups, including 6 non-manufacturing, 7 energy intensive and 2 energy non-intensive -manufacturing industries. For each industry, loop through each of 4 census regions

I.RDBIN: Read memory management file with previous year's data for this industry, region
J.CALPROD:Compute revised productive capacity and throughput by process/assembly step and vintage; implement retirement and vintaging assumptions.
K.CALCSC:Conservation Supply Curve: Evaluate changes in UECs based on Technological Possibility
L.CALBYPROD:Calculate consumption of byproduct fuels
M.CALPATOT:Compute consumption of energy in the process assembly component
  1.MOTORS:Compute consumption of electricity for machine-drive for four end-use industries
  2.INDPALOG:Optionally, adjust fuel shares for process-assembly industries using a 2-stage logit equation. First year, read spreadsheet file (INDPALOG.WK1) with logit coefficients
a.CALPALOG: Evaluate logit shares for a given industry and a given set of fuels, given changes in energy prices since the base year.
N.CALBTOT:Compute consumption of energy in the buildings component
O.CALGEN:Compute electricity generation for sale and internal use by fuel. Calculates steam for cogeneration and estimates penetration of new builds. Calls the following routines:
  1.COGENTRead cogen assumptions spreadsheet (first year)
  2.SteamSegAssign fraction of steam load in current load segment for current industry
  3.COGINITInitialize the cogen data arrays with capacity, generation, and fuel use data
  4.EvalCogenEvaluate investment payback of a cogen system in a given year
P.CALBSC:Estimate boiler fuel shares as a function of changing boiler fuel prices.
Q.CALSTOT:Compute Energy consumption in the Boiler-Steam-Cogeneration (BSC) component
R.WRBIN:Write memory management file with data on this industry, region
S.INDTOTAL:Accumulate total energy consumption for the industry

II.National Sums:

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

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

A.SEDS Benchmarking:
  1.SEDS years (through 2001: calculate regional benchmark factors as the ratio of actual consumption to model consumption for each fuel in four Census regions.
  2.Post SEDS Years (2002-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 projection for each fuel.
  2.Post-STEO years: Optionally, over the period 2002 to 2005, multiply model consumption by the STEO benchmark factors.
Assign final results to NEMS variables

Subroutines and Equations

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

IND

IND is the main industrial subroutine called by NEMS. This subroutine calls some data initialization subroutines, including one to retrieve energy price and macroeconomic data (Setup_Mac_and_Price), and calls routines to solve the model (ISEAM) and to export its results to NEMS global variables (WEXOG).

Setup_Mac_and_Price

In subroutine "Setup_Mac_and_Price," the value of shipments data from the NEMS Macroeconomic (MACRO) model is processed. Employment is also obtained from the MACRO model for each non-agricultural industry. Prices for the various fuels as well as the previous year's consumption are obtained from NEMS COMMON blocks. The Industrial Model energy demand projections are benchmarked to values presented in *Annual Energy Review 2004* in subroutine WEXOG. The national-level values reported in *Annual Energy Review 2004* were allocated to the Census Divisions using the *State Energy Data Report 2001*. Because detailed data for the industrial model are available only for the four Census regions, the energy prices obtained from NEMS, available for each of the nine Census divisions, are combined using a weighted average of the fuel prices as shown in the following equation for the first model year. A similar weighted average is used for all other fuels and model years. However, the previous year's consumption is used rather than SEDS consumption.

$$PRCX_{elec,r} = \frac{\sum_{d=1}^{Num_r} DPRCX_{elec,r} * QSELIN_{d,2001}}{\sum_{d=1}^{Num_r} QSELIN_{d,2001}} \qquad (7)$$

where:

$PRCX_{elec,r}$ = Price for electricity in Census region *r*,

NUM_r = Number of Census divisions in Census region *r*,

$DPRCX_{elec,d}$ = Price of electricity in Census division *d,* and

$QSELIN_{d,2001}$ = SEDS consumption of electricity in Census division *d* in 2001.

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

ISEAM

ISEAM controls all of the industrial model calculations and initiates some of the model input operations. It opens external files for debugging, binary files for restarting on successive iterations and projection years, and opens the input data files. In the first model year and only on the first iteration, ISEAM calls RCNTRL to read runtime parameters file (INDRUN.TXT) and base year boiler data (ITLBSHR.TXT). ISEAM also reads a data file, INDBEU.TXT, containing building energy use for lighting, heating, ventilation, and air conditioning. ISEAM calls REXOG to read in exogenous inputs on each model run. For the first model year, ISEAM calls the following subroutines for each Census region within each industry: IEDATA, UECTPC, CALBYPROD, CALPATOT, CALBTOT, CALGEN, CALBSC, CALSTOT, and INDTOTAL. After the projection for the last Census region for a particular industry has been calculated, the following two subroutines are called to compute totals: NATTOTAL and CONTAB. After the first model year, ISEAM calls two subroutines, RDBIN to read the restart files, and MODCAL to carry out model calculations. After all model calculations have been completed, ISEAM calculates industry totals and saves information to the restart files in the subroutine WRBIN. Finally, after each industry has been processed, ISEAM calls the subroutines ADDUPCOGS and INDCGN to aggregate and report industrial cogeneration estimates to NEMS.

RCNTRL

RCNTRL reads data from the input files INDRUN.TXT and ITLBSHR.TXT. The INDRUN.TXT file contains internal control variables for the industrial model. Data in this file are based on user defined parameters consisting of indicator variables for subroutine tracing, debugging, writing summary tables, options to calculate model sensitivities, and benchmarking options. The ITLBSHR.TXT data contain estimated 2002 boiler energy use by fuel and is used for calculating boiler fuel shares.

REXOG

REXOG prepares exogenous data obtained from the NEMS MACRO model for use in the industrial model. Dollar value of shipments and employment are aggregated over the appropriate Census divisions to obtain data at the Census region level. The macroeconomic variables used by the industrial model are based on NAICS categories beginning with *AEO2006*. Employment data is obtained from NEMS at the three-digit NAICS level. For some industries, employment data must be shared out among industries within a three-digit NAICS level.

IEDATA

IEDATA stands for Industrial ENPROD Data where ENPROD.TXT is the name of the initial industrial input data file. This routine consists of many subprograms designed to retrieve industrial input data.

The call order of these routines is consistent with the data structure of the model. Most of these subroutines perform no calculations and are simply listed with a description of their function. The routines (and replacement routines in parentheses) are as follows:

IRHEADER

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

The ratio of physical output to 2002 value of shipments for pulp and paper, glass, cement, steel and aluminum industries is calculated. This constant ratio is applied to value of shipments in subsequent years.

$$PHDRAT_i = \frac{PHYSICAL_i}{PRODVX_{i,r}} \qquad (8)$$

where:

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

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

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

where:

PRODXi,r = Output in physical units for industry i in Census region r,

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

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

$$PRODX_{i,r} = PRODVX_{i,r} \qquad (10)$$

where:

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

MECS2002

Get production throughput coefficients, process step retirement rates, and other process step flow information from the file PRODFLOW.TXT. This includes process step number, number of links, the process steps linked to the current step, physical throughput to each process step, the retirement rate, and process step name.

Note that only the energy-intensive industries have process steps. Four industries--food manufacturing, bulk chemicals, metal-based durables, and the balance of manufacturing industries--do not have linkages among steps because the steps represent end-uses (e.g., refrigeration and freezing in the food products industry). As a result, the down-step throughput for these four industries is equal to 1. A linkage is defined as a link between more than one process step. For example, in paper manufacturing, 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 manufacturing industry. The algebraic representation is as follows:

Let:

Y_1 = Number of tons of paper to be produced.
Y_2 = Number of tons of material to go through the bleaching process.
Y_3 = Number of tons of material to go through the waste fiber pulping process.
Y_4 = Number of tons of material to go through the mechanical pulping process.
Y_5 = umber of tons of material to go through the semi-mechanical pulping process.
Y_6 = umber of tons of material to go through the kraft pulping process.

$Y_7 =$ Number of tons of material to go through the wood preparation process.

Then, we have the following:

$Y_1 =$ Output, in tons
$Y_2 = 0.502\ Y1$
$Y_3 = 0.317\ Y1 + 0.317\ Y2$
$Y_4 = 0.041\ Y1 + 0.041\ Y2$
$Y_5 = 0.028\ Y1 + 0.028\ Y2$
$Y_6 = 0.377\ Y1 + 0.377\ Y2$
$Y_7 = 1.689\ Y4 + 1.689\ Y5 + 1.689\ Y6$

If $Y_1 = 96$ million tons of paper produced, then $Y_2 = 48$, $Y_3 = 46$, $Y_4 = 6.5$, $Y_5 = 4$, $Y_6 = 54$, and $Y_7 = 109$.

The papermaking process is as follows. We need 109 million tons of output from the wood preparation process and 46 million tons of output from the waste fiber pulping process. Of the 109 million tons of material, 10 million tons flow through mechanical pulping, 7 million tons into semi-mechanical pulping, and 92 million tons into the kraft pulping process. In the NEMS industrial model, these calculations are performed in an input-output formulation (see CALPROD below for more information).

Physical throughput is obtained for two vintages, old and new. Old vintage is considered to be any capital installed in 2002 or earlier. Middle vintage includes installations from 2003 to the lag of the current projection year. New vintage includes any capital installed in the current projection year.

The following subroutines collect data from the input files.

ISEAM

Get building energy use data including lighting; heating, ventilation, and air conditioning; facility support; and onsite transportation from INDBEU.TXT

IRBSCBYP

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

RDCNTL

Read INDRUN.TXT and ITLBSHR.TXT. The latter contains base year boiler fuel use and is used to calculate boiler fuel shares. Biomass data is retrieved in the IRBSCBYP routine.

IRCOGEN

Get cogeneration information from file EXSTCAP.TXT, including capacity, generation, fuel use, and thermal output from 1990 through 2004. Get corresponding data for planned units from file PLANCAP.TXT

IRSTEPBYP

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

MECS2002

Get process step data for the energy intensive industries from PRODFLOW.TXT. These data consist of fuel identifier numbers, base year process step flow rates and retirement rates.

UECTPC

Reads a data file, Industrial Technology (ITECH.TXT), to update the initial ENPROD.TXT data file with 2002 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:

$$PRODSUM_{s,l} = PRODFLOW_{old,s,l} * PRODX_{i,r} \tag{11}$$

where:

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

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

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

$$PRODSUM_{s,l} = PRODFLOW_{old,s,l} * PRODCUR_{total,IP} \tag{12}$$

where:

$PRODSUM_{s,l}$ = Amount of throughput used at process step *s* through link *l*,
$PRODFLOW_{old,s,l}$ = Down-step throughput to process step *s* linked by link *l* for old vintage, and
$PRODCUR_{total,IP}$ = Current production at process step *IP* linked to process step *s* through link *l* for all vintages.

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

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

where:

$PRODCUR_{total,s}$ = Current production at process step *s* for all vintages,
$NTMAX_s$ = Number of links at process step *s*, and
$PRODSUM_{s,l}$ = Amount of throughput used at process step *s* through link *l*.

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 2002, the ratio of the current year's average industrial energy price to the average price in 2002 is computed, TPCPrat. If TPCPrat is greater than 1.0, the positive TPC (0.001 by default) is an increasing function of TPCPrat:

$$
\begin{aligned}
&X = TPCPrat^{TPCBeta} \\
&TPCPriceFactor = \frac{X}{(1+X)} \\
&TPCRate_v = 2*TPCPriceFactor*BYPCSC_{v,f,s}
\end{aligned}
\qquad (14)
$$

where:

$TPCPrat$ = Ratio of current year average industrial energy price to 2002 price;
$TPCBeta$ = Parameter of logistic function, currently specified as 4;
$TPCPriceFactor$ = TPC price factor, ranging from 0 (no price effect) to 2 for byproducts;
$TPCRate_v$ = TPC multiplier on TPC rate due to energy price increases for vintage *v*;
$BYPCSC_{v,f,s}$ = Initial TPC for vintage *v*, fuel *f*, and step *s*.

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

$$
BYPINT_{v,f,s} = (BYPINTLag_{v,f,s})^{TPCBeta} \qquad (15)
$$

where:

$BYPINT_{v,f,s}$ = Rate of byproduct energy production (or UEC) for byproduct fuel *f* at process step *s* for vintage *v*,
$BYPINTLAG_{v,f,S}$ = Lagged rate of byproduct energy production for byproduct fuel *f* at process step *s* for vintage *v*, and
$TPCRate_v$ = TPC for vintage *v*.

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

$$BYPINT_{mid,f,s} = \left(\frac{PRODLag_{mid,f,s} * BYPINTLag_{mid,f,s})\,)}{PRODLag_{mid,s} + PRODLag_{new,s}}) \atop \frac{+\,(PRODLAG_{new,s} * BYPINTLAG_{new,f,s})}{PRODLag_{mid,s} + PRODLag_{new,s}} \right)^{TPCBeta} \tag{16}$$

where:

$PRODLAG_{new,s}$ = Prior year production from new capacity at process step *s*,
$BYPINTLAG_{mid,f,s}$ = Lagged rate of byproduct energy production for byproduct fuel *f* at process step *s* for vintage *mid*,
$PRODLAG_{,s}$ = Prior year production from middle capacity at process step *s*, and
$TPCBeta$ = Parameter of logistic function, currently specified as 4.

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.

$$BYPQTY_{v,f,s} = PRODCUR_{v,s} * BYPINT_{v,f,s} \tag{17}$$

where:

$BYPQTY_{v,f,s}$ = Byproduct energy production for byproduct fuel *f* at process step *s* for vintage *v*,
$PRODCUR_{v,s}$ = Production at process step *s* for vintage *v*, and
$BYPINT_{v,f,s}$ = Rate of byproduct energy production for byproduct fuel *f* at process step *s* for vintage *v*.

