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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 14th 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 2010*. These changes include:

- Updated benchmarks to annual data sets including:
    - The State Energy Data System (*SEDS2007*)
    - The Annual Energy Review (*AER2008*)
    - EIA Surveys 860, 923, and 906
- Extended projections to 2035
- Revised bulk chemical industry model
- Extended Technology Possibility Curves to 2035

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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 Module. 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 Module for model analysts, users, and the public. Second, this report meets the legal requirement of the U.S. 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 Module 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 Module generates long-term (up to the year 2035) projections of industrial sector energy demand as a component of the NEMS integrated modeling system. From the NEMS system, the Industrial Module receives fuel prices, employment data, and the value of industrial shipments. Based on the values of these variables, the Industrial Module passes back to the NEMS system estimates of consumption by fuel types.

The NEMS Industrial Module estimates energy consumption by energy source (fuels and feedstocks) for 15 manufacturing and 6 nonmanufacturing industries. The manufacturing industries are classified as energy-intensive manufacturing industries and non-energy-intensive manufacturing industries. The manufacturing industries are modeled through the use of a detailed process flow or end-use accounting procedure. The energy-intensive bulk chemicals industry is sub-divided into four components, each with individual detailed process flows. The nonmanufacturing industries are represented in less detail. The Industrial Module projects energy consumption at the four Census Region level; energy consumption at the Census Division level is allocated by using data from the *State Energy Data Report 2007*.[1] The national-level values reported in *Annual Energy Review 2008*[2] were allocated to the Census Divisions using the *State Energy Data Report 2007*.[3]

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[1] Issued August 28, 2009, http://www.eia.doe.gov/emeu/states/_seds.html

[2] Energy Information Administration, Annual Energy Review 2008, DOE/EIA-384(2008), June 2009, http://www.eia.doe.gov/emeu/aer/contents.html

[3] 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*

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

Archival Media

The model is archived as part of the National Energy Modeling System production runs used to generate the *Annual Energy Outlook 2010*.

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Organization of this Report

Chapter 2 of this report discusses the purpose of the NEMS Industrial Demand Module, detailing its objectives, input and output variables, and the relationship of the Industrial Module to the other modules of the NEMS system. Chapter 3 of the report describes the rationale behind the Industrial Module 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 Module. Appendix A is a bibliography of data sources and background materials used in model development. Appendix B provides the input data for *AEO2010*. Appendix C is the model abstract.

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.

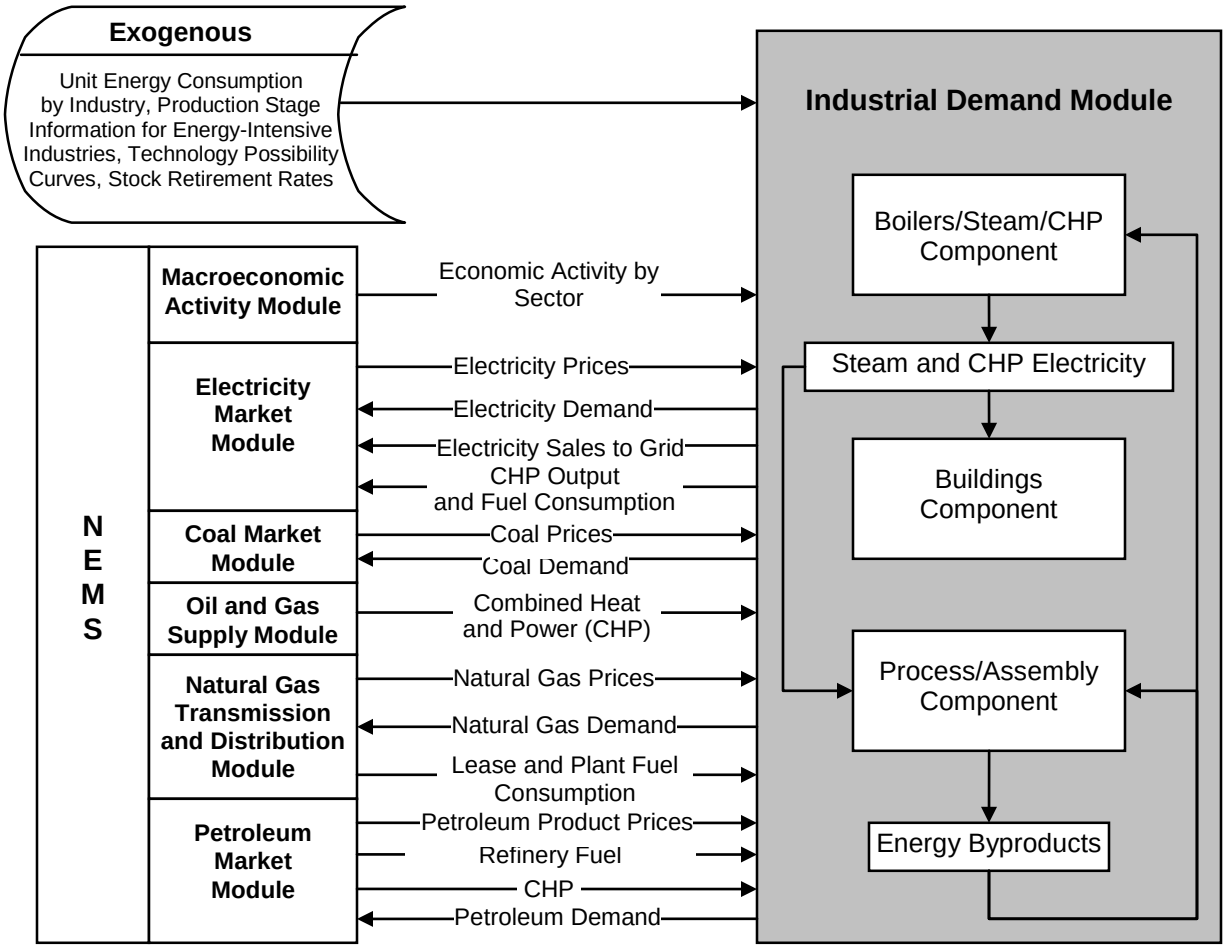
2. Model Purpose

Model Objectives

The NEMS Industrial Demand Module was designed to project industrial energy consumption by fuel type and industry as defined in the North American Industrial Classification System (NAICS). [4] The Industrial Module generates long-term (up to the year 2035) projections of industrial sector energy demand as a component of the NEMS integrated modeling system. From the NEMS system, the Industrial Module receives fuel prices, employment data, and the value of shipments, which are expressed in 2007 dollars, for industrial activity. Based on the values of these variables, the Industrial Module passes back to the NEMS system estimates of fuel consumption for 17 main fuels, including feedstocks and renewables, (Figure 1) for each of 21 industry groups. The Industrial Module projects energy consumption at the four Census Region level; energy consumption is allocated to the Census Division level based on State Energy Data System (SEDS) data.[5]

[4]Executive Office of the President, Office of Management and Budget, *North American Industry Classification System, United States, 2007*. Washington, DC, 2007.
[5] *State Energy Data Report 2007*, http://www.eia.doe.gov/emeu/states/_seds.html.

Figure 1. Industrial Module Interactions Within NEMS



The NEMS Industrial Module 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 uses 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 Module 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 the major production processes or end uses, is used to model the manufacturing industries. This approach provides considerable detail about how energy is consumed in a particular industry. The Industrial Module uses "technology bundles" to characterize technological change. These bundles are defined for each production process step for five of the manufacturing industries, for each end use in the four remaining manufacturing industry groups, and for whole industries in the nonmanufacturing sub-sector. The industries defined by process steps are pulp and paper, glass, cement, steel, and aluminum. The industries defined by end use 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 2035 UEC' is the intensity expected to prevail for a new installation in 2035. 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.

Interaction with Other NEMS Modules

Figure 1 shows the Industrial Module 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.