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

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

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

where:

$ENBYPM_{f,v}$ = Byproduct energy production for main byproduct fuel *f* for vintage *v*,
$MPASTP$ = Number of process steps, and
$BYPQTY_{v,f,s}$ = Byproduct energy production for byproduct fuel *f* at process step *s* for vintage *v*.

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.

$$ENPQTY_{v,f,s} = PRODCUR_{v,s} * ENPINT_{v,f,s} \tag{19}$$

where:

$ENPQTY_{v,f,s}$ = Consumption of fuel *f* at process step *s* for vintage *v*,
$PRODCUR_{v,s}$ = Production at process step *s* for vintage *v*, and
$ENPINT_{v,f,s}$ = Unit energy consumption of fuel *f* at process step *s* for vintage *v*.

Consumption of each fuel is converted to trillions of Btu. Energy consumption is subdivided into main fuels, intermediate fuels, and renewable fuels. Main fuels include the following:[24]

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

Intermediate fuels include the following:

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

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

Renewable fuels include the following although only the first three are represented in the model:

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

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

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

where:

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

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

$$ENPMQTY_{coke} = ENPIQTY_{coke} - \left(PRODCUR_{total,co} * \frac{24.8}{10^6} \right) \tag{21}$$

where:

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

MOTORS

Subroutine MOTORS calculates machine drive energy consumption for the end use manufacturing industries (food, bulk chemicals, metal-based durables, and the balance of manufacturing). The motor model is a stock model which tracks the number of motors in each of these four industries for seven size groups (1-5 horsepower (hp), 6-20 hp, 21-50 hp, 51-100 hp, 101-200 hp, 201-500 hp, >500 hp). The first step is to initialize the following variables for their base year (2002) values:

$MotorStock_{i,s,r,y}$ = Motor stock for industry *i,* motor size group *s*, Census region *r*, and year *y* (2002), number of motors,

$MotAvgEnergy_{i,\,s,\,r,\,y}$ = Average energy consumption per motor for industry i, motor size group *s*, Census region r, and year *y* (2002), kWh per motor per year,

$MotAvgEff_{i,\,s,\,r,\,y}$ = Average motor energy efficiency for industry *i*, motor size group *s*, Census region *r*, and year *y* (2002),

$FailurePct_{i,\,s}$ = Percentage of motors which fail each year for industry *i* and motor size group *s*,

$MotorRetPct_{i,\,s}$ = Percentage of motors retired upon failure for industry *i* and motor size group *s*,

$MotorRewDrop_{i,\,s}$ = Drop in efficiency for rewound motors in industry *i* and motor size group *s*,

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

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

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

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

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

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

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

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

$$TotalMotorEnergy_{i,s,r,y} = MotorStock_{i,s,r,y} * \left(MotorEnergy_{i,s,r,y} * \frac{3412}{10^{12}} \right) \qquad (22)$$

where:

$TotalMotorEnergy_{i,\,s,\,r,\,y}$ = Motor energy consumption in trillion Btu for industry *i*, motor size group *s*, Census region *r*, and year *y* (2002), and

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

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

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

where:

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

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

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

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

The energy expenditure savings are calculated as follows:

$$ReplaceAnnSav_{i,s,r,y} = MotorHP_{i,s}*HPtoKW*MotorOpHr_{i,s} *IndElecPrice_{r,y}*\left[\left(\frac{1}{RewoundEff_{i,s}}\right)-\left(\frac{1}{EEPctEff_{i,s}}\right)\right] \tag{24}$$

where:

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

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

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

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

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

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

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

$EEPctEff_{i,s}$ = The efficiency rating for an EPACT92 minimum efficiency motor for industry *i*, and motor size group *s*.

The simple payback period in years is:

$$ReplacePayback_{i,s,r,y} = \frac{ReplacePrPrem_{i,s}}{ReplaceAnnSav_{i,s,r,y}} \tag{25}$$

where:

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

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

Given the payback calculated for each industry and motor size group, the model estimates the number of failed motors that are replaced with EPACT92 minimum efficiency motors and the number of failed motors that are retired. This calculation uses an assumed distribution of required investment payback periods referred to as the payback acceptance curve. Rather than using an actual curve, a table of assumed acceptance rates is used for each integer payback period from 0 to 4 years. To obtain an acceptance fraction, or economic fraction, from a non-integer value for payback, a linear interpolation is done. The economic fraction is determined from a lookup table and interpolation function called

Acceptance, given the table of acceptance fractions, the number of rows in the table (5), and the payback period for the motor size group:

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

where:

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

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

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

The number of failed motors is given by:

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

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

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

where:

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

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

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

where:

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

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

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

The new motor stock is then:

$$\begin{aligned} MotorStock_{i,s,r,y} &= MotorStock_{i,s,r,y-1} - FailedMotors_{i,s,r,y} + RewoundMotors_{i,s,r,y} \\ &\quad + TotalMotorFlow_{i,s,r,y} \end{aligned} \tag{30}$$

All variables are defined above.

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

$$RewoundMotors_{i,s,r,y} = FailedMotors_{i,s,r,y} * RepMotFlow_{i,s,r,y} \tag{31}$$

where:

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

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

Before calculating the projected motor energy consumption for the four industries, a decision must be made whether EPACT92 minimum efficiency motors, or premium efficiency motors are purchased. This decision is made for all new motor purchases, whether to accommodate growth in the industry, or to replace failed motors. The decision is evaluated by a cost and performance algorithm. The initial cost differential for the premium motor is weighed against the energy expenditure savings to determine the payback period in years. A payback acceptance curve provides the split between premium and minimum efficiency motors purchased. The first calculation is the price differential for the premium efficiency motor:

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

where:

$PEPricePrem_{i,\,s}$ = The price premium for the premium efficiency motor for industry i, and motor size group s, in 2002 dollars,
$PEListPrice_{i,\,s}$ = The price for the premium efficiency motor for industry i, and motor size group s, in 2002 dollars,
$EEListPrice_{i,\,s}$ = The price for the EPACT92 minimum efficiency motor for industry i, and motor size group s in 2002 dollars, and
$DealerDisc$ = The average dealer discount offered on motor purchases.

The EPACT92 minimum efficiency standards only apply to motors up to 200 horsepower, and the Motor Master+ database only includes premium motor characteristics for motors up to 350 horsepower, so there currently is no premium efficiency motor option for the largest motor size group.

The energy expenditures savings are calculated as follows:

$$\begin{aligned} PEAnnSav_{i,s,r,y} &= MotorHP_{i,s} * AvgPartLoad_{i,s} * HPtoKW * MotorOpHr_{i.s} \\ &\quad * IndElecPrice_{r,y} * \left(\left(1/EEPctEff_{i,s}\right) - \left(1/PEPctEff_{i,s}\right)\right) \end{aligned} \tag{33}$$

where:

$PEAnnSav_{i,\,s}$ = The expected annual savings from the premium efficiency motor for industry *i*, and motor size group *s*, in 2002 dollars,
$MotorHP_{i,s}$ = The rated motor horsepower for industry *i*, and motor size group *s*,
$AvgPartLoad_{i,s}$ = The average motor part load for industry *i*, and motor size group *s*,
$HPtoKW_{i,s}$ = The conversion factor from horsepower to kilowatts,
$MotorOpHr_{i,s}$ = The annual operating hours for motors in industry *i*, and motor size group *s*,
$IndElecPr_{r,y}$ = The industrial electricity price for region *r*, and year *y*, in 2002 dollars per kWh,
$EEPctEff_{i,s}$ = The efficiency rating for an EPACT92 minimum efficiency motor for industry *i*, and motor size group *s*, and
$PEPctEff_{i,s}$ = The efficiency rating for a premium efficiency motor for industry *i*, and motor size group *s*.

The simple payback period in years is:

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

where:

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

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

Given the payback calculated for each industry and motor size group, the model estimates the number of premium motors and the number of EPACT92 minimum efficiency motors purchased. This calculation uses an assumed distribution of required investment payback periods referred to as the payback acceptance curve. Rather than using an actual curve, a table of assumed acceptance rates is used for each integer payback period from 0 to 4 years. To obtain an acceptance fraction, or economic fraction, from a non-integer value for payback, a linear interpolation is done. The economic fraction is determined from a table lookup and interpolation function called Acceptance, given the table of acceptance fractions, the number of rows in the table (5), and the payback period for the motor size group:

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

where:

$MotAccept_{i,s,r,y}$	=	Fraction of premium efficiency motors purchased based on payback period acceptance assumptions,
$PremAccept$	=	Array of payback acceptance rates corresponding to integer payback periods ranging from 0 to 4 (5 rates altogether), and

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

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

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

where:

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

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

The number of EPACT92 minimum efficiency motors follows:

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

where:

$EffMotorFlow_{i,s,r,y}$	=	Number of EPACT92 minimum efficiency motors purchased for industry *i*, motor size group *s*, Census region *r*, and year *y*,

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

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

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

where:

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

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

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

The efficiency of new motors is calculated as a weighted average of the EPACT92 minimum efficiency and the premium efficiency motors purchased:

$$NewMotorEff_{i,s,r,y} = \left(\begin{pmatrix} EEPctEff_{i,s} * EffMotorFlow_{i,s,r,y} \\ + \left(PEPctff_{i,s} * PremMotorFlow_{i,s,r,y}\right) \end{pmatrix}\right) / RepMotFlow_{i,s,r,y} \qquad (39)$$

where:

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

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

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

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

where:

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

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

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

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

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

where:

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

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

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

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

$$\begin{aligned} MotAvgEnergy_{i,s,r,y} = (&MotAdjEnergy_{i,s,r,y-1} * \\ &\left(MotorStock_{i,s,r,y-1} - FailedMotors_{i,s,r,y}\right) \\ &+ \left(TotalMotorFlow_{i,s,r,s} * NewMotorEnergy_{i,s,r,y}\right) \\ &+ \left(RewoundMotors_{i,s,r,y} * RewMotorEnergy_{i,s,r,y}\right)) \\ &\div MotorStock_{i,s,r,y} \end{aligned} \tag{42}$$

where:

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

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

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

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

$$RewoundEff_{i,s,r,y} = MotAvgEff_{i,s,r,y-1} - MotRewDrop_{i,s} \tag{43}$$

where:

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

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

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

$$\begin{aligned} SystemSavingsR_{i,s} = &\begin{pmatrix} \left(PumpAppPct_{i,s} * PumpSavPct_{i,s,r,y}\right) + \left(FanAppPct_{i,s} * FanSavPct_{i,s}\right) \\ + \left(CompAppPct_{i,s} * CompSavPct_{i,s}\right) \end{pmatrix} \\ &/ \, MotSysLife_{i,s} \end{aligned} \tag{44}$$

where:

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

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

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

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

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

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

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

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

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

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

where:

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

$MotorAvgEnergy_{i,\,s,\,r,\,y\text{-}1}$, and $SystemSavingsR\ _{i}$ are defined above.

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

$$TotalMotorEnergy_{i,s,r,y} = \left(\left(MotorStock_{i,s,r,y} * MotorAveEnergy_{i,s,r,y}\right) * 3412\right) / 10^{12} \qquad (46)$$

where:

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

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

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

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

where:

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

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

CALBTOT

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

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

where:

$ENBQTY_{e,f}$ = Consumption of fuel *f* for building end use *e*,
$EMPLX_{i,r}$ = Employment for industry *i* in Census region *r*,
$ProdVX_{i,r}$ = Output of industry *i* in Census region *r*,
$ENBINT_{e,f}$ = Employment unit energy consumption of fuel *f* for building end use *e*,
$ONBINT_{e,f}$ = Output unit energy consumption of fuel *f* for building end use *e*,
EWeight = Weight for Employment unit energy consumption,
PWeight = Weight for Output unit energy consumption, and
BldPfac = Reflects the effect of energy price increases on buildings energy consumption.

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

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

where:

BldPRat = Ratio of current year average industrial energy price to 2002 price; and
BldElas= Assumed elasticity, currently -0.2.
BldPRat = Ratio of current year average industrial energy price to 2002 price, and
BldElas = Assumed elasticity, currently -0.2.

CALGEN

Subroutine CALGEN accounts for electricity generation from cogeneration by combining existing and planned cogeneration with an estimate of new, unplanned penetration based on an economic and engineering evaluation. The subroutine estimates market penetration of new (unplanned) cogeneration capacity as a function of steam load, steam already met through cogeneration, and cost and performance factors affecting cogeneration economics. CALGEN calls subroutine COGENT to read in the cogeneration assumptions and calls subroutine EvalCogen to evaluate the economics of prototypical cogeneration systems sized to match steam loads in four size ranges. A function SteamSeg is also called to access a size distribution of steam loads for the current industry. Generation for own use and electricity sales to the grid are calculated from the share of sales to the grid from EIA-860B data.[25]

CALGEN begins by computing total steam demand as the sum of steam use in buildings and steam use from the process and assembly component.[26]

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

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[25] Several subroutines not shown here perform the calculations required to initialize, aggregate, and summarize the cogeneration data derived from the EIA-860B and EIA-906 surveys and to incorporate changes from model additions. These subroutines include IRCOGEN, COGINIT, MECSLESS860B, and ADDUPCOGS.

[26] 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:

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

where:

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

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

$$AggSteamLoad_{loadsegment} = NonCogSteam + SteamSeg_{inddir,loadsegment} \qquad (52)$$

where:

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

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

$$AveHourlyLoad_{loadsegment} = AggSteamLoad_{loadsegment} / 0.008760 \qquad (53)$$

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

$$TechPot_{loadsegment} = AvgHourlyLoad_{loadsegement} * PowerSteam_{isys} \tag{54}$$

where:

$TechPot_{loadsegment}$ = Technical potential for cogeneration, in megawatts, for this load segment if all cogeneration was adopted, irrespective of the economics,
$AveHourlyLoad_{\ loadsegment}$ = Average hourly steam load in each load segment, and
$PowerSteam_{isys}$ = Power-Steam ratio of the cogeneration system (equivalent to the ratio of electrical efficiency to thermal efficiency), *isys*.

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

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

where:

$EconPot_{\ loadsegment}$ = Economic potential for cogeneration (megawatts),
$TechPot_{loadsegment}$ = Technical potential for cogeneration, in megawatts, for this load segment if all cogeneration was adopted, irrespective of the economics,
$EconFrac_{\ loadsegment}$ = Economic fraction based on the payback period and the assumed payback acceptance curve.

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

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

where:

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

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

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

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

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

$$COGELF_{cdiv,year,inddir,ngas} = COGELF_{cdiv,year,inddir,ngas} + \\ ((CAPADDGWH*AVEHTRT/10.**6) - (STMADDTRIL/0.8))*DSHR \tag{60}$$

where:

CAPADDGWH	=	Generation from new capacity in gigawatthours,
CAPADDMW	=	Capacity added in megawatts,
STMADDTRIL	=	Thermal (steam) output of new capacity in trillion Btu,
STMADDTRIL/0.8	=	Fuel input assumed to be associated with thermal output based on assumed 80 percent boiler efficiency, and
AVEHTRT	=	Heat rate, or total fuel use per unit of generation (Btu/kWh).

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

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

where:

$BioAvail_{indreg,year}$	=	Biomass available in the current year,
$BioAvail_{indreg,year-1}$	=	Biomass available in the previous year, and
HeatRate	=	Converts Btu to kWh (assumed to be 25,000 through 2003 and decline linearly to 17,000 by 2020).

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

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

where:

$COGGEN_{cdiv,year,inddir,biomass}$	=	Total biomass cogeneration by Census division, year, and industry,
DSHR	=	Factor to share Census region addition to Census divisions such that each division gets an equal share, and

BIO is defined above.

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

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

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

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

$$NEWGEN = CapAddGWH * DSHR \tag{63}$$

$$OLDGRD = COGGEN_{cdiv,year,inddir,fuel} + COGGRD_{cdiv,year,inddir,fuel} \tag{64}$$

$$NEWGRD = NEWGEN + COGGRDNEW_{inddir} \tag{65}$$

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

where:

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

Electricity generation for own use is then calculated as follows:

$$ELOWN_{year,inddir} = \sum_{cdiv} \sum_{fuel} \left(COGGEN_{cdiv,year,inddir,fuel} * COGGRD_{cdiv,year,inddir,fuel}\right) \tag{67}$$

where:

$ELOWN_{year,inddir}$ = Electricity generation for own use, for the current industry and model year,
$OLDGRD$ = Generation sold to the grid, prior to adjusting the sales and generation to reflect the new additions,
$COGGEN_{cdiv,year,inddir,fuel}$ = Cogeneration after adding generation from capacity additions,
$COGGRD_{cdiv,year,inddir,fuel}$ = Cogeneration grid share, recomputed as above.

Electricity generation for sales to the grid is calculated similarly.

EvalCogen

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

$$SteamLoad_{loadsegment} = AveBoilSize_{loadsegment} * EboilEff_{loadsegment} \tag{68}$$

where:

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

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

$CogSizeKW_{isys}$ = Net electric generation capacity in kilowatts,
$CogCapCostKW_{isys}$ = Total installed cost, in 2003 dollars per kilowatthour-electric,
$CapFac_{isys}$ = System capacity factor,
$CHeatRate_{isys}$ = Total fuel use per kilowatthour-electric generated (Btu/kWhe), and
$OverAllEff_{isys}$ = 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:

$ElecGenEffisys$ = 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
= $ElecGenEff_{isys} / (OverAllEff_{isys} - ElecGenEffi_{sys})$
$SteamOutputisys$ = Thermal output of the cogeneration system (mmBtu/hr)
= $CogSizeKW_{isys} * 0.003412 / PowerSteam_{isys}$

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

$CogSys_{loadsegment}$ = $Isys$

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

$$SteamOutput_{isys} <= SteamLoad_{loadsegment} < SteamOutput_{isys+1} \tag{69}$$

where:

$SteamOutput_{isys}$ = Steam output of the preselected cogeneration system, and
$SteamLoad_{loadsegment}$ = 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* $_{\text{loadsegment}}$) 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 for generation. 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. 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 *AEO2006*). 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:

$$FuelCost_{loadsegment} = FuelUse_{isys} * CogFuelPrice \tag{70}$$

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

$$ExistFuelUse_{loadsegment} = SteamOutput_{isys} * 8.76 * CapFac_{isys} / EboilEff_{loadsegment} \tag{71}$$

$$ExistFuelCost_{loadsegment} = ExistFuelUse_{loadsegment} * CogFuelPrice \tag{72}$$

Determine incremental fuel cost and the value of cogenerated electricity:

$$IncrFuelCo\ st_{loadsegmen\ t} = FuelCost_{\ loadsegmen\ t} - ExistFuelC\ ost_{loadsegmen\ t} \tag{73}$$

$$ElecValue_{loadsegment} = ElecSizeMWH_{isys} * CogElecPrice * .003412 \tag{74}$$

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

$$Oper\,\mathrm{Pr}\,ofit_{loadsegment} = ElecValue_{loadsegment} - IncrFuelCost_{loadsegment} \tag{75}$$

Determine the investment capital cost and the investment payback period:

$$Investment_{\ loadsegmen\ t} = CogSizeKW_{\ isys} * CogCapCos\ tKW_{isys} \tag{76}$$

$$CpayBack_{loadsegment} = Investment_{loadsegment} / Oper\,\mathrm{Pr}\,ofit_{loadsegment} \tag{77}$$

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

$$EconFrac_{loadsegment} = Acceptance\left(AcceptFrac, 13, CpayBack_{loadsegment}\right) \tag{78}$$

where:

$EconFrac_{\ loadsegment}$ = Fraction of cogeneration investments adopted based on payback period acceptance assumptions,

$AcceptFrac$ = Array of payback acceptance rates corresponding to integer payback periods ranging from 0 to 12 (13 rates altogether), and

$Cpayback_{loadsegment}$ = Cogeneration investment payback period.

CALSTOT

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

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

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

$$FuelSys_{fuel} = \sum_{cdiv} COGELF_{cdiv,year,inddir,fuel} + (COGOTHR_{cdiv,year,inddir,fuel} / 0.8) \qquad (79)$$

Conventional boiler fuel use is split between biomass-derived and fossil fuel. The total available biomass is determined as by-product fuels ($\mathrm{BYPBSCR}_{\mathrm{biofuel}}$). Some of it is accounted for and used in cogeneration; the remainder of the available biomass (AvailBiomass) is assumed to be used as boiler fuel. The amount of steam for this biomass, BIOSTEAM, is calculated from an assumed biomass boiler efficiency (0.65).

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

The derivation of the boiler fuel calibration factor is based on the results of Subroutine MecsLess860b, which, as its name implies, calculates the difference between total MECS indirect fuels (BSC2002) and the cogeneration (or CHP) fuel use from form 860B (CHP2002), and stores it in array BOIL2002. A separate calibration is performed for biomass- and fossil-fueled boilers. The calibration factor for fossil-fuels is computed as follows in model year 2002:

Estimated = NonCogFosSteam / 0.8,
Implied = SUM of ($\mathrm{BOIL2002}_{\mathrm{inddir,indreg,ifuel}}$) across boiler fuels, and
$CALIB2002\_FOS_{inddir,indreg}$ = *Implied / Estimated.*

where:

Estimated = Trial value for fossil fuel use from conventional boilers,
Implied = Conventional boiler fuel use, and
$CALIB2002\_FOS_{inddir,indreg}$ = Calibration factor for conventional boiler fuel use.

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

$$NonCogFosFuel = \left(\frac{NonCogFosSteam}{0.8} \right) * \left(CALIB2002\_FOS_{inddir,indreg} \right) \tag{80}$$

where:

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

$NonCogFosSteam$ and $CALIB2002\_FOS_{inddir,indreg}$ are defined above.

Conventional boiler fuel use (FuelFosSteam) is allocated to fuels based on fuel shares adjusted for price changes since 2002. The fuel shares (BSSHR) are estimated in Subroutine CALBSC:

$$FuelFos_{steam} = \left(NonCogFosFuel \right) * \left(BSSSHR_{fuel} \right) \tag{81}$$

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

$$EnSQty_{fuel} = CogBoilFuel_{fuel} * FosFuelSteam_{fuel} \tag{82}$$

where:

$CogBoilFuel_{fuel}$ = Fossil fuel consumption for cogeneration by *fuel*, and
$FosFuelSteam_{fuel}$ = Fossil fuel consumption for conventional boilers by *fuel*.

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.

$$QTYMAIN_{f,r} = ENPMQTY_f + ENBQTY_{total,f} + ENSQTY_f + BYPBSCM_f \tag{83}$$

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
$BYPBSCMf$ = 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.

$$QTYMAIN_{elec,r} = ENPMQTY_{elec} + ENBQTY_{total,elec} - ELOWN \tag{84}$$

where:

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

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.

$$TQMAIN_{f,r} = \sum_{i=1}^{INDMAX} QTYMAIN_{f,r} \tag{85}$$

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.

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 products industry.[27] All other industries have similar equations.

$$FOODCON_f = \sum_{f=1}^{NUM_{fg}} QTYMAIN_{f,total} \tag{86}$$

where:

$FOODCON_f$ = Total consumption of fuel f in the food products industry,
NUM_{fg} = Number of fuels in fuel group fg, and
$QTYMAIN_{f,total}$ = Consumption of main fuel f for all Census regions.

WRBIN

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

INDCGN

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

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

$$\begin{aligned}
CGINDCAP_{cdiv,year,fuel,grid} &= \sum_{inddir}^{fg} \left(COGCAP_{cdiv,year,inddir,fuel} * COGGRD_{cdiv,year,inddir,fuel} \right) \\
CGINDCAP_{cdiv,year,fuel,ownuse} &= \sum_{inddir}^{fg} \left(COGCAP_{cdiv,year,inddir,fuel} * (1 - COGGRD_{cdiv,year,inddir,fuel}) \right) \\
CGINDGEN_{cdiv,year,fuel,grid} &= \sum_{inddir}^{fg} \left(COGGEN_{cdiv,year,inddir,fuel} * COGGRD_{cdiv,year,inddir,fuel} \right) \\
CGINDGEN_{cdiv,year,fuel,ownuse} &= \sum_{inddir}^{fg} \left(COGGEN_{cdiv,year,inddir,fuel} * (1 - COGGRD_{cdiv,year,inddir,fuel}) \right) \\
CGINDQ_{cdiv,year,fuel,grid} &= \sum_{inddir}^{fg} \left(COGELF_{cdiv,year,inddir,fuel} * COGGRD_{cdiv,year,inddir,fuel} \right) \\
CGINDQ_{cdiv,year,fuel,ownuse} &= \sum_{inddir}^{fg} \left(COGELF_{cdiv,year,inddir,fuel} * (1 - COGGRD_{cdiv,year,inddir,fuel}) \right)
\end{aligned} \tag{87}$$

where:

CGINDCAP = Cogeneration capacity by Census division, year, fuel, and use (grid or own-use);
CGINDGEN = Cogeneration generation by Census division, year, fuel, and use;
CGINDG = Cogeneration fuel use, electricity portion, by Census division, year, fuel and use;
COGGRD = Share of cogeneration sold to the grid by Census division, year, industry, and fuel;
COGCAP = Cogeneration capacity by Census division, year, industry, and fuel;
COGGEN = Cogeneration generation by Census division, year, industry, and fuel; and
COGELF = Cogeneration fuel use, electricity portion, by Census division, year, and fuel.

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) projection 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.[28]

$$BMAIN_{fuel.region} = TQMAIN_{fuel,region} + QELRF_{region} \tag{88}$$

where:

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[28] Including consumption of electricity and fuels for the production of ethanol calculated in the Petroleum Market Module and consumption of electricity for the processing of oil shale calculated in the Oil and Gas Supply Module.

$TQMAIN_{fuel,region}$ = Consumption of *fuel* = electricity in Census *region*, and
$QELRF_{region}$ = Refinery consumption of *fuel* = electricity in Census *region*.

The equation for total industrial natural gas consumption is:

$$BMAIN_{fuel.region} = TQMAIN_{fuel,region} + QNGRF_{region} + CGOGQ_{sales,region} + CGOGQ_{own,region} \tag{89}$$

where:

$BMAIN_{fuel,region}$ = Consumption of *fuel* natural gas in Census *region*,
$TQMAIN_{fuel,region}$ = Consumption of *fuel* natural gas in Census *region*,
$QNGRF_{region}$ = Refinery natural gas consumption in Census *region*,
$CGOGQ_{sales,region}$ = Consumption of natural gas from cogeneration of electricity for sales to the grid in enhanced oil recovery in Census *region*, input from Oil and Gas Module, and
$CGOGQ_{own,region}$ = Consumption of natural gas from cogeneration of electricity for own use in enhanced oil recovery by Census *region*, input from Oil and Gas Module.

Total industrial consumption for other fuels is calculated similarly.