3. Model Rationale

Theoretical Approach

Introduction

The NEMS Industrial Module 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 knowledge 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 the inclusion of not only manufacturing, but also agriculture, mining, and construction industries in this sector. 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. Other industrial modeling approaches 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 Module. 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 Module 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 capital stock vintage 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 Module uses “technology bundles” to characterize technological 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

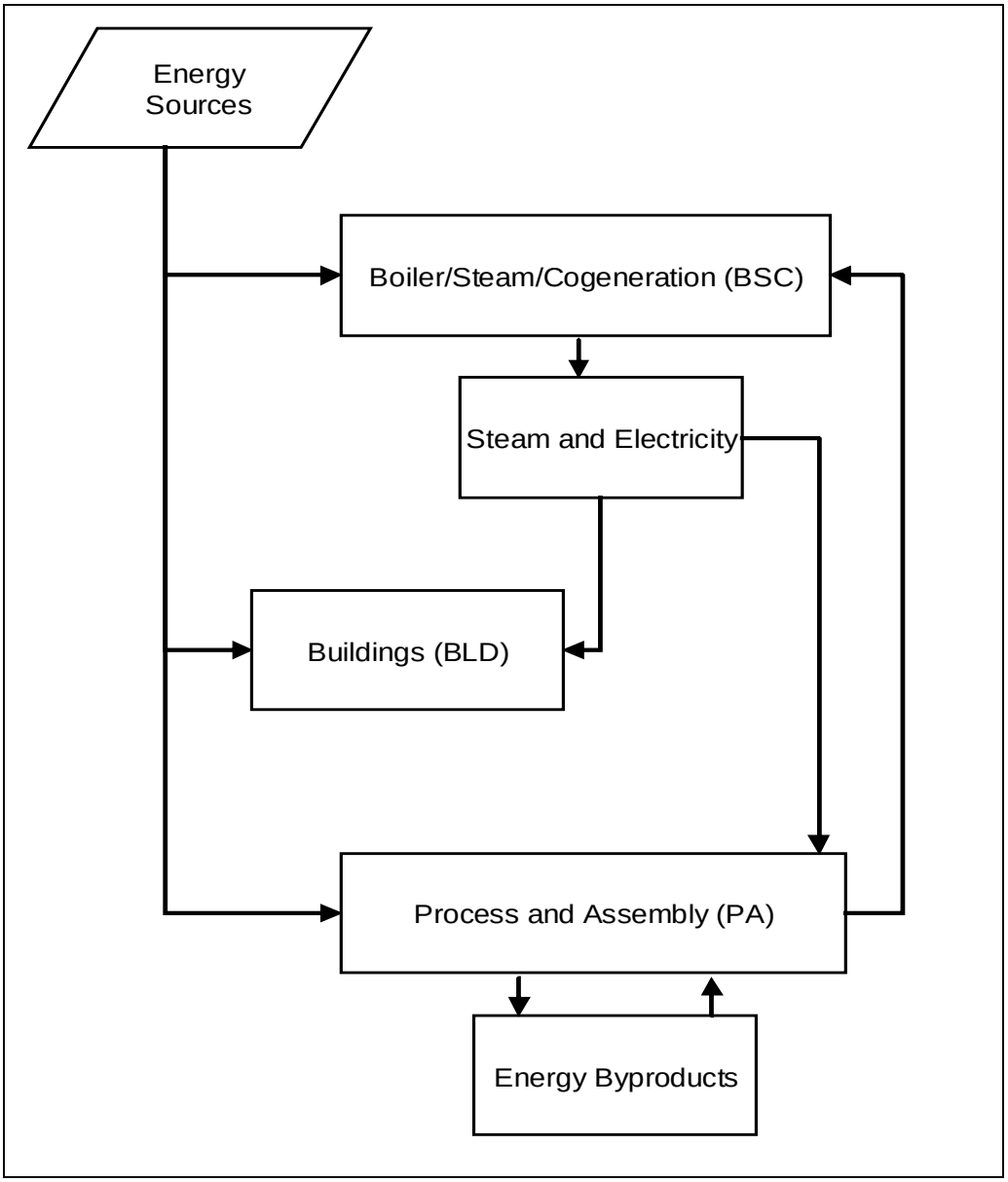
The industrial sector consists of numerous heterogeneous industries. The Industrial Module classifies these industries into three general groups: energy-intensive manufacturing industries, non-energy-intensive manufacturing industries, and non-manufacturing industries. There are eight energy-intensive manufacturing industries; seven of these are modeled in the Industrial Module. 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 eight non-energy-intensive industries. These are as follows: fabricated metals (NAICS 332), machinery (NAICS 333), computers and electronics (NAICS 334), electrical equipment and appliances (NAICS 335), transportation equipment (NAICS 336), wood products (NAICS 321), plastic and rubber products (NAICS 326), and the balance of manufacturing (all NAICS manufacturing sectors that are not included elsewhere). The eighth energy-intensive industry, petroleum refining (NAICS 32411) is modeled in detail in the Petroleum Market Module, 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.

For each industry, the flow of energy among the three model components follows the arrows in Figure 2. Industrial Module Components

. 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 Module 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 (in constant 2007 dollars) produced by each industry group. The value of shipments by NAICS classification is provided to the Industrial Module 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 Module 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 2. Industrial Module 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.[6] This formulation has been used to account for the countervailing movements in manufacturing employment and value of shipments. Manufacturing 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 1 identifies 6 nonmanufacturing and 15 manufacturing industries 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). Of the manufacturing industries, seven of the most energy-intensive are modeled in greater detail in the Industrial Demand Module. Energy consumption for Petroleum Refining (NAICS 32411), also an energy-intensive industry, is modeled by the Petroleum Market Module of NEMS.

Energy Sources Modeled

The NEMS Industrial Module estimates energy consumption by 21 industries for 14 fuels. The fuels modeled in the Industrial Module 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.

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

Table 1. Industry Categories

Energy-Intensive Manufacturing
Food Products (NAICS 311)
Paper and Allied Products (NAICS 322)
Bulk Chemicals
Inorganic (NAICS 32512 to 32518)
Organic (NAICS 32511, 32519)
Resins (NAICS 3252
Agricultural (NAICS 3253)
Glass and Glass Products (NAICS 3272)
Cement (NAICS 32731)
Iron and Steel (NAICS 3311)
Aluminum (NAICS 3313)
Non-energy-Intensive Manufacturing
Metal-Based Durables
Fabricated Metals (NAICS 332)
Machinery (NAICS 333)
Computers and Electronics (NAICS 334)
Electrical Machinery (NAICS 335)
Transportation Equipment (NAICS 336)
Wood Products (NAICS 321)
Plastic Products (NAICS 326)
Balance of Manufacturing (all remaining manufacturing NAICS, excluding Petroleum refining (32410)
Non-Manufacturing Industries
Agriculture, Crops (NAICS 111)
Agriculture, Other (NAICS 112-115)
Coal Mining (NAICS 2121)
Oil and Gas Mining (NAICS 211)
Other Mining (NAICS 2122-2123)
Construction (NAICS 233-235)
NAICS = North American Industrial Classification System Source: Office of Management and Budget, *North American Industry Classification System*, United States, 2007 (Springfield, VA, National Technical Information Service, 2007).

Key Computations

The key computations of the Industrial Module 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 Module.

Buildings Component UEC

Buildings are estimated to account for 9 percent of allocated heat and power energy consumption in manufacturing industries.[7] Estimates of 2002 manufacturing sector building energy consumption 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.

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.

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

[7]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.

durables, and the balance of manufacturing (excluding petroleum refining that is modeled in the Petroleum Market Module 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)

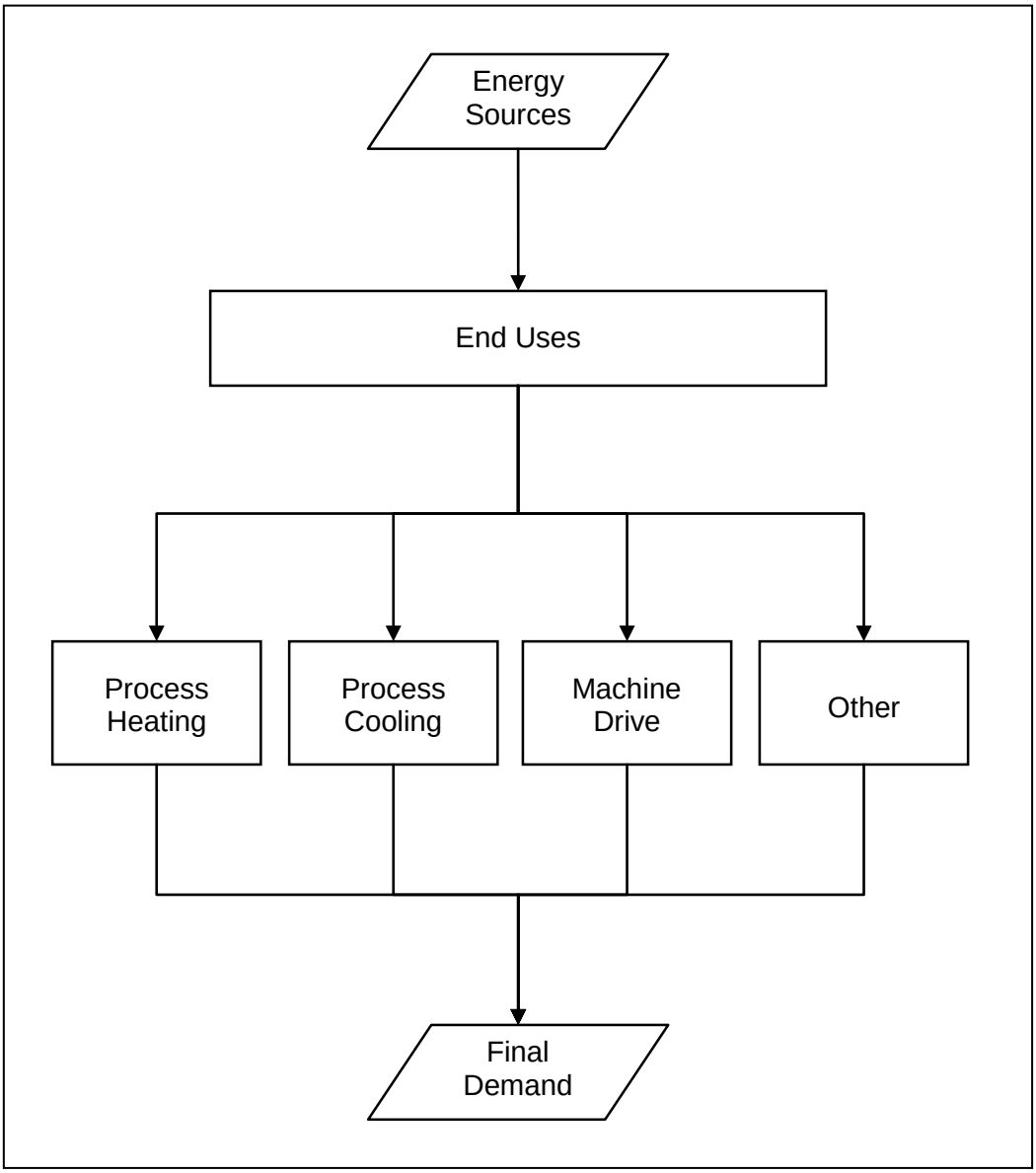
The food products industry accounted for 11 percent ($447 billion) of manufacturing value of shipments in 2002. The food products industry consumed approximately 1,123 trillion Btu of energy in 2002.[8] Energy use in the food products industry for the PA Component was estimated on the basis of end use in four major categories:

Process Heating;
Process Cooling;
Machine Drive; and
All Other Uses.

[8]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 3 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 3. 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 4 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/re-drying, effluent treatment, and other miscellaneous processes.

In 2002, 91 million tons of paper and paperboard products were produced. The major paper products include wood-free printing paper, ground wood 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 pulping, 5 percent from mechanical (ground wood) pulping, and 43 percent from waste fibers. The unit energy consumption 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 B13**.** Future additions to pulping capacity are assumed 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 inorganic and organic chemicals are basic chemicals, while plastics, agricultural chemicals, and other chemicals are either intermediates or final products. The bulk chemical industry was estimated to consume 36 percent (7.3 quadrillion Btu) of the total energy consumed in the manufacturing sector, while accounting for less than 4 percent ($195 billion) of manufacturing value of shipments.[9] This industry is a major energy feedstock user and a major cogenerator of electricity.