SEDS benchmark factors are calculated as follows:

$$SEDSBF_{fuel,region} = \frac{SEDS4_{fuel,region}}{BMAIN_{fuel,region}} \tag{90}$$

where:

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

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

$$BENCH_{fuel.region} = SEDSBF_{fuel,region} * BMAIN_{fuel,region} \tag{91}$$

STEO benchmark factors are calculated as follows:

$$STEOBF_{fuel} = \frac{STEO_{fuel,year}}{\sum_{fuel} \sum_{region} BENCH_{fuel,region}} \tag{92}$$

where:

$STEOBF_{fuel}$ = STEO benchmark factor by *fuel* which equals each fuel's share of the total SEDS benchmarked industrial consumption.(note that these factors are applied post SEDS data years),
$STEO_{fuel,year}$ = STEO consumption by *fuel* for each STEO projection *year*
$BENCH_{fuel,region}$ = Benchmarked total industrial *fuel* consumption by *region*.

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

$$BENCH_{fuel.region} = STEOBF_{fuel} * BENCH_{fuel,region} \tag{93}$$

STEO benchmark factors are faded to zero beginning in the first year after the STEO projection year through 2010.

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.

$$DSRENW_{f,d} = \frac{OUTIND_{13,d} + OUTIND_{11,d}}{\sum_{d=1}^{NUM_R} \left(OUTIND_{13,d} + OUTIND_{11,d} \right)} \tag{94}$$

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.

$$BENCHFAC_{bm,d} = \frac{BIOFUELS_d}{\sum_{f=2}^{3} DQRENW_{f,d}} \tag{95}$$

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

$$DQRENW_{f,d} = TQRENW_{f,region} * DSRENW_d \tag{96}$$

where:

$TQRENW_{f,r}$ = Industrial total consumption of renewable fuel *f* in Census region *r*, and
$DSRENW_{f,d}$ = Share of output for renewable fuel *f* in Census division *d*.

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

$$QELIN_{cdiv,year} = BENCH_{elec,region} * SEDSHR_{elec,region,cdiv} \tag{97}$$

where:

$QELIN_{cdiv,year}$ = Industrial consumption of electricity in Census division 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.

$$QGFIN_{cdiv,year} = BENCH_{ngas,region} * SEDSHR_{ngas,region,region} * \left[\frac{TQMAIN_{cgn,region} + TQMAIN_{fds,region}}{BMAIN_{ngas,region}} \right] \tag{98}$$

where:

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

$$QGIIN_{cdiv,year} = QNGIN_{ngas,region} - QGFIN_{cdiv,year} \tag{99}$$

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

Industrial consumption of biomass is calculated in the following equation.

$$QBMIN_{d,y} = \left[\sum_{f=2}^{3} DQRENW_{f,d} \right] + \left[\sum_{u=1}^{2} CGOGO_{d,y,bm,u} \right] + QBMRF_{d,y} \tag{100}$$

where:

$QBMIN_{d,y}$ = Industrial consumption of biomass in Census division *d* in year *y*,
$DQRENW_{f,d}$ = Consumption of renewable fuel *f* in Census division *d*,
$CGOGQ_{d,y,bm,u}$ = Consumption of biomass from cogeneration of electricity for use *u* in enhanced oil recovery in Census division *d* in year *y*, and
$QBMRF_{d,y}$ = Biomass consumed by petroleum refining industry in Census division *d* in year *y*.

Consumption of total renewables is calculated through the following equation. Currently, only biomass (including pulping liquor) and hydropower are nonzero.

$$QTRIN_{d,y} = QHOIN_{d,y} + QBMIN_{d,y} + QGEIN_{d,y} + QSTIN_{d,y} + QPVIN_{d,y} + QWIIN_{d,y} + QMSIN_{d,y} \tag{101}$$

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*.

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.

CALPROD

CALPROD determines the throughput for production flows for the process and assembly component. Existing old and middle vintage production is reduced by applying a retirement rate of capital (Table B13). The retirement rate is posited to be a positive function of energy prices. For years after 2002, the ratio of the current year's average industrial energy price to the average price in 2002 is computed, RetirePrat.

If RetirePrat is greater than 1.0, the following relationships hold:

$$X = RetirePrat^{RetireBeta}$$

$$RetirePriceFactor = \frac{X}{(1+X)} \qquad (102)$$

$$RetireRate_s = 2*RetirePriceFactor*ProdRetr_s$$

where:

$RetirePrat$ = Ratio of current year average industrial energy price to 2002 price,
$RetireBeta$ = Parameter of logistic function, currently specified as 2 for retirements,

$RetirePriceFactor$ = TPC price factor, ranging from 0 (no price effect) to 2 for retirements,
$RetireRate_s$ = Retirement rate after accounting for energy price increases for step *s*; and
$ProdRetr_s$ = Default retirement rate for step *s*.

$$PRODCUR_{old,s} = \left(PRODCUR_{old,s} + IDLCAP_{old,s}\right) * \left(1 - RetireRate_s\right) \tag{103}$$

where:

$PRODCUR_{old,s}$ = Existing production for process step *s* for old vintage,
$IDLCAP_{old,s}$ = Idle production at process step *s* for old vintage, and
$RetireRate_s$ = Retirement rate after accounting for energy price increases for step *s*.

$$PRODCUR_{mid,s} = \left(PRODCUR_{mid,s} + PRODCUR_{new,s}\right) * \left(1 - RetireRate_s\right) \tag{104}$$

where:

$PRODCUR_{mid,s}$ = Existing production for process step *s* for mid vintage,
$IDLCAP_{new,s}$ = Idle production at process step *s* for new vintage, and
$RetireRate_s$ = Retirement rate after accounting for energy price increases for step *s*.

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

$$PRODX_{i,r} = PHDRAT \ * PRODVX_{i,r} \tag{105}$$

where:

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

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

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

The following definitions are provided to illustrate the problem:

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

I = Identity Matrix

D = Final demand vector, but only the first element is nonzero. (**D₁** is equivalent to PRODX.)

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

The input-output model is written as:

$$(\mathbf{I}-\mathbf{A})*\mathbf{X}=\mathbf{D} \tag{106}$$

X is obtained by premultiplying both sides by the inverse of (**I-A**):

$$\mathbf{X}=(\mathbf{I}-\mathbf{A})^{-1}*\mathbf{D} \tag{107}$$

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

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

$$\begin{gathered}\mathbf{Xtot}=\mathbf{Xsurv}+\mathbf{Xnew}\\ \textit{or}\\ \mathbf{Xtot}=\mathbf{Xold}-\mathbf{Xret}+\mathbf{Xnew}\end{gathered} \tag{108}$$

Xold is defined in the base year as follows:

$$\begin{gathered}\mathbf{IAold*Xold}=\mathbf{D_{98}}\\ \textit{or}\\ \mathbf{Xold}=\mathbf{IAold^{-1}*D}\end{gathered} \tag{109}$$

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

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

$$\mathbf{Xret}=\mathbf{Xold}*\left(1-(1-R)\right)^{(Year-1998)} \tag{110}$$

$$\mathbf{Xsurv}=\mathbf{Xold}-\mathbf{Xret} \tag{111}$$

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

$$\mathbf{Dold}=\mathbf{IAold*Xsurv} \tag{112}$$

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

$$\mathbf{IAold*Xsurv_{Year}}+\mathbf{IAnew*Xnew_{Year}}=\mathbf{D_{year}} \tag{113}$$

where, $\mathbf{Xnew}_{\mathbf{year}}$ is the cumulative additions to productive capacity since the base year. $\mathbf{Xnew}_{\mathbf{year}}$ can be determined by solving the following system:

$$\mathbf{IAnew * Xnew}_{\mathbf{Year}} = \mathbf{D}_{\mathbf{year}} - \mathbf{IAold * Xsurv}_{\mathbf{Year}} \tag{114}$$

Therefore,

$$\mathbf{Xnew}_{\mathbf{Year}} = \mathbf{IAnew}^{-1} * (\mathbf{D}_{\mathbf{year}} - \mathbf{IAold * Xsurv}_{\mathbf{Year}}) \tag{115}$$

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

CALCSC

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

$$ENPINT_{v,f,s} = ENPINTLAG_{v,f,s} * \left(1 + TPCRate_v\right) \tag{116}$$

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 for vintage *v* after accounting for the impact of increased energy prices.

The TPCRate_v are calculated using the following relationships if the TPCPrat is greater than 1.0. Otherwise, the default values for the intensity decline rate is used, $\text{BCSC}_{\text{v,fuel,step}}$.

If the TPCPrat is greater than 1.0, the following relationships hold:

$$X = TPCPrat^{TPCBeta}$$

$$TPCPriceFactor = \frac{X}{\left(1 + X\right)} \tag{117}$$

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

where:

$TPCPrat$ = Ratio of current year average industrial energy price to 2002 price,

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

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

$TPCRate_v$ = Energy intensity decline rate for vintage *v* after accounting for the impact of increased energy prices, and

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

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

$$ENPINT_{mid,f,s} = \frac{SUMPINT_{f,s}}{CUMPROD_{new,s}} \tag{118}$$

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.

CALBSC

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

$$ShareFuel_i = \frac{\left(P_i^{\alpha_i}\beta_i\right)}{\sum_{i=1}^{3} P_i^{\alpha_i}\beta_i} \tag{119}$$

where the fuels (*i*)are coal, petroleum, and natural gas. Base year boiler shares for individual petroleum products are calculated explicitly to obtain exact estimates of these fuel shares from the aggregate petroleum fuel share calculation. The P_i are the fuel prices, α_i are sensitivity parameters, the default value is -1.50; and the βi are calibrated to reproduce the 2002 fuel shares using the relative prices that prevailed in 2002. The byproduct fuels are consumed before the quantity of purchased fuels is estimated.

The α_i sensitivity parameters are posited to be a positive function of the average price of the primary boiler fuels (coal, natural gas, and residual fuel). For years after 2002, the ratio of the current year's average boiler fuel energy price to the average price in 2002 is computed, SwitchPrat.

If the SwitchPrat is greater than 1.0, the following relationships hold:

$$\begin{aligned} X &= SwitchPrat^{SwitchBeta} \\ SwitchPriceFactor &= 4 * \frac{X}{\left(1+X\right)} \\ \alpha_{iPrice} &= SwitchPriceFactor * \alpha_i \end{aligned} \tag{120}$$

where:

SwitchPrat = Ratio of current year average industrial energy price to 2002 price,
SwitchBeta = Parameter of logistic function, currently specified as 4,
SwitchPriceFactor = Fuel switching price factor, ranging from 0 (no price effect) to 4 for boiler fuel switching,
α_{iPrice} = Fuel switching sensitivity parameters after accounting for energy price increases
α_i = Default fuel switching sensitivity parameters.

Appendix A. Bibliography

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Appendix B. Data Inputs

Table B1. Building Component Energy Consumption, Part 1 (trillion Btu)					
		Lighting	Heating, Ventilation, Air		
	Region	Electricity	Electricity	Natural Gas	Steam
Food	NE	1.64	1.75	4.05	1.43
	MW	7.25	7.70	16.92	4.50
	SO	5.83	6.19	12.05	6.43
	WE	2.54	2.70	7.46	3.58
Paper	NE	1.92	2.05	3.63	0.00
	MW	3.49	3.73	6.44	0.00
	SO	7.06	7.53	13.98	0.00
	WE	2.88	3.07	3.42	0.00
BChem	NE	1.73	2.08	1.40	0.00
	MW	3.19	3.83	1.93	0.00
	SO	12.24	14.71	15.82	0.00
	WE	0.92	1.10	1.09	0.00
Glass	NE	0.35	0.52	2.18	0.00
	MW	0.59	0.89	2.05	0.00
	SO	0.84	1.26	3.29	0.00
	WE	0.25	0.37	0.87	0.00
Cement	NE	0.14	0.14	0.05	0.00
	MW	0.24	0.24	0.43	0.00
	SO	0.40	0.40	0.61	0.00
	WE	0.21	0.21	0.31	0.00
Steel	NE	0.58	0.70	3.36	0.00
	MW	2.13	2.56	8.09	0.00
	SO	2.05	2.46	3.21	0.00
	WE	0.36	0.43	0.31	0.00
Aluminum	NE	0.32	0.42	0.68	0.00
	MW	0.84	1.12	1.62	0.00
	SO	1.54	2.06	3.73	0.00
	WE	0.27	0.35	0.53	0.00
MBD	NE	12.61	18.25	28.37	14.77
	MW	32.33	46.80	94.97	44.90
	SO	23.75	34.37	47.26	25.85
	WE	11.14	16.12	16.71	10.40
BOM	NE	8.33	11.15	18.47	12.19
	MW	21.15	28.31	37.34	27.00
	SO	36.18	48.43	70.30	48.83
	WE	10.09	13.51	22.67	14.88

Table B2. Building Component Energy Consumption, Part 2 (trillion Btu)