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

Figure 4. Paper Manufacturing Industry Process Flow

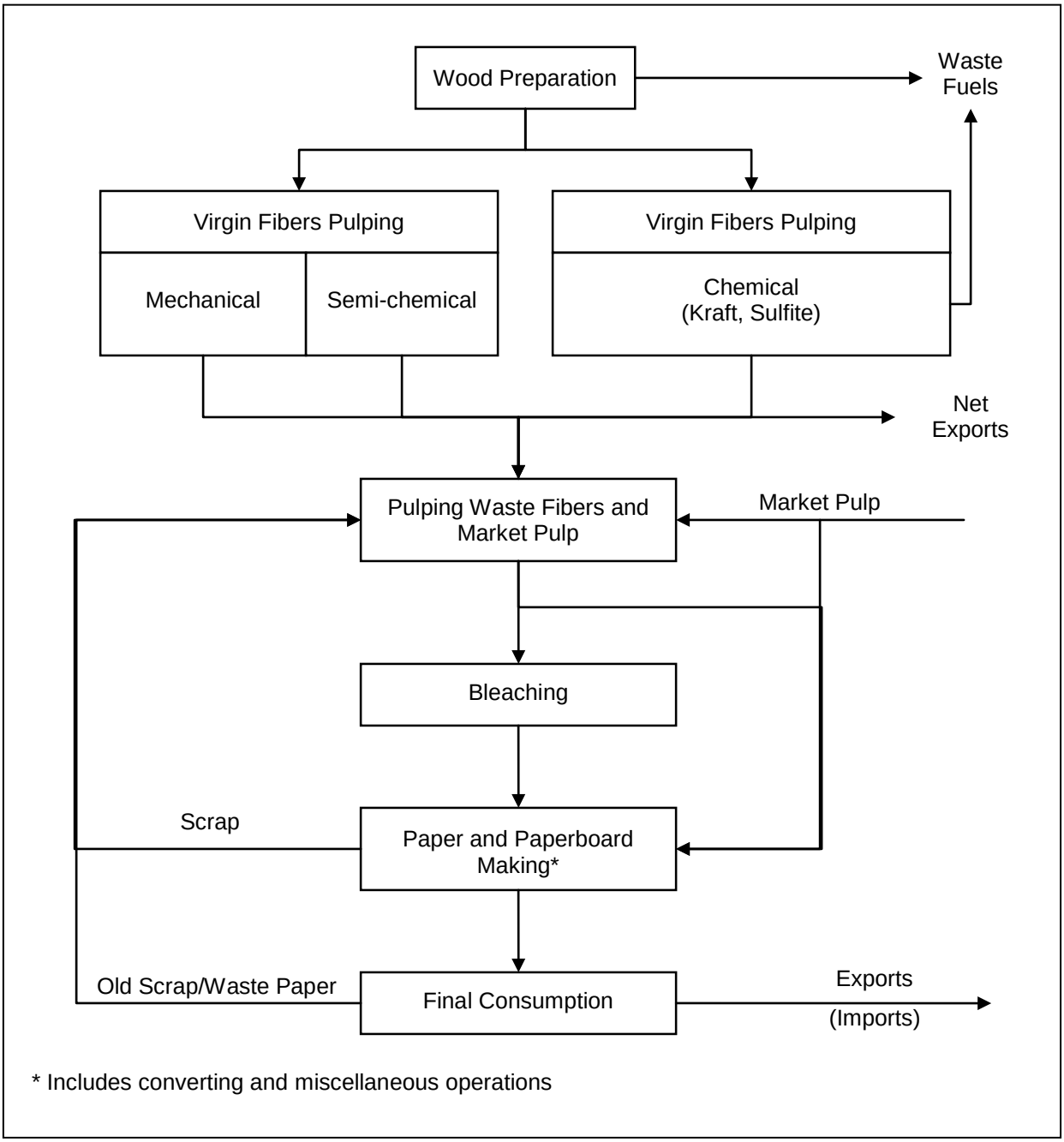
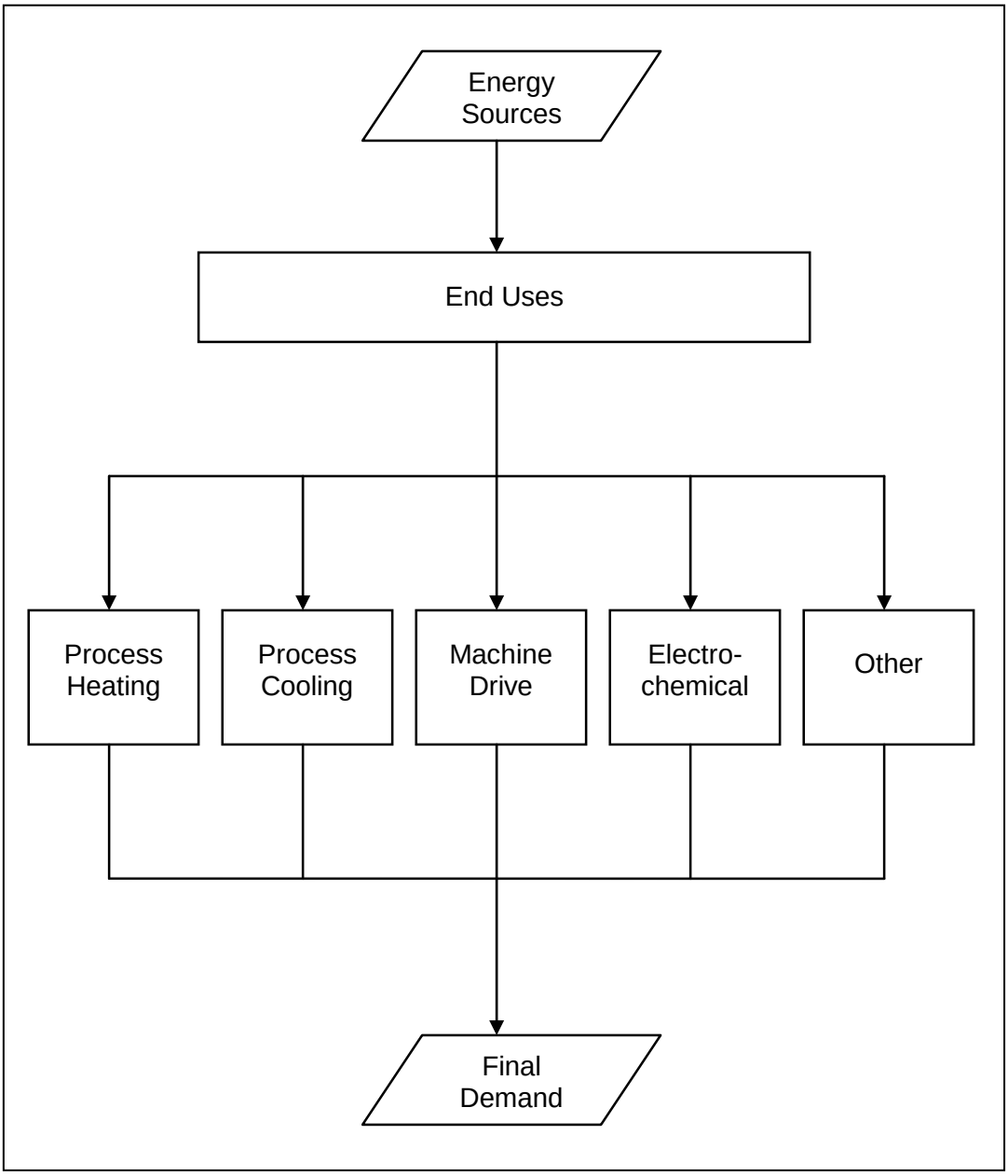


Figure 5. Bulk Chemical Industry End Uses



For the *AEO2010*, a new bulk chemical industry model was implemented. In the previous versions of IDM, the treatment of this industry was based on an end-use approach, as shown in Figure 5. Although this approach has been adequate for the past *AEO* projections, there was a need for a capability to analyze the impacts of high energy prices on feedstock use and also to track some of the chemical products that are highly dependent on energy resources, such as ammonia and ethylene. Thus, a new bulk chemical industry model, which includes these capabilities, was developed.

The chemical industry is the largest energy consumer in the industrial sector. Most of the consumption is used in the production of bulk chemicals, which are basically organic, inorganic, plastic resins and agricultural chemicals. The industry that produces these chemicals is referred to as the bulk chemical industry and is the focus of this model.

The bulk chemical industry's energy consumption patterns are complex, with demands for heat, steam, electricity, and energy feedstocks driven by the demand for and production of numerous chemical products, as well as the processes and technologies involved in these products. Because it would be almost impossible to model each and every chemical product without huge demands for time and resources, a bulk chemical industry model that forecasts the industry's energy use should focus on energy-intensive chemicals and/or chemicals that have high production levels. However, for completeness, the model should also represent the rest of the chemicals, although in simpler form. Furthermore, it should also represent chemicals that are fast-growing or at least energy industry-related, such as ethanol and hydrogen.

Apart from identifying the main chemical products to be represented in detail in the model, a bulk chemical industry model should also be able to reflect the relationships between the basic chemicals, with their intermediate products, and then with their final products. The bulk chemical industry produces numerous basic chemicals that are used to make other chemicals (called intermediates), which are then used to make final products. For example, the production of polyvinyl chloride (used to make pipes, sidings, etc.) requires vinyl chloride, which in turn, relies on ethylene dichloride production. Ethylene dichloride requires ethylene, which can be produced from propane, ethane, butane or naphthas. These complex relationships between chemicals and feedstocks add to the complexity of modeling the industry.

The technologies and processes used to produce a chemical product determine energy use. For some chemicals, there is only one process/technology that is used by the entire industry. For example, in producing sulfuric acid, all producers use the contact process. Thus, the energy use for sulfuric acid would be simple to calculate based on the typical unit energy requirements of the contact process and the demand for sulfuric acid. However, for some chemicals, it could be more complex. There are some chemical products that are made using the same basic process, but the feedstock requirement is more flexible, as in the case of ethylene. Although the basic process is the same with ethylene production, the energy use could be different with the different feedstocks (ethane, butane, propane, naphthas, and gas oils). Furthermore, chemical production rate is different for each feedstock. There are also some chemical products that can be made with entirely different processes, such as chlorine. Chlorine can be produced using either the mercury cell process, membrane cell process, or the diaphragm cell process. The energy requirements of each process differ from each other.

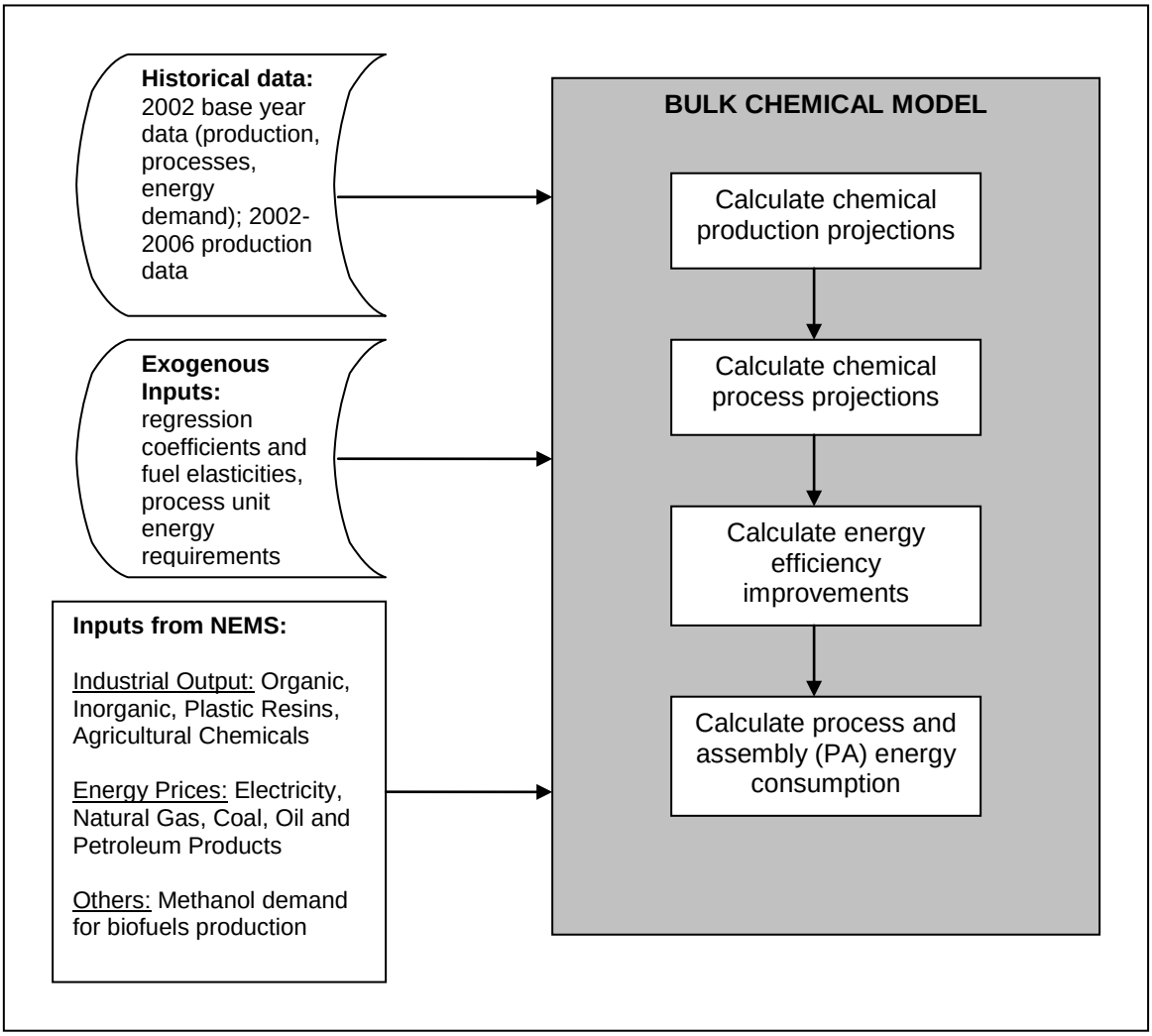
Thus, a bulk chemical model with a good snap-shot or representation of these complexities in products and technologies and processes was developed. The new model is described further below.

Figure 6 provides an overview of the new bulk chemical industry model. The new bulk chemical model includes the following capabilities:

- Includes a base year database for 2002 of production, chemical processes, energy consumption by region for each chemical and chemical group
- Forecasts production of several chemicals and chemical groups
- Forecasts processes involved in producing each chemical and chemical group
- Forecasts process energy consumption (including feedstocks) to produce each chemical and chemical group, taking into consideration process and conservation trends driven by changes in energy prices and growth in production

- Calculates process energy consumption projections for machine drive electricity, non-machine drive electricity, feedstocks, steam, and direct process heat fuels
- Calculates process energy consumption projections by chemical and chemical group and by region.

Figure 6. New Bulk Chemical Industry Model



It is important to note that this model only replaces the PA component of the bulk chemical energy consumption projections. The PA component estimates energy consumption for direct process heating, cooling, machine drive (and motors), and other uses. The BSC and BLD components remain the same for this industry. Thus, steam demand projections are passed from the PA component to the BSC component. The BSC component then calculates fuel consumption to generate the steam. The BLD component projects energy consumption for this industry's use of its facilities for space heating, space cooling, lighting, and off-road transportation.

Table 2 shows the list of the chemical products represented in the model. There are 16 organic, 5 inorganic, 5 resins, and 2 agricultural chemicals, plus four aggregate groups (other organic, other inorganic, other resins, and other agricultural chemicals).

Table 2. Chemical Products in the Bulk Chemical Industry Model

Organic Chemicals	Inorganic Chemicals	Plastic Resins	Agricultural Chemicals
Ethylene	Acetylene	Polyvinyl Chloride	Ammonia
Propylene	Chlorine	Polyethylene	Phosphoric Acid
Butadiene	Oxygen	Polystyrene	Other Agricultural Chemicals
Acetic Acid	Sulfuric Acid	Styrene-Butadiene-Rubber	
Acrylonitrile	Hydrogen	Vinyl Chloride	
Ethylbenzene	Other Inorganic Chemicals	Other Resins	
Ethylene Dichloride			
Ethylene Glycol			
Ethylene Oxide			
Formaldehyde			
Methanol			
Styrene			
Vinyl Acetate			
Ethanol			
On-Purpose Propylene (and byproduct ethylene)			
Other Organic Chemicals			

The choice of chemicals included in the model is driven by several categories, including relatively large production volumes, high energy intensity, expected high production growth, and/or high energy and feedstock consumption.

The bulk chemical model has several components:

- 2002 base year data for each chemical in Table 2
- Chemical production component- forecasts chemical production for each chemical in Table 2
- Chemical process component - forecasts processes for each chemical in Table 2
- Ethylene/propylene/butadiene feedstocks component - forecasts ethylene/propylene/butadiene feedstocks consumption
- Energy consumption component - calculates the energy requirements (machine drive, non-machine drive electricity, direct process heat, feedstocks, steam) for each chemical/chemical group in Table 2

These components are discussed below.

2002 Base Year Data

The 2002 base year data provide a one-year picture of the bulk chemical industry's production, processes, and energy consumption patterns. The calculations to create the 2002 base year data are not included in the model calculations. Nevertheless, the base year data are a critical component of the model.

The methodology used to develop the 2002 base year data incorporates a bottom-up and top-down approach with a calibration process at the end. The 2002 base year database has production, manufacturing process, and energy consumption information for 26 specific chemicals and 4 aggregate groups of chemicals.