		Facility Support				Onsite Transportation			
	Region	Electricity	Natural Gas	Distillate	LPG	Electricity	Natural Gas	Distillate	LPG
Food	NE	0.31	0.48	0.04	0.03	0.10	0.02	0.53	0.31
	MW	1.36	2.13	0.03	0.03	0.45	0.11	0.35	0.31
	SO	1.09	1.46	0.09	0.06	0.36	0.08	1.06	0.63
	WE	0.48	0.91	0.10	0.03	0.16	0.05	1.24	0.31
Paper	NE	0.38	0.04	0.04	0.06	0.03	0.04	0.31	0.47
	MW	0.70	0.05	0.02	0.12	0.06	0.05	0.15	0.94
	SO	1.41	0.12	0.17	0.12	0.12	0.12	1.38	0.94
	WE	0.58	0.04	0.02	0.06	0.05	0.04	0.15	0.47
BChem	NE	0.41	0.17	0.07	0.01	0.12	0.07	0.79	0.10
	MW	0.76	0.35	0.01	0.00	0.21	0.15	0.13	0.00
	SO	2.92	2.71	0.04	0.34	0.81	1.20	0.46	3.46
	WE	0.22	0.19	0.00	0.00	0.06	0.09	0.00	0.00
Glass	NE	0.04	0.03	0.45	0.00	0.04	0.03	0.45	0.00
	MW	0.07	0.07	0.00	0.00	0.07	0.07	0.00	0.00
	SO	0.10	0.08	0.70	0.00	0.10	0.08	0.70	0.00
	WE	0.03	0.03	0.01	0.00	0.03	0.03	0.01	0.00
Cement	NE	0.04	0.00	0.02	0.00	0.04	0.00	0.70	0.00
	MW	0.06	0.08	0.03	0.00	0.06	0.00	1.39	0.00
	SO	0.10	0.12	0.03	0.00	0.10	0.00	1.39	0.00
	WE	0.05	0.05	0.03	0.00	0.05	0.00	1.39	0.00
Steel	NE	0.12	0.48	0.00	0.00	0.03	0.00	0.80	0.00
	MW	0.43	1.15	0.00	0.00	0.11	0.00	6.40	0.00
	SO	0.41	0.46	0.00	0.00	0.10	0.00	0.80	0.00
	WE	0.07	0.04	0.00	0.00	0.02	0.00	0.00	0.00
Aluminum	NE	0.11	0.13	0.00	0.00	0.03	0.03	0.08	0.02
	MW	0.28	0.32	0.00	0.00	0.07	0.07	0.00	0.00
	SO	0.51	0.67	0.00	0.00	0.13	0.14	0.71	0.20
	WE	0.09	0.11	0.00	0.00	0.02	0.02	0.00	0.00
MBD	NE	3.48	0.83	0.14	0.00	0.34	0.20	0.66	0.00
	MW	8.93	2.88	0.09	0.19	0.87	0.69	0.44	1.53
	SO	6.56	1.42	0.09	0.23	0.64	0.34	0.44	1.91
	WE	3.08	0.51	0.14	0.00	0.30	0.12	0.66	0.00
BOM	NE	1.88	1.51	0.00	0.00	0.00	0.00	1.51	0.74
	MW	4.76	3.28	0.00	0.00	0.00	0.00	3.37	1.09
	SO	8.15	5.78	0.00	0.00	0.00	0.00	6.78	3.68
	WE	2.27	1.79	0.00	0.00	0.00	0.00	4.24	2.58

Source: Energy Information Administration, Office of Integrated Analysis and Forecasting estimates based on *Manufacturing Consumption of Energy 2002*.

Table B3. Food Industry National UECs, 2002
(Thousand Btu/2000$ of Shipments, Unless Otherwise Indicated)

End Use	Shipments (Billion 2000$)	Electricity	Natural Gas	Residual	Distillate	LPG	Coal	Steam
Direct Heat	437.3	0.020	0.488	0.009	0.002	0.004	0.014	0.978
Refrigeration	437.3	0.153	0.019	0.000	0.005	0.000	0.000	0.000
Machine Drive	437.3	0.306	0.031	0.000	0.007	0.000	0.000	0.000
Other	437.3	0.003	0.010	0.000	0.000	0.000	0.000	0.000

Source: FOCIS Associates, Inc., *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, October 2005.

Table B4. Pulp and Paper Industry National UECs, 2002
(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Resid	Distillate	LPG	Coal	Steam	Byproduct Produced
Wood Preparation	91.1	0.270	0.000	0.000	0.000	0.000	0.000	0.000	3.266
Pulping									
Waste	43.1	1.350	0.000	0.000	0.000	0.000	0.000	1.230	0.000
Mech	4.6	5.380	0.000	0.000	0.000	0.000	0.000	0.440	0.000
Semi-chem	3.5	1.450	0.000	0.000	0.000	0.000	0.000	4.730	0.000
Kraft	49.8	1.450	1.523	0.267	0.020	0.014	0.077	10.160	16.466
Bleaching	49.5	0.270	0.000	0.000	0.000	0.000	0.000	4.990	0.000
Papermaking	91.1	1.660	0.914	0.160	0.011	0.008	0.046	5.960	0.000

Source: FOCIS Associates, Inc., *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, October 2005.

Table B5. Bulk Chemical Industry Total and Components National UECs, 2002
(Thousand Btu/2000$ of Shipments, Unless Otherwise Indicated)

	Shipments (Billion 2000)	Electricity	Natural Gas	Residual	Distillate	LPG	Coal	Steam	Feed-stocks
Bulk Chemicals									
End-Use									
Direct Heat	195.6	0.139	2.883	0.085	0.003	0.161	0.035	6.555	0.0
Refrigeration	195.6	0.242	0.122	0.0	0.001	0.001	0.0	0.0	0.0
Machine Drive	195.6	1.819	0.086	0.0	0.005	0.002	0.0	0.0	0.0
Electrolytic	195.6	0.566	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	195.6	0.009	0.121	0.0	0.002	0.0	0.003	0.0	0.0
Feedstocks	195.6	0.0	3.108	0.002	0.0	10.383	0.0	0.0	6.497
Inorganic									
End-Use									
Direct Heat	28.9	0.112	2.223	0.261	0.007	0.0	0.086	5.327	0.0
Refrigeration	28.9	0.404	0.009	0.0	0.001	0.0	0.0	0.0	0.0
Machine Drive	28.9	4.804	0.0	0.0	0.013	0.001	0.0	0.0	0.0
Electrolytic	28.9	2.210	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	28.9	0.008	0.074	0.0	0.009	0.0	0.017	0.0	0.0
Feedstocks	28.9	0.0	0.967	0.0	0.0	0.455	0.0	0.0	0.314
Organic									
End-Use									
Direct Heat	78.8	0.121	3.314	0.010	0.001	0.399	0.013	10.806	0.0
Refrigeration	78.8	0.238	0.279	0.0	0.001	0.003	0.0	0.0	0.0
Machine Drive	78.8	1.306	0.081	0.0	0.005	0.004	0.0	0.0	0.0
Electrolytic	78.8	0.274	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	78.8	0.010	0.238	0.0	0.002	0.0	0.0	0.0	0.0
Feedstocks	78.8	0.0	2.600	0.0	0.0	12.339	0.0	0.0	7.716
Resins									
End-Use									
Direct Heat	69.3	0.187	1.457	0.002	0.001	0.0	0.033	3.981	0.0
Refrigeration	69.3	0.221	0.025	0.0	0.0	0.0	0.0	0.0	0.0
Machine Drive	69.3	1.299	0.036	0.0	0.001	0.0	0.0	0.0	0.0
Electrolytic	69.3	0.363	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	69.3	0.007	0.033	0.0	0.0	0.0	0.0	0.0	0.0
Feedstocks	69.3	0.0	0.981	0.0	0.0	15.079	0.0	0.0	9.429
Agricultural Chemicals									
End-Use									
Direct Heat	18.5	0.077	7.416	0.054	0.007	0.0	0.054	0.013	0.0
Refrigeration	18.5	0.077	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Machine Drive	18.5	1.285	0.430	0.0	0.011	0.0	0.0	0.0	0.0
Electrolytic	18.5	0.000	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	18.5	0.015	0.027	0.0	0.0	0.0	0.0	1.118	0.0
Feedstocks	18.5	0.0	16.577	0.0	0.0	0.0	0.0	0.0	0.0

Source: FOCIS Associates, Inc., *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, October 2005.

Table B6. Glass Products Industry National UECs, 2002
(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Residual	Distillate	LPG	Steam
Virgin							
Batch Prep	14.6	0.220	0.0	0.0	0.0	0.0	0.0
Melting/Refining	14.6	0.520	5.121	0.018	0.008	0.014	0.200
Scrap							
Batch Prep	2.4	0.190	0.0	0.0	0.0	0.0	0.0
Melting/Refining	2.4	0.420	4.098	0.014	0.006	0.011	0.190
Forming	17.0	0.970	1.578	0.006	0.002	0.004	0.060
Post-Forming	17.0	0.420	1.856	0.007	0.003	0.005	0.070

Source: FOCIS Associates, Inc., *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, October 2005.

Table B7. Cement Industry National UECs, 2002
(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Residual	Distillate	LPG	Coal	Coke	Steam
Dry Process	69.7	0.230	0.192	0.010	0.013	0.002	2.255	0.079	0.0
Wet Process	20.2	0.210	0.260	0.013	0.018	0.002	3.056	0.107	0.820
Finish Grinding	98.9	0.220	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source: FOCIS Associates, Inc., *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, October 2005.

Table B8. Iron and Steel Industry National UECs, 2002
(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Resid	Distillate	Coal	Coke	Steam	Byproduct Consumed
Coke Ovens	11.8	0.110	0.010	0.0	0.0	36.800	0.0	0.710	2.241
Iron & Steelmaking									
BOF	50.1	0.230	1.650	0.035	0.070	0.690	8.710	1.040	1.360
EAF	50.8	1.660	0.631	0.0	0.003	0.0	0.0	0.0	0.0
Casting									
Ingot	2.8	0.340	1.532	0.0	0.008	0.068	0.090	0.030	0.0
Continuous	98.2	0.100	0.270	0.0	0.002	0.028	0.000	0.010	0.0
Hot Rolling	105.7	0.400	1.300	0.0	0.009	0.0	0.0	0.020	0.0
Cold Rolling	39.4	0.900	1.532	0.0	0.008	0.0	0.0	1.310	0.0

Source: FOCIS Associates, Inc., *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, October 2005.

Table B9. Aluminum Industry National UECs, 2002
(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Distillate	LPG	Steam	Petroleum Coke
Alumina Refining	4.8	0.400	1.687	0.005	0.008	7.100	0.0
Primary Smelting	3.0	53.400	3.870	0.012	0.019	0.600	13.700
Secondary/Scrap	3.1	0.900	7.343	0.022	0.035	0.0	0.0
Semi-Fabrication							
Sheet, Plate, Foil	4.9	3.200	10.022	0.030	0.048	0.0	0.0
Other	2.3	3.400	5.458	0.016	0.026	0.0	0.0

Source: FOCIS Associates, Inc., *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, October 2005.

Table B10. Non-Energy-Intensive Manufacturing Sector PA Component National UECs, 2002
(Thousand Btu/2000$ of Shipments, Unless Otherwise Indicated)

Industry	Shipments (Billion 2000$)	Electricity	Natural Gas	Residual	Distillate	LPG	Coal	Petroleum Coke	Steam
Metal-Based Durables									
Heating	1693.6	0.052	0.164	0.001	0.002	0.001	0.0	0.0	0.026
Refrigeration	1693.6	0.019	0.002	0.0	0.0	0.0	0.0	0.0	0.0
Machine Drive	1693.6	0.145	0.004	0.0	0.0	0.0	0.0	0.0	0.0
Electrochemical	1693.6	0.043	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	1693.6	0.004	0.006	0.0	0.001	0.0	0.0	0.041	0.0
Other Manufacturing									
Heating	1143.8	0.093	0.473	0.0	0.015	0.010	0.080	0.0	0.513
Refrigeration	1143.8	0.048	0.003	0.0	0.0	0.0	0.0	0.0	0.0
Machine Drive	1143.8	0.366	0.024	0.002	0.004	0.004	0.0	0.0	0.0
Electrochemical	1143.8	0.019	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	1143.8	0.002	0.012	0.012	0.001	0.0	0.0	0.0	0.0

Source: FOCIS Associates, Inc., *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, October 2005.

Table B11. Non-Manufacturing Sector PA Component National UECs, 2002
(Thousand Btu/2000$ of Shipments, Unless Otherwise Indicated)

Industry	Shipments (Billion 2000$)	Electricity	Natural Gas	Distillate	LPG	Motor Gasoline	Coal	Asphalt
Agri-Crops	92.5	0.743	0.735	2.606	0.448	1.237	0.000	0.000
Agri-Other	160.7	0.353	0.147	1.427	0.240	0.597	0.000	0.000
Coal Mining	23.5	1.482	0.031	2.048	0.000	0.089	0.242	0.000
Oil & Gas	145.4	0.724	5.638	0.258	0.000	0.068	0.000	0.000
Other Mining	26.0	3.947	2.807	1.887	0.000	0.143	0.205	0.000
Construction	924.0	0.122	0.205	0.495	0.000	0.090	0.000	1.342

Notes: Natural gas excludes lease and plant fuel.
Sources: Calculated from data provided in U.S. Census Bureau, *Economic Census 2002: Mining Industry Series*; U.S. Census Bureau, *Economic Census 2002: Construction Industry Series*; and U.S. Department of Agriculture, *2002 Census of Agriculture*.

Table B12. Regional Technology Shares (percent)

		Census Region			
Industry	Technology	Northeast	Midwest	South	West
Pulp and Paper	Kraft (incl.Sulfite)	7	6	74	13
	Semi-Chemical	2	35	56	7
	Mechanical	13	15	49	23
	Waste Fiber	15	25	42	18
	Bleaching	10	13	62	15
	Papermaking	13	18	56	13
Cement	Wet Process	24	26	42	9
	Dry Process	8	25	38	29
	Clinker	10	28	39	23
Iron and Steel	Electric Arc Furnace	12	34	46	8
	Basic Oxygen Furnace	5	80	15	0
	Coke Oven	32	46	22	0
Aluminum	Alumina Refining	0	0	100	0
	Primary Smelting	6	20	39	35
	Secondary/Scrap	10	42	31	18
	Semi-Fab: Sheet	19	22	54	4
	Semi-Fab: Other	15	33	38	14

Source: FOCIS Associates, Inc., *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, October 2005.