Projections of Chemical Production

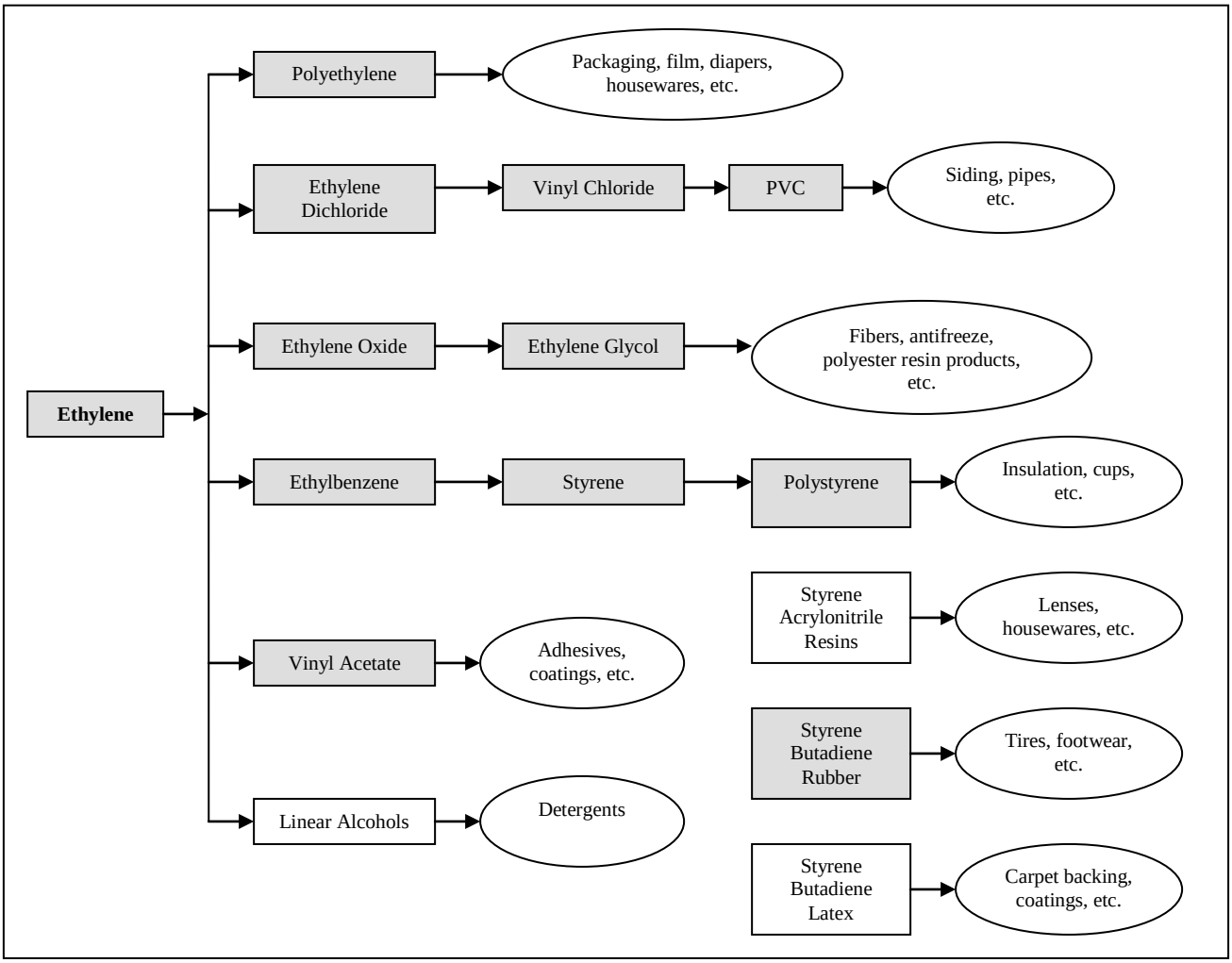
In the bulk chemical industry, there is significant interplay among basic chemicals, intermediate chemicals, and final chemical products. A good understanding of the relationships among these chemicals helps in the development of a reasonable methodology or set of methodologies to forecast the production levels of each chemical. Figure 7 provides an example of how chemicals in the bulk chemical industry model are related. The chemicals shaded in grey are represented in the new bulk chemical model.

As shown in Figure 7, ethylene is used directly to produce several of the chemicals in the model's chemical slate: ethylbenzene, polyethylene, ethylene oxide, ethylene dichloride, and vinyl acetate. Further, there are chemicals that are produced indirectly from ethylene, for example ethylbenzene is used to produce styrene. Considering the styrene products, the figure shows that styrene is used to produce polystyrene and styrene-butadiene-rubber (SBR), which are also specifically handled in the model.

To develop the models or equations that forecast chemical production, the relationships between the chemicals were considered. In addition, the relationships between the production levels of the chemicals and dollar value of output (or shipments) of the chemical industry and other industries that use the chemicals, and other drivers such as gross domestic product (GDP), energy prices, and U.S population were also considered. Table 3 summarizes the methods used to model the projections of production for each chemical product modeled.

Except for methanol, the impact of energy prices on import or export levels is not modeled in the bulk chemical model. It is assumed that these impacts are already incorporated in the value of shipment model inputs received from the Macroeconomic Module. In the case of methanol, it was essential to have more specificity in its representation, given that one of the critical uses of methanol in the future is for the production of biodiesel. Thus, total methanol demand is calculated in the model following the production of formaldehyde (which is the primary use of methanol) plus methanol demand for biodiesel production coming from the Petroleum Market Module. After the total methanol demand is established, total domestic methanol production is calculated by estimating the share of imports, given the domestic price of natural gas.

Figure 7. Ethylene Chain



Source: American Chemistry Council, Guide to the Business of Chemistry 2003.

Table 3. Chemical Production Model

CHEMICALS	HOW IT IS MODELED
A. Organic Chemicals	
Ethylene	"Function of" or f*(total bulk chemicals value of shipments)*; value of shipments is from the Macroeconomic Module
Propylene	*f(ethylene production); byproduct of ethylene production*
Butadiene	*f(ethylene production); byproduct of ethylene production*
Acetic Acid	*f(vinyl acetate production)*
Acrylonitrile	*f(butadiene production)*
Ethylbenzene	*f(ethylene production)*
Ethylene Dichloride	*f(vinyl chloride production)*
Ethylene Glycol	*f(ethylene oxide production)*
Ethylene Oxide	*f(ethylene production)*
Formaldehyde	*f(wood industry value of shipments, printing industry value of shipments)*; values of shipments are from Macroeconomic Module

CHEMICALS	HOW IT IS MODELED
Methanol	Total demand for methanol = *f(formaldehyde production) plus methanol demand for biodiesel production coming from Petroleum Market Module*; Domestic methanol production=*f(total methanol demand, natural gas price)*
Styrene	*f(ethylbenzene production)*
Vinyl Acetate	*f(ethylene production)*
Ethanol	*f(total organic chemicals value of shipments)*; value of shipments is from Macroeconomic Module
On-Purpose Propylene (and byproduct ethylene)	*Exogenous projection based on assumption that total propylene production will grow by 1% per year. The projection of on-purpose propylene production is the difference between the production at 1% growth rate and the production of byproduct propylene (from ethylene production). The process of producing on-purpose propylene produces a small amount of byproduct ethylene.*
B. Inorganic	
Acetylene	*f(vinyl acetate production)*
Chlorine	*f(paper industry value of shipments)*; value of shipments is from Macroeconomic Module
Oxygen	*f(vinyl acetate production)*
Sulfuric Acid	*f(phosphoric acid production)*
Hydrogen	*f(inorganic chemicals value of shipments)*; value of shipments is from Macroeconomic Module
C. Plastic Resins	
Polyvinyl Chloride (PVC)	*f(construction value of shipments, polyethylene production)*; value of shipments is from Macroeconomic Module
Polyethylene	*f(plastic resins value of shipments)*; value of shipments is from Macroeconomic Module
Polystyrene	*f(styrene production, PVC production)*
Styrene-Butadiene-Rubber	*f(butadiene production)*
Vinyl Chloride	*f(PVC production)*
D. Agricultural Chemicals	
Ammonia	*f(agricultural chemicals value of shipments)*; value of shipments is from Macroeconomic Module
Phosphoric Acid	*f(ammonia production)*
E. Aggregate Groups	
Other Organic	*f(organic chemicals value of shipments)*; value of shipments is from Macroeconomic Module
Other Inorganic	*f(inorganic chemicals value of shipments)*; value of shipments is from Macroeconomic Module
Other Plastic Resins	*f(plastic resins value of shipments)*; value of shipments is from Macroeconomic Module
Other Agricultural Chemicals	*f(agricultural chemicals value of shipments)*; value of shipments is from Macroeconomic Module

Projections of Processes of All Chemical Products

Besides the level of chemical production, a major driver of energy consumption in the bulk chemical industry is the process used to produce a chemical product. Table 4 shows the industrial processes used to produce each chemical represented in the model.