Table B13. Coefficients for Technology Possibility Curves, Reference Case

	Existing Facilities		New Facilities			Retirement Rate (%)
Industry/Process Unit	REI 2030	TPC	REI 2002	REI 2030	TPC	
Food Product						
Process Heating	0.900	-0.0038	0.900	0.800	-0.0042	1.7
Process Cooling - electricity	0.875	-0.0048	0.850	0.750	-0.0045	1.7
Process Cooling - fuels	0.900	-0.0038	0.900	0.800	-0.0042	1.7
Other - electricity	0.914	-0.0032	0.915	0.810	-0.0043	1.7
Other - fuels	0.900	-0.0038	0.900	0.800	-0.0042	1.7
Paper & Allied Products						
Wood Preparation	0.792	-0.0083	0.882	0.701	-0.0082	2.3
Waste Pulping	0.936	-0.0024	0.936	0.936	0.0000	2.3
Mechanical Pulping	0.816	-0.0072	0.931	0.701	-0.0101	2.3
Semi-Chemical(a)	0.954	-0.0017	0.971	0.937	-0.0013	2.3
Kraft, Sulfite	0.870	-0.0049	0.914	0.827	-0.0036	2.3
Bleaching	0.798	-0.0080	0.878	0.719	-0.0071	2.3
Paper Making	0.869	-0.0050	0.885	0.852	-0.0014	2.3
Bulk Chemicals						
Process Heating	0.900	-0.0038	0.900	0.800	-0.0042	1.7
Process Cooling - electricity	0.875	-0.0048	0.850	0.750	-0.0045	1.7
Process Cooling - fuels	0.900	-0.0038	0.900	0.800	-0.0042	1.7
Electro-Chemical	0.980	-0.0007	0.950	0.850	-0.0040	1.7
Other - electricity	0.914	-0.0032	0.915	0.810	-0.0043	1.7
Other - fuels	0.900	-0.0038	0.900	0.800	-0.0042	1.7
Glass & Glass Products						
Batch Preparation	0.941	-0.0022	0.882	0.882	0.0000	1.3
Melting/Refining	0.934	-0.0024	0.900	0.868	-0.0013	1.3
Forming	0.984	-0.0006	0.982	0.968	-0.0005	1.3
Post-Forming	0.978	-0.0008	0.968	0.955	-0.0005	1.3
Cement						
Dry Process	0.905	-0.0036	0.900	0.810	-0.0038	1.2
Wet Process(c)	0.951	-0.0018	NA	NA	NA	1.2
Finish Grinding	0.975	-0.0009	0.950	0.950	0.0000	1.2
Iron & Steel						
Coke Oven	0.935	-0.0024	0.902	0.869	-0.0013	2.5
BF/BOF	0.994	-0.0002	0.987	0.987	0.0000	1.5
EAF	0.925	-0.0028	0.990	0.849	-0.0055	1.5
Ingot Casting	1.000	0.0000	1.000	1.000	NA	2.9
Continuous Casting	1.000	0.0000	1.000	1.000	0.0000	2.9
Hot Rolling	0.826	-0.0068	0.800	0.652	-0.0073	2.9
Cold Rolling	0.737	-0.0108	0.924	0.474	-0.0236	2.9
Aluminum						
Alumina Refinery	0.930	-0.0026	0.900	0.860	-0.0016	1.0
Primary Aluminum	0.900	-0.0038	0.950	0.800	-0.0061	1.0
Secondary Aluminum	0.875	-0.0048	0.850	0.750	-0.0045	1.0
Semi-Fab. Sheet/plate/foil	0.900	-0.0038	0.900	0.800	-0.0042	1.0
Semi-Fab. Other	0.925	-0.0028	0.950	0.850	-0.0040	1.0

Table B13. Coefficients for Technology Possibility Curves, Reference Case

	Existing Facilities		New Facilities			Retirement Rate (%)
Industry/Process Unit	REI 2030	TPC	REI 2002	REI 2030	TPC	
Metal-Based Durables						
Process Heating	0.900	-0.0038	0.900	0.800	-0.0042	1.3
Process Cooling - electricity	0.875	-0.0048	0.850	0.750	-0.0045	1.3
Process Cooling - fuels	0.900	-0.0038	0.900	0.800	-0.0042	1.3
Electro-Chemical	0.980	-0.0007	0.950	0.850	-0.0040	1.3
Other - electricity	0.914	-0.0032	0.915	0.810	-0.0043	1.3
Other - fuels	0.900	-0.0038	0.900	0.800	-0.0042	1.3
Balance of Manufacturing						
Process Heating	0.900	-0.0038	0.900	0.800	-0.0042	1.3
Process Cooling - electricity	0.875	-0.0048	0.850	0.750	-0.0045	1.3
Process Cooling - fuels	0.900	-0.0038	0.900	0.800	-0.0042	1.3
Electro-Chemical	0.980	-0.0007	0.950	0.850	-0.0040	1.3
Other - electricity	0.914	-0.0032	0.915	0.810	-0.0043	1.3
Other - fuels	0.900	-0.0038	0.900	0.800	-0.0042	1.3
Non-Manufacturing						
Distillate	0.894	-0.0040	0.850	0.718	-0.0060	1.0
Asphalt	0.776	-0.0090	0.850	0.642	-0.0100	1.0
Other Fuels	0.894	-0.0040	0.900	0.760	-0.0060	1.0

Sources:Manufacturing: FOCIS Associates, Inc., *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, October 2005; Non-manufacturing: Office of Integrated Analysis and Forecasting estimates.

Table B14. Coefficients for Technology Possibility Curves, High Technology Case

	Existing Facilities		New Facilities	
Industry/Process Unit	REI 2030	TPC	REI 2030	TPC
Food Products				
Process Heating	0.890	-0.0041	0.781	-0.0050
Process Cooling - electricity	0.863	-0.0053	0.731	-0.0053
Process Cooling - fuels	0.890	-0.0041	0.781	-0.0050
Other - electricity	0.905	-0.0035	0.790	-0.0052
Other - fuels	0.890	-0.0041	0.781	-0.0050
Paper & Allied Products				
Wood Preparation	0.747	-0.0104	0.532	-0.0179
Waste Pulping	0.898	-0.0038	0.800	-0.0056
Mechanical Pulping	0.771	-0.0092	0.580	-0.0167
Semi-Chemical	0.948	-0.0019	0.777	-0.0079
Kraft, Sulfite	0.827	-0.0067	0.549	-0.0181
Bleaching	0.758	-0.0099	0.627	-0.0120
Paper Making	0.766	-0.0095	0.451	-0.0238
Bulk Chemicals				
Process Heating	0.890	-0.0041	0.781	-0.0050
Process Cooling - electricity	0.863	-0.0053	0.731	-0.0053
Process Cooling - fuels	0.890	-0.0041	0.781	-0.0050
Electro-Chemical	0.978	-0.0008	0.831	-0.0048
Other - electricity	0.914	-0.0035	0.790	-0.0052
Other - fuels	0.890	-0.0041	0.781	-0.0050
Glass & Glass Products				
Batch Preparation	0.941	-0.0022	0.819	-0.0026
Melting/Refining	0.822	-0.0070	0.449	-0.0245
Forming	0.965	-0.0013	0.826	-0.0061
Post-Forming	0.971	-0.0011	0.865	-0.0040
Cement				
Dry Process	0.800	-0.0079	0.531	-0.0187
Wet Process(c)	0.894	-0.0040	NA	NA
Finish Grinding	0.850	-0.0058	0.600	-0.0163
Iron & Steel				
Coke Oven	0.845	-0.0060	0.637	-0.0124
BF/BOF	0.950	-0.0018	0.785	-0.0081
EAF	0.845	-0.0060	0.655	-0.0146
Ingot Casting	1.000	0.0000	NA	NA
Continuous Casting	1.000	0.0000	1.000	0.0000
Hot Rolling	0.761	-0.0097	0.337	-0.0304
Cold Rolling	0.706	-0.0124	0.400	-0.0295
Aluminum				
Alumina Refinery	0.915	-0.0032	0.576	-0.0158
Primary Aluminum	0.800	-0.0079	0.522	-0.0212
Secondary Aluminum	0.825	-0.0068	0.376	-0.0287
Semi-Fab. Sheet/plate/foil	0.750	-0.0102	0.457	-0.0239
Semi-Fab. Other	0.825	-0.0068	0.467	-0.0250

Table B14. Coefficients for Technology Possibility Curves, High Technology Case

	Existing Facilities		New Facilities	
Industry/Process Unit	REI 2030	TPC	REI 2030	TPC
Metal-Based Durables				
Process Heating	0.890	-0.0041	0.781	-0.0050
Process Cooling - electricity	0.863	-0.0053	0.731	-0.0053
Process Cooling - fuels	0.890	-0.0041	0.781	-0.0050
Electro-Chemical	0.978	-0.0008	0.831	-0.0048
Other - electricity	0.905	-0.0035	0.790	-0.0052
Other - fuels	0.890	-0.0041	0.781	-0.0050
Balance of Manufacturing				
Process Heating	0.890	-0.0041	0.781	-0.0050
Process Cooling - electricity	0.863	-0.0053	0.731	-0.0053
Process Cooling - fuels	0.890	-0.0041	0.781	-0.0050
Electro-Chemical	0.978	-0.0008	0.831	-0.0048
Other - electricity	0.905	-0.0035	0.790	-0.0052
Other - fuels	0.890	-0.0041	0.781	-0.0050
Non-Manufacturing				
Distillate	0.799	-0.0080	0.606	-0.0120
Asphalt	0.601	-0.0180	0.483	-0.0200
Other Fuels	0.799	-0.0080	0.642	-0.0120

Sources: Manufacturing: FOCIS Associates, Inc., *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, October 2005; Non-Manufacturing: Office of Integrated Analysis and Forecasting estimates.

Table B15. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
Pulp/Paper (S-O-A)					
	Wood Preparation				
		Bar-type chip screens	1		
		Belt conveyor	1		
		Chip conditioners	1		
		Chip Screening Equipment*	1		
		Cradle debarker		1	
		Enzyme-assisted debarker		1	
		Fine slotted wedge wire baskets	1		
		Improved screening processes	1		
		Ring Style debarker		1	
		Whole Tree Debarking/Chipping*		1	
	Chemical Pulping Technologies (Kraft, Sulfite)				
		Advanced Black Liquor Evaporator	1		
		Alkaline Sulfite Anthraquinone (ASOQ) & Neutral Sulfite Anthraquinone (NSAQ) Pulping		1	
		Anthraquinone Pulping		1	
		Batch Digesters	1		
		Continuous Digesters	1		
		EKONO's White Liquor Impregnation		1	
		Falling Film black liquor evaporation	1		
		Lime kiln modifications	1		
		Process Controls System	1		
		Radar Displacement Heating	1		
		Sunds Defibrator Cold Blow and Extended Delignification		1	
		Tampella Recovery System	1		
	Mechanical and Semi-Mechanical Technologies				
		Biopulping		1	
		Chemimechanical Pulping	1		
		Chemi-Thermomechanical Pulping (CTMP)	1		
		Cyclotherm System for Heat Recovery*	1		
		Heat Recovery in TMP*	1		
		Improvements in Chemi-thermomechanical pulping	1		
		LCR (low consistency refining)	1		
		PGW-Plus		1	
		Pressurized Groundwood (PGW)		1	
		Process Control System	1		
		Refiner Improvements	1		
		RTS (short Residence time, elevated Temperature, high speed)		1	
		Super Pressurized ground wood pulping		1	
		Thermopulping		1	

Table B15. Advanced and State of the Art Technologies

Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
		Thermo-Refiner Mechanical Pulping	1		
	Semi-Chemical	See Chemical and Mechanical S-O-A technologies above			
	Waste Paper Pulping Technologies				
		Advanced Deinking	1		
		Advanced Pulping	1		
		Improvements in steam use, computer control, etc.	1		
	Bleaching Oxygen Predelignification Technologies				
		Oxygen Bleaching		1	
		Displacement Bleaching	1		
		Bio-bleaching		1	
		Extended cooking (delignification)		1	
		Oxygen predelignification		1	
		Ozone Bleaching		1	
		Oxidative Extraction		1	
		Improved brownstock washing		1	
		Washing presses (post delignification)		1	
	Papermaking Technologies				
		Condebelt drying	1		
		Direct Drying cylinder firing	1		
		Dry sheet forming		1	
		Extended Nip Press*	1		
		Gap Forming	1		
		High consistency forming	1		
		Hot Pressing	1		
		Infrared profiling	1		
		IR Moisture Profiling*	1		
		Process Control System*	1		
		Reduced Air Requirement*	1		
		Waste Heat Recovery*	1		
Pulp/Paper (Advanced)					
	Wood Preparation				
		Improvements in S-O-A technologies shown above.			
	Chemical (Kraft/Sulfite) Technologies				
		Advanced Alcohol Pulping		1	
		Alcohol based solvent pulping		1	
		Biological Pulping		1	
		Black Liquor Concentration*	1		
		Black liquor gasifier and gas turbines	1	1	
		Black Liquor Heat Recovery *	1		
		Black Liquor Steam Reforming/Pulsed Combustion	1		1
		Combined Cycle Biomass Gasification	1	1	1
		Direct alkali recovery system	1		