Table 4. Chemical Processes in Bulk Chemical Model

CHEMICALS	MANUFACTURING PROCESSES
A. Organic Chemicals	
Ethylene	Pyrolysis of ethane Pyrolysis of propane Pyrolysis of gas oil Pyrolysis of naphtha Pyrolysis of butane Biomass to ethylene conversion
Propylene	Pyrolysis of ethane Pyrolysis of propane Pyrolysis of gas oil Pyrolysis of naphtha Pyrolysis of butane
Butadiene	Pyrolysis of ethane Pyrolysis of propane Pyrolysis of gas oil Pyrolysis of naphtha Pyrolysis of butane Catalytic dehydrogenation of butane Catalytic dehydrogenation of n-butane
Acetic Acid.	N-butane oxidation Methanol carbonylation Biomass fermentation
Acrylonitrile	Ammoxidation of propylene
Ethylbenzene	Alkylation of benzene with ethylene
Ethylene Dichloride	Catalytic oxychlorination of ethylene Direct catalytic chlorination of ethylene
Ethylene Glycol	Hydration of ethylene oxide Biomass to EG conversion
Ethylene Oxide	Catalytic oxidation of ethylene
Formaldehyde	Catalytic oxidation of methanol (silver) Catalytic oxidation of methanol (mixed) Dehydrogenation of methanol (silver)
Methanol	LP cat of reform natural gas LP synthesis from partial oxidation of resid HP cat conversion of synthesis gas Coal to methanol conversion Biomass to methanol conversion
Styrene	Catalytic dehydrogenation of ethylbenzene Ethylbenzene hydroperoxidation
Vinyl Acetate	Catalytic oxyacetylation of ethylene Acetic acid and acetylene
Ethanol (excludes wet milling)	Dry milling Ethylene hydration
On-Purpose Propylene (and byproduct ethylene)	Generic process – on-purpose propylene
Other Organic Chemicals	Generic process – organic
B. Inorganic Chemicals	
Acetylene	Partial oxidation of methane Crude oil submerged flame
Chlorine	Diaphragm cell Mercury cell Membrane cell
Oxygen	Air liquefaction/refrigeration

CHEMICALS	MANUFACTURING PROCESSES
Sulfuric Acid	Contact process
Hydrogen	Steam methane reforming – natural gas Coal gasification Biomass gasification Electrolysis
Other Inorganic Chemicals	Generic process – inorganic
C. Plastics Resins	
Polyvinyl Chloride	Suspension process
Polyethylene	Slurry process Solution process Emulsification process
Polystyrene	Mass polymerization of styrene
Styrene-Butadiene-Rubber	Emulsification process Solution-polymerized solid rubber
Vinyl Chloride	Pyrolysis of ethylene dichloride
Other Plastic Resins	Generic process – plastic resins
D. Agricultural Chemicals	
Ammonia	Catalytic synthesis of methane Partial oxidation of coal Coal gasification Petroleum coke gasification
Phosphoric Acid	Wet process Electric furnace process
Other Agricultural Chemicals	Generic process – agricultural chemicals

The unit energy requirements of steam, electricity, and fuel for each process listed in Table 4 are provided for 14 categories of energy services:

Process water cooling
Pumping
Compression
Motive force
Direct clean heat
Indirect heat
Indirect drying
Concentration
Distillation
Electrolysis
Feedstocks
Reforming
Fuel from feed[10]
Byproduct adjustment[11]

Table B26 provides the unit energy requirements for each chemical, process and energy service represented in the bulk chemical model.

[10] Fuel from feed represents the heat (essentially fuel) from the oxidation of excess feedstocks.
[11] Byproduct adjustment represents recoverable byproduct heat.

In general, the choice of processes is not driven just by energy prices. As such, the shares of processes used to produce a chemical are mostly exogenous to the model. The exceptions are those chemicals and their processes that use significant amounts of energy feedstocks, such as ethylene, propylene and butadiene. These chemicals are sensitive to energy prices, and as such, the model captures the feedstock switching response to changing energy prices. Also, there are chemicals in which only one process is used for its production (at an industrial-scale). For these chemicals, the process is assigned 100 percent. Table 5 summarizes the methodologies used to project the process shares for all the chemical products in the model.

Table 5. Methodologies for Process Share Projections

Chemicals	How To Model
A. Organic Chemicals	
Ethylene	*F(oil price, gas price, production of ethylene, propylene, butadiene); assumed biomass conversion will not penetrate market as revealed by an off-line economic assessment*
Propylene	
Butadiene	
Acetic Acid	Exogenous; assumed fixed to 2002
Acrylonitrile	This chemical is produced with only one industrial process
Ethylbenzene	This chemical is produced with only one industrial process
Ethylene Dichloride	Exogenous; assumed fixed to 2002
Ethylene Glycol	Exogenous; assumed fixed to 2002
Ethylene Oxide	This chemical has only one industrial process
Formaldehyde	Exogenous; assumed fixed to 2002
Methanol	Exogenous; assumed all coal-based methanol production stays on-line; gas-based methanol is assumed to retire following any increase in imports
Styrene	Exogenous; assumed fixed to 2002
Vinyl Acetate	Exogenous; assumed fixed to 2002
Ethanol	Exogenous; assumed fixed to 2002
On-Purpose Propylene (and byproduct ethylene)	This chemical is assumed to have only one process for now. This process is based on the ExxonMobil PCC^{SM} Process
B. Inorganic	
Acetylene	Exogenous; assumed fixed to 2002
Chlorine	Exogenous; assumed fixed to 2002
Oxygen	This chemical is produced with only one process
Sulfuric Acid	This chemical is produced with only one process
Hydrogen	Assumed fixed to 2002; Off-line economic assessment of potential for non-natural gas processes reveal no market penetration over entire projection period
C. Plastic Resins	
Polyvinyl Chloride (PVC)	This chemical is produced with only one process
Polyethylene	Exogenous; assumed fixed to 2002
Polystyrene	This chemical is produced with only one process
Styrene-Butadiene-Rubber	Exogenous; assumed fixed to 2002
Vinyl Chloride	This chemical is produced with only one process
D. Agricultural Chemicals	
Ammonia	Assumed fixed to 2002; Off-line economic assessment of potential for non-natural gas processes reveal no market penetration over entire projection period
Phosphoric Acid	Exogenous; assumed fixed to 2002
E. Aggregate Groups	
Other Organic	There is only one (generic) process considered for this group

Chemicals	How To Model
Other Inorganic	There is only one (generic) process considered for this group
Other Plastic Resins	There is only one (generic) process considered for this group
Other Agricultural Chemicals	There is only one (generic) process considered for this group

It is important to note that the choice for the production processes for chlorine is driven by a couple of important factors. There is a current movement to phase-out the mercury cell process. However, the driver for this phase-out is environmental in nature, not energy-related. Also, the balance between the demand for chlorine and caustic soda affects the choice of whether or not to retire a mercury cell plant. Mercury cell plants are more efficient producers of caustic soda, and when the caustic soda markets are strong, chlorine producers would prefer to keep the mercury cell plants. Caustic soda is not one of the chemicals in the slate of chemicals in the model and so there is no capability to forecast the demand for it. Given that the factors determining the type of processes are mostly non-energy-related, the projections of chlorine processes are exogenous and for the *AEO2010*, they are fixed to the 2008 value (last available update of types of processes by plant in the chlorine industry).

In the U.S., the production of ammonia and hydrogen uses primarily natural gas as the feedstock. Nevertheless, there has been some interest in using other feedstocks such as coal and biomass for both ammonia and hydrogen, as well as electrolytic process for hydrogen. Off-model pro-forma evaluations for these technologies (or feedstocks) were performed for ammonia and hydrogen. The benefits and costs of replacing existing natural gas plants were estimated and compared in the pro forma analysis. The competition between natural gas and the alternatives for a new plant was also analyzed. When using the *AEO2010* projections of energy prices, the pro forma analysis shows that natural gas will continue to dominate the production of ammonia and hydrogen. The costs of using the alternatives are significantly prohibitive. As such, for the *AEO2010*, it is assumed that the process shares for ammonia and hydrogen will be the same as those for 2002, the base year, with natural gas dominating the feedstock sources.