Table B15. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
		High Selectivity Oxygen Delignification	1		1
		Improved composite tubes for Kraft Recovery Boilers*	1		1
		Increasing Yield and Quality of Low-Temperature, Low-Alkali Kraft Cooks with Microwave Pretreatment	1		1
		Non-Sulfur Chemimechanical (NSCM) Pulping		1	
		Ontario Paper Co. (OPCO) Process		1	
		Pretreatment of incoming pulp into drying section		1	
		Steam Reforming Black Liquor Gasification*	1		1
		Use of Borate Autocausticizing to Supplement Lime Kiln and Causticizing Capacities	1		1
	Mechanical Technologies				
		Advanced Chemical/Thermal Treatment	1		
		Non-Sulfur Chemimechanical (NSCM)		1	
		OPCO Process		1	
	Semi-Chemical Technologies				
		NSCM Process	1		
		OPCO Process		1	
	Waste Pulping				
		Mechanical alternatives to chemicals in recycle mills		1	1
		Replacing Chemicals in Recycle Mills with Mechanical Alternatives	1	1	1
		Removal of Light and Sticky Contaminants from Waste Paper	1		1
	Bleaching Technologies				
		Biobleaching		1	
		NO2/O2 Bleaching		1	
		Ozone Bleaching		1	
	Papermaking Technologies				
		Acoustic Humidity Sensor*	1		1
		Acoustic Separation Technology*	1		1
		Advances in Wet Pressing*	1		
		Air Impingement drying	1		
		Air Radio-Frequency-Assisted (ARFA) Drying*	1		
		Airless Drying	1		
		High-Consistency Forming*	1		
		Impulse Drying of Paper	1		1
		Impulse Drying*	1		
		Infrared Drying	1		
		Linear Corrugating		1	1

Table B15. Advanced and State of the Art Technologies

Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
		Molten-Film High-Intensity Paper Dryer*		1	1
		Online Fluidics Controlled Headbox*	1		1
		Online Paper Sensors*	1		1
		Press Drying*	1		
		Steam impingement drying	1		
	Sludge Combustion				
		Methane De-Nox Reburn Process*	1		1
Glass (S-O-A)					
	Batch Preparation Technologies		1		
		Computerized Weighing, Mixing, and Charging	1		
	Melting/Refining Technologies				
		Automatic Tap Charging Transformers for Electric Melters	1		
		Chemical Boosting	1		
		Chimney Block Regenerator Refractories	1		
		Dual-Depth Melter	1		
		Oxygen Enriched Combustion Air*	1		
		Recuperative Burners*	1		
		Reduction of Regenerator Air Leakage*	1		
		Sealed-in Burner Systems*	1		
	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				
		Integrated Batch and Cullet Preheat for Glass Furnaces*	1		1
		Electrostatic Batch Preheater System*			1
		SingleChip Color Sensor*	1		1
	Melting/Refining Technologies				
		Coal-Fired Hot Gas Generation*	1		
		Direct Coal Firing	1		
		Energy Efficient, Electric Rotary Furnace for Glass Molding of Precision Optical Blanks	1		1
		Excess Heat Extraction from Regenerators	1		
		Furnace Insulation Materials*	1		
		High Luminosity, Low-Nox Burner	1		1
		High-Intensity Plasma Glass Melter		1	1
		Hollow Fiber Membrane Air Separation Process*		1	
		Measurement and Control of Glass	1		1

Table B15. Advanced and State of the Art Technologies

Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
		Feedstocks			
		Molybdenum-Lined Electric Melter		1	
		Oxy-Gas submerged combustion (Energy-Efficient Glass Melting)		1	1
		Oxygen Enriched Combustion System Performance Study	1		1
		Phase/Doppler Laser Light-Scattering System*	1		1
		Pressure Swing Adsorption Oxygen Generator*	1		
		Rotary Burner Technology Demonstration (Phase I)	1		1
		Sol-Gel Process		1	
		Thermochemical Recuperator	1		
		Ultrasonic Bath Agitation/Refining*	1		
	Forming/Post-Forming Technologies				
		Advanced Low-E Coatings	1		1
		Automatic Gob Control	1		
		Improved Glass Strengthening Techniques*	1		
		Improved Protective Coatings*	1		
		Mold Cooling Systems	1		
		Mold Design*	1		
Cement (S-O-A)					
	Process Technologies				
		Addition of pre-calciner to pre-heater kiln	1		
		Controlled Particle Size Distribution Cement	1		
		Conversion to modern grate cooler	1		
		Dry-Preheater/Precalciner Kilns	1		
		Finish Mill Internals, Configuration, and Operation	1		
		Grinding Aids*	1		
		Heat Recovery for Power Generation	1		
		Kiln combustion system improvements	1		
		Kiln Feed Slurry Dewatering*	1		
		Kiln Internal Efficiency Enhancement*	1		
		Kiln Radiation and Infiltration Losses*	1		
		Kiln shell heat loss reduction	1		
		Long dry kiln conversion to multi-stage pre-heater, pre-calciner kiln		1	
		Low Pressure drop cyclones for suspension pre-heaters	1		
		Optimize grate coolers	1		
		Use of waste fuels	1		
		Waste Heat Drying*	1		
	Finish Grinding Technologies				

Table B15. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
		Controlled Particle Size Distribution Cement*	1		
		Finish Mill Internals, Configuration, and Operation	1		
		Grinding Media and Mill Linings*	1		
		High efficiency classifiers	1		
		High Pressure Roller Press	1		
		High-Efficiency Classifiers*	1		
		High-pressure roller press	1		
		Improve mill internals	1		
		Improved grinding media (ball mills)	1		
		Roller Mills*	1		
		Utilization of Ground Granulated Blast Furnace Slag (GGBS)	1		
Cement (Advanced)					
	Process Technologies				
		Advanced (Non-Mechanical) Comminution	1		
		Advanced Kiln Control*	1		
		Advanced Waste Combustion	1		
		Alkali Specification Modification*	1		
		All-Electric Kilns		1	
		Autogenous Mills	1		
		Blended Cements*	1		
		Catalyzed, Low-Temperature Calcination		1	
		Cone Crushers*	1		
		Differential Grinding	1		
		Fluidized-Bed Drying	1		
		Grinding Mill Optimization Software*	1		1
		Modifying Fineness Specifications*	1		
		Sensors and Controls*	1		
		Sensors for On-Line Analysis*	1		
		Stationary Clinkering Systems	1		
	Finish Grinding	Advanced (Non-Mechanical) Comminution		1	
		Blended Cements*	1		
		Cone Crushers*	1		
		Grinding Mill Optimization Software	1		1
		Modifying Fineness Specifications*	1		
		Sensors and Controls*	1		
I&S (S-O-A)					
	Cokemaking Technologies				
		Carbonization Control	1		
		Coal Moisture Control			
		Coke Dry Quenching (CDQ)*	1		
		Continuous Coke Making		1	

Table B15. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
		Non-Recovery Coke Ovens		1	
		Programmed Heating	1		
		Sensible Heat Recovery of Off-Gases*	1		
		Wet Quenching of Coke with Energy Recovery*	1		
	Ironmaking Technologies				
		Coal Injection*	1		
		COREX		1	
		Direct Reduced Iron (DRI) use	1		
		External Desulfurization-inject calcium carbide or mag-coke as a desulfurizing reagent*	1		
		Hot Stove Waste Heat Recovery*	1		
		Induction Heated Hot Metal Mixer	1		
		Insulation of Cold Blast Main*	1		
		Midrex/HBI		1	
		Movable Throat Armor*	1		
		Optimization by enhanced control systems*	1		
		Optimize Preheated Blast Air	1		1
		Other fuel injection* (e.g., natural gas, oil, coke oven gas)	1		
		Oxygen injection	1		
		Paul Wurth Top*	1		
		Recovery of BF Gas Released During Charging	1		
		Slag Waste Heat Recovery*	1		
		Stave-cooling & steam recovery	1		
		Stove Operation Optimization	1		
		Submerged Arc Furnace (SAF) to produce iron from reduced pellets		1	
		Top Gas Pressure Recovery*	1		
		Top Gas Pressure Recovery*	1		
		Waste energy fuel injection* (e.g., plastics)	1		
	Steelmaking Technologies (BOF)				
		Combined Top and Bottom Oxygen Blowing*	1		
		Gas Recovery in Combination with Sensible Heat Recovery*	1		
		In-Process Control (Dynamic) of Temp and Carbon Content*	1		
		Post Combustion*	1		
		Two working vessels concept*	1		
	Steelmaking Technologies (EAF)				
		Bottom Tap Vessels*	1		
		Computerization*	1		

Table B15. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
		DC Arc Furnaces*	1		
		Direct reduced Iron (DRI)			
		Energy Optimizing Furnaces*		1	
		Foamy Slag Practice (with Long Arc)	1		
		Gas stirring including Argon stirring	1		
		Hot Briquetted Iron (HBI)	1		
		Hot Charging DRI	1		
		Induction Furnaces*		1	
		Induction Stirring	1		
		Long Arc Foamy Slag Practice*	1		
		Material Handling Practices*	1		
		Oxy-Fuel Burners*	1		
		Post Combustion*	1		
		Process Control by Laser Based Gas Sensor*	1		1
		Scrap-Preheating*	1		
		Ultra-High Power (UHP)*	1		
		Water-Cooled Electrode Sections*	1		
		Water-Cooled Furnace Panels and Top*	1		
	Other Technologies				
		Injection Steelmaking (ladle metallurgy)	1		
		Ladle Drying and Preheating*	1		
	Specialty Steelmaking Processes				
		Argon-Oxygen Decarburization (AOD)*		1	
		Electron Beam Melting (EBM)*		1	
		Electroslag Remelting (ESR)*		1	
		Vacuum Arc Decarburization*			
		Vacuum Arc Remelting (VAR)*		1	
		Vacuum Induction Melting (VIM)*		1	
	Steelcasting Technologies				
		Clean Cast Steel			1
		Continuous-Conti-Casting	1		
		Modern Casters (near net shape)*		1	
		Plasma heated Tundish for temperature control	1		
		Slab Heat Recovery*	1		
		Soaking Pit Utilization and Pit Vacant Time*	1		
		Thin Slab Casting		1	
		Thin Strip Caster*		1	
	Steelforming (Rolling) Technologies				
		Air Preheating*	1		
		Combustion Control*	1		
		Continuous Cold Rolling		1	
		Covered Delay Table*	1		

Table B15. Advanced and State of the Art Technologies

Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
		Direct Rolling (Hot Direct Rolling, Hot Charge Rolling)	1		
		Evaporative Cooling of Furnace Skids	1		
		Fuel Gas Preheating	1		
		Improved Insulation*	1		
		Increased Length of the Preheating Furnace	1		
		PC Controlled Hot Rolling	1		1
		Preheating Furnaces			
		Ultra-thin steel		1	
		Waste Heat Boilers on Furnaces	1		
		Waste Heat Recovery and Air Preheating*	1		
		Waste Heat Recovery and Fuel Gas Preheating*	1		
	Steel Finishing				
		Continuous Annealing		1	
		Pickling - Insulated Floats*	1		
I&S (Advanced)					
	Scrap Preparation				
		Electrochemical Dezincing of Steel Scrap		1	1
	Ironmaking Technologies				
		Advanced Sensors	1		1
		AISI direct smelting		1	
		CCF direct smelting		1	
		Cicored		1	
		Cyclone Converter Furnace		1	
		DIOS direct smelting		1	
		FASTMELT		1	
		HiSmelt		1	
		Hot Oxygen Injection into the Blast Furnace*	1		1
		Intelligent Control of the Cupola Furnace	1		1
		Iron Carbide Process		1	
		Plasmared		1	
		Pulverized Coal Injection (PCI) at High Rates	1		1
		REDSMELT		1	
		Rotary Hearth Iron Ore Reduction		1	1
		Submerged Arc Furnace (SAF)		1	
	Steelmaking Technologies				
		BOF Scrap Preheating*	1		
		Capture heat from off-gases by constructing twin shells		1	
		Capture heat from off-gases by mounting shafts on the furnace roof		1	
		Capture heat from off-gases by pulling gases through a side door into scrap-filled		1	

Table B15. Advanced and State of the Art Technologies

Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
		tunnel			
		Continuous charging of scrap to EAF		1	
		Direct Steelmaking (AISI)		1	1
		Elred		1	
		Energy Optimizing Furnace (EOF)		1	
		Fast electrode changing		1	
		Flue Dust Recycling	1		1
		Full Post Combustion in BOF	1		
		Full Post Combustion in EAF	1		
		Increase gas, oxygen, and carbon use in EAF		1	
		Increased Scrap Use in BOF			
		Injection of Carbonaceous Fuels			
		Injection Steelmaking	1		
		Inred		1	
		Ladle Drying and Preheating*	1		
		Modern Electric Arc Furnace with Continuous Charging/Scrap Preheating	1		
		Optical Sensor for Post-Combustion Control in EAF Steelmaking	1		1
		Optimization of Post Combustion (in BOF and EAF)	1		1
		Plasmamelt		1	
		Processing Electric Arc Furnace Dust into Salable Products	1		1
		Use multiple burner/lances for carbon, oxygen, and oxy-fuel in EAF		1	
		Use waste gas to preheat scrap		1	
	Steelcasting Technologies				
		Advanced Sensors	1		1
		Clean Cast Steel	1		1
		Direct Strip Casting*		1	
		Horizontal Continuous Caster*		1	
		Magnetic Gate System for Molten Metal Flow Control	1		1
		Near Net Shapecasting*		1	
		Spray Casting		1	1
		Three-Dimensional Objects by Photosolidification*	1		1
		Ultra Thin Strip Casting*		1	
		Use surface inspection devices to measure surface quality		1	
	Hot Rolling/Cold Rolling/Finishing				
		Advanced Coating	1		
		Advanced High Intensity Infra-Red Preheating of Steel Strip	1		1
		Automated surface inspection	1		1