Three chemicals, ethylene, propylene, and butadiene, are modeled with more detail than the other chemicals in the model. More detailed descriptions of the representations of process choices among these chemicals are discussed in the next section.

Projections of Ethylene/Propylene/Butadiene Feedstocks

Ethylene, propylene and butadiene are the bases of a variety of other chemical and consumer products. Their production processes (Table 4) are energy-intensive and the major raw materials (or feedstocks) used for their manufacture are energy-based and switchable. These three chemicals are mostly co-produced, except for biomass to ethylene conversion which solely produces ethylene, and catalytic dehydrogenation of butane and n-butane, which are solely to produce butadiene. The discussion in this section focuses on the manufacturing processes that pertain to the pyrolysis of various feedstocks, which co-produce ethylene, propylene and butadiene.

The primary feedstocks used to produce ethylene, propylene, and butadiene, are natural gas liquids (NGLs) (ethane, propane, butane) and petrochemical feedstocks (gas oil, naphtha). Biomass can be a potential raw material source, although it is assumed that there will be no-

biomass-based capacity over the projection period because of economic barriers. The type of feedstock not only determines the feedstocks usage but also the energy for heat and power requirements to produce the chemicals. For example, the use of naphthas would require more energy than the use of ethane since naphthas are a heavier product and require more energy to process.

The main approach used to forecast the shares of ethylene, propylene and butadiene feedstocks is the use of linear regression equations relating the feedstock shares with oil prices and natural gas prices. Naphthas and gas oils are oil products and ethane, propane, and butane are natural gas liquids. Thus, the relative values of natural gas and oil prices are key drivers for the choice between using oil-based feedstocks and gas-based ones.

In the model, first the shares of total natural gas liquids (NGL includes ethane, propane, butane) and total petrochemical feedstocks (includes naphthas and gas oils) are determined by the natural gas and oil prices. The next step determines the shares of propane and ethane based also on the natural gas and oil price trends. Butane share is determined separately using a regression equation relating butane share with oil prices. To allocate the total petrochemical feedstocks to naphthas and gas oils, the 2002 shares between the two feedstocks are maintained throughout the projection period.

Projections of Energy Consumption

The final step is to calculate energy consumption for each chemical or chemical group. To do this, the chemical production by process projections and the unit energy requirements for each process are multiplied. In the model, unit energy requirements change based on changes in energy prices.

Glass and Glass Products Industry (NAICS 3272)

An energy use profile has been developed for the whole glass and glass products industry, NAICS 3272. This industry 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 8 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 products industry produced approximately 17 million tons of glass products.

The glass and glass products industry consumed approximately 203 trillion Btu of energy in 2002.[12] This accounts for about 20 percent of the total energy consumed in the "stone, clay and glass manufacturing" industry. The fuels consumed are predominantly for direct fuel use, because there is very little steam demand. Direct fuel use is mainly in furnaces for melting. Table B6 shows the unit energy consumption values for each process step.

[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.

Cement Industry (NAICS 32731)

The cement industry uses raw materials from non-manufacturing quarrying and mining industries. These materials are sent through crushing and grinding mills and converted to clinker in the clinker producing step. This clinker is then further 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 in 2002, while the dry process accounted for about 75 percent. The dry process is less energy-intensive than the wet process and, thus the dry process has steadily gained favor in cement production. Even with older facilities and longer kilns, the wet process shows somewhat smaller electric energy consumption because of the use of energy efficient wet grinding and lack of preheaters/pre-calciners 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. As a result, it is assumed in the model that all new plants will be based on the dry process. Figure 9 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.

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 410 trillion Btu of energy in 2002.[12] Direct fuel, used in clinker-producing kilns, accounted for 88 percent of the total PA energy consumption.

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 B13.

Figure 8. Glass Industry Process Flow

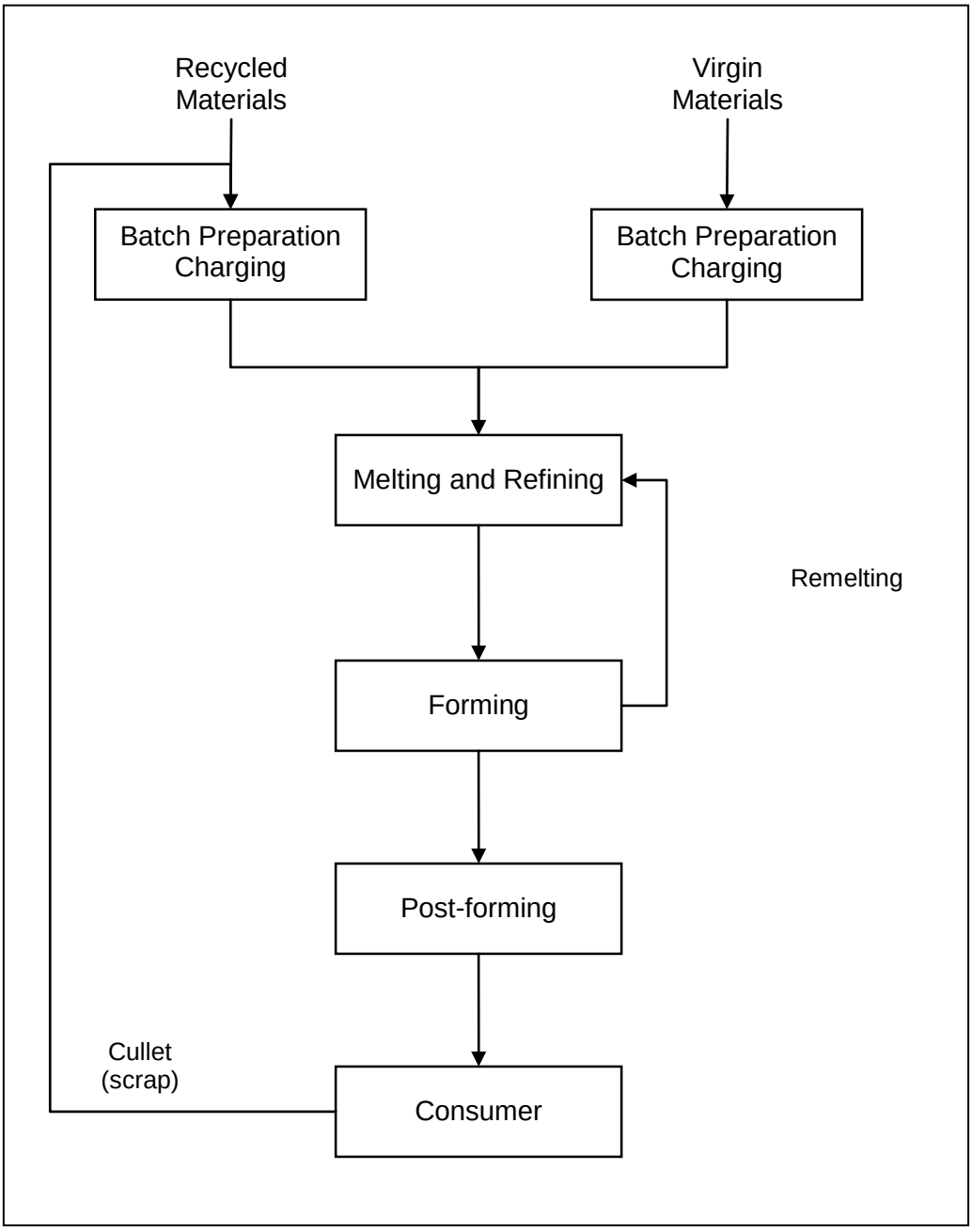