Table B15. Advanced and State of the Art Technologies

Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
		Continuous Cold Rolling and Finishing	1		
		Controlled Thermo-Mechanical Processing (CTMP) of Tubes and Pipes for Enhanced Manufacturing and Performance	1		1
		Direct Flame Impingement Reheat Furnace (Development and Demonstration of a High-Efficiency, Rapid-Heating, Low-Nox alternative to Conventional Heating of Steel Shapes)	1		1
		Efficient reheat furnaces with elements such as recuperators, low-nox burners, and computer controls		1	
		Improved Surface Quality of Exposed Automotive Sheet Steels	1		1
		Intelligent Systems for Induction Hardening	1		1
		Laser Ultrasonics to Measure Grain Size	1		1
		Laser Ultrasonics to Measure Tube Wall Thickness	1		1
		Nickel Aluminide Radiant Heater	1		1
		Non-Chromium Passivation Techniques for Electrolytic Tin Plate		1	1
		On-Line Non-Destructive Mechanical Properties Measurement	1		1
		Phase Measurement of Galvanneal	1		1
		Ultra-thin strip caster to strip ready for galvanizing		1	
Aluminum (S-O-A)					
	Alumina Refining Technologies				
		Advanced Digesters	1		
		Heat Recovery*	1		
	Primary Aluminum Technologies				
		Advanced Cells	1		
		Advanced Process Controls*	1		1
		Pre-baked Anodes	1		
	Semi-Fabrication Technologies				
		Continuous-Strip Casting		1	
		Advanced Burners for Melting Furnaces			
		Electromagnetic Casting	1		
		Induction Heating	1		
	Secondary Aluminum Technologies				
		Advanced Burners	1		
		Advanced Melting		1	
		Induction Melting		1	
Aluminum (Advanced)					
	Alumina Refining Technologies				
		Advanced Digestors	1		

Table B15. Advanced and State of the Art Technologies

Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
	Primary Aluminum Technologies				
		Aluminum Carbothermic Technology Advanced Reactor Process		1	1
		Bipolar Cell Technology		1	
		Converting Spent Pot Liners (SPL) to Products*		1	1
		Inert Anodes*	1		1
		Low-Temperature Reduction of Alumina		1	1
		Microwave-Assisted Electrolytic Cell	1		1
		Reduction of Oxidative Melt Loss	1		1
		Wettable Cathodes*	1		
	Semi-Fabrication Technologies				
		Improved Grain-Refinement Process*	1		1
		Induction Heaters		1	
		Novel Techniques for Increasing Corrosion Resistance of Aluminum and Al Alloys	1		1
		Spray Casting	1		1
		Spray Rolling Aluminum Strip	1		1
	Secondary Aluminum Technologies				
		Aluminum Salt Cake: Electrodialysis Processing of Brine*		1	1
		Heat Recovery Technology	1		
		Immersion Heating (Advanced Clean Aluminum Melting Systems)		1	1
		New Melting Technology (submerged radiant burners)	1		
		Oxidative Melt Loss Reduction*	1		1
		Plasma Furnaces for dross treatment	1	1	
		Preheaters for scrap*	1		
		Vertical Flotation Melter		1	1
Chemical and Generic Technologies (Advanced)					
	Synthesis				
		Advanced Catalytic Hydrogenation Retrofit Reactor*	1		1
		Biofine Technology	1		1
		Novel Membrane-based Process for Producing Lactate Esters		1	1
		Alloys for Ethylene Production*	1		1
	Separation				
		Advanced Sorbents for Gas Separation*		1	1
		Advanced Inorganic Membranes(Impact Chemical and Petrochemical Industries)	1	1	1
		Membrane Systems for Energy Efficient Separation of Light Gases	1	1	1
	Electrochemistry				
		Advanced Electrodeionization	1		1

Table B15. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Subprocess	Alternative Process	EERE
		Technology*			
		Advanced Chlor-Alkali Technology		1	1
	Product Recovery				
		Chlorosilane Recovery from Silicone Production	1		1
		Olefine Recovery from Chemical Waste Streams*	1		1
		Pressure Swing Adsorption for Product Recovery*	1		1
		Separation and Recovery of Thermo Plastics for Reuse via Froth Flotation*	1		1
	Heating				
		Development of a Highly Preheated Combustion Air System with/without Oxygen Enrichment	1		1
		Low-Nox High Luminosity Burner	1		1
		Nox Emission Reduction by Oscillating Combustion	1		1
		Ultra-Low Nox Burners with Flue Gas Recirculation and Partial Reformer	1		1
	Boilers				
		Forced Internal Recirculation Burner	1		1
		Super Boiler - including recovery of latent heat in flue gases		1	1
	Metals-based Durables				
		Lost Form Casting Technology		1	1

Source: FOCIS Associates, Inc., *Industrial Technology and Data Analysis Supporting the NEMS Industrial Model*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, October 2005.

Table B16. 2002 Motor Characteristics

Industrial Sector Horsepower Range	2002 Stock	2002 Average Energy Use (kWh/motor)	2002 Average Efficiency	Average Part Load	Average Operating Hours
Food					
1 - 5 hp	676117	5568	0.8130	0.61	3829
6 - 20 hp	232005	24840	0.8713	0.61	3949
21 - 50 hp	63280	96574	0.9013	0.61	4927
51 - 100 hp	24649	212729	0.9272	0.61	5524
101 - 200 hp	18733	323470	0.9348	0.61	5055
201 - 500 hp	8784	605525	0.9375	0.61	3711
> 500 hp	4487	1537901	0.9303	0.61	5362
Bulk Chemicals					
1 - 5 hp	325877	5326	0.8197	0.65	4082
6 - 20 hp	230184	29476	0.8739	0.65	4910
21 - 50 hp	111141	86578	0.9044	0.65	4873
51 - 100 hp	45277	216594	0.9241	0.65	5853
101 - 200 hp	31124	484522	0.9348	0.65	5868
201 - 500 hp	16900	1132905	0.9333	0.65	6474
> 500 hp	7737	5631554	0.9324	0.65	7566
Metal-Based Durables					
1 - 5 hp	3646335	2752	0.8189	0.62	1985
6 - 20 hp	1144239	15472	0.8704	0.62	2959
21 - 50 hp	295346	49198	0.8992	0.62	3371
51 - 100 hp	49862	157962	0.9198	0.62	4621
101 - 200 hp	29050	210203	0.9348	0.62	4905
201 - 500 hp	5413	1580555	0.9367	0.62	7409
> 500 hp	2429	3010632	0.9303	0.62	8164
Balance of					
1 - 5 hp	1561446	4221	0.8293	0.62	2933
6 - 20 hp	878175	17479	0.8828	0.62	3180
21 - 50 hp	291577	62012	0.9032	0.62	3785
51 - 100 hp	103188	189860	0.9267	0.62	4990
101 - 200 hp	66816	338198	0.9426	0.62	4601
201 - 500 hp	18822	838473	0.9423	0.62	5454
> 500 hp	5705	4321343	0.9291	0.62	7501

Sources: U.S. Department of Energy, *United States Industrial Electric Motor Systems Market Opportunities Assessment* (Burlington, MA, December 1998); Energy Information Administration, *Manufacturing Consumption of Energy 2002*.

Table B17. Cost and Performance Parameters for Industrial Motor Choice Model

Industrial Sector Horsepower Range	2002 Stock Efficiency (%)	EPACT92 Minimum Efficiency (%)	EPACT92 Minimum Eff. Cost (2002$)	Premium Efficiency (%)	Premium Cost (2002$)
Food					
1 - 5 hp	81.3	86.7	327	88.9	351
6 - 20 hp	87.1	91.4	901	92.7	947
21 - 50 hp	90.1	92.6	1,448	93.7	1,618
51 - 100 hp	92.7	94.4	3,338	95.1	3,430
101 - 200 hp	93.5	94.6	6,734	95.9	7,670
201 - 500 hp	93.8	93.4	12,147	96.1	13,560
> 500 hp	93.0	94.8	19,148	na	na
Bulk Chemicals					
1 - 5 hp	82.0	86.9	327	89.1	351
6 - 20 hp	87.4	91.6	901	92.9	947
21 - 50 hp	90.4	92.7	1,448	93.8	1,618
51 - 100 hp	92.4	94.4	3,338	95.2	3,430
101 - 200 hp	93.5	94.7	6,734	96.0	7,670
201 - 500 hp	93.3	93.6	12,147	96.1	13,560
> 500 hp	93.2	94.9	19,148	na	na
Metal-Based Durables					
1 - 5 hp	81.9	86.8	327	88.9	351
6 - 20 hp	87.0	91.5	901	92.8	947
21 - 50 hp	89.9	92.6	1,448	93.8	1,618
51 - 100 hp	92.0	94.4	3,338	95.1	3,430
101 - 200 hp	93.5	94.6	6,734	95.9	7,670
201 - 500 hp	93.7	93.5	12,147	96.1	13,560
> 500 hp	93.0	94.8	19,148	na	na
Balance of					
1 - 5 hp	82.9	86.8	327	88.9	351
6 - 20 hp	88.3	91.5	901	92.8	947
21 - 50 hp	90.3	92.6	1,448	93.8	1,618
51 - 100 hp	92.7	94.4	3,338	95.1	3,430
101 - 200 hp	94.3	94.6	6,734	95.9	7,670
201 - 500 hp	94.2	93.5	12,147	96.1	13,560
> 500 hp	92.9	94.8	19,148	na	na

Sources: U.S. Department of Energy, *United States Industrial Electric Motor Systems Market Opportunities Assessment* (Burlington, MA, December 1998), and U.S. Department of Energy, *MotorMaster+ 3.0* software database (October 13, 1999).

Note: The efficiencies listed in this table are operating efficiencies based on average part-loads. Because the average part-load is not the same for all industries, the listed efficiencies for the different motor sizes vary across industries.

Table B18. Payback Acceptance Rate Assumptions for Motor Decisions

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

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

Table B19. Energy Consumption in Boilers (trillion Btu)

Industry	Region	Alpha	Natural Gas	Coal	Oil	Renewables
Food	Northeast	-1.50	28	2	5	2
	Midwest	-1.50	125	154	4	15
	South	-1.50	86	10	3	33
	West	-1.50	53	13	4	6
Pulp and Paper	Northeast	-1.50	56	2	30	87
	Midwest	-1.50	64	75	8	103
	South	-1.50	157	128	58	864
	West	-1.50	48	14	7	164
Bulk Chemicals	Northeast	-1.50	41	3	10	0
	Midwest	-1.50	86	31	18	0
	South	-1.50	663	180	319	0
	West	-1.50	48	27	3	0
Glass	Northeast	-1.50	0	0	6	2
	Midwest	-1.50	1	0	0	1
	South	-1.50	1	0	9	1
	West	-1.50	0	0	0	0
Cement	Northeast	-1.50	0	1	0	0
	Midwest	-1.50	0	2	0	0
	South	-1.50	0	3	0	0
	West	-1.50	0	2	0	0
Steel	Northeast	-1.50	10	1	0	0
	Midwest	-1.50	24	1	0	67
	South	-1.50	9	0	0	22
	West	-1.50	1	0	0	10
Aluminum	Northeast	-1.50	2	0	0	1
	Midwest	-1.50	5	0	0	0
	South	-1.50	10	0	0	8
	West	-1.50	2	0	0	0
Metal-Based Durables	Northeast	-1.50	18	21	5	9
	Midwest	-1.50	63	0	1	13
	South	-1.50	31	0	2	3
	West	-1.50	11	0	1	1
Balance of Manufacturing	Northeast	-1.50	40	1	5	15
	Midwest	-1.50	87	89	4	125
	South	-1.50	153	21	31	158
	West	-1.50	47	6	2	69

Note: Alpha is the parameter of the logistic switching function.
Source: Energy Information Administration, Office of Integrated Analysis and Forecasting estimates based on *Manufacturing Consumption of Energy 2002*.

Table B20. Boiler Population Characteristics Used for Cogeneration System Sizing and Steam Load Segmentation

	Firing Capacity (million Btu/hour)					
Industry	1.5 -10	10-50	50-100	100-250	250-500	> 500
Food	14.8%	31.0%	18.1%	22.9%	5.4%	7.8%
Paper	1.1%	6.5%	9.7%	21.7%	25.0%	36.0%
Chemicals	6.9%	19.8%	15.7%	21.0%	15.0%	21.6%
Primary Metals	6.7%	17.2%	20.1%	15.8%	16.5%	23.8%
Other Manufacturing	10.5%	28.4%	22.1%	22.2%	6.9%	10.0%

Source: Energy and Environmental Analysis, Inc, *Characterization of the U.S. Industrial Commercial Boiler Population* (submitted to Oak Ridge National Laboratory), May 2005

Table B21. Characteristics of Candidate Cogeneration Systems

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

Source: National Renewable Energy Laboratory, *Gas-Fired Distributed Energy Resource Technology Characterizations*, NREL/TP-630-34783, Golden, CO, November 2003.

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

Table B22. Payback Acceptance Rate Assumptions for Cogeneration Market Penetration

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

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

Appendix C. Model Abstract

Model Name:
Industrial Demand Model

Model Acronym:
None

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

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

Most Recent Model Update:
October 2005.

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

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

Official Model Representatives:

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Documentation:
Model Documentation Report: Industrial Sector Model of the National Energy Modeling System, January 2006.

Archive Media and Installation Manual(s):
The model is archived as part of the National Energy Modeling System production runs used to generate the *AEO2006*.

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, 2002 through 2030.

Modeling Features:

Structure: 9 manufacturing and 6 nonmanufacturing industries. The manufacturing industries are further subdivided into the energy intensive and non-energy-intensive industries.

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

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

Non-DOE Input Sources:

Historical Dollar Value of Shipments in the Industrial Sector
Energy Expenditures in the Agriculture and Construction sectors
Energy Consumption in the Mining sector

DOE Input Sources:

Form EI-860B: Annual Electric Generator Report – Nonutility
Electricity generation, total and by prime mover
Electricity generation for own use and sales
Capacity utilization
Manufacturing Energy Consumption Survey 2002, March 2005
State Energy Data System 2001, August 2004

Computing Environment:

Hardware Used: Intel Xeon CPU
Operating System: Microsoft Windows XP
Language/Software Used: Intel Visual Fortran 9.0
Estimated Run Time: 30 seconds for a 2002-2030 run in non-iterating, stand-alone mode.
Special Features: None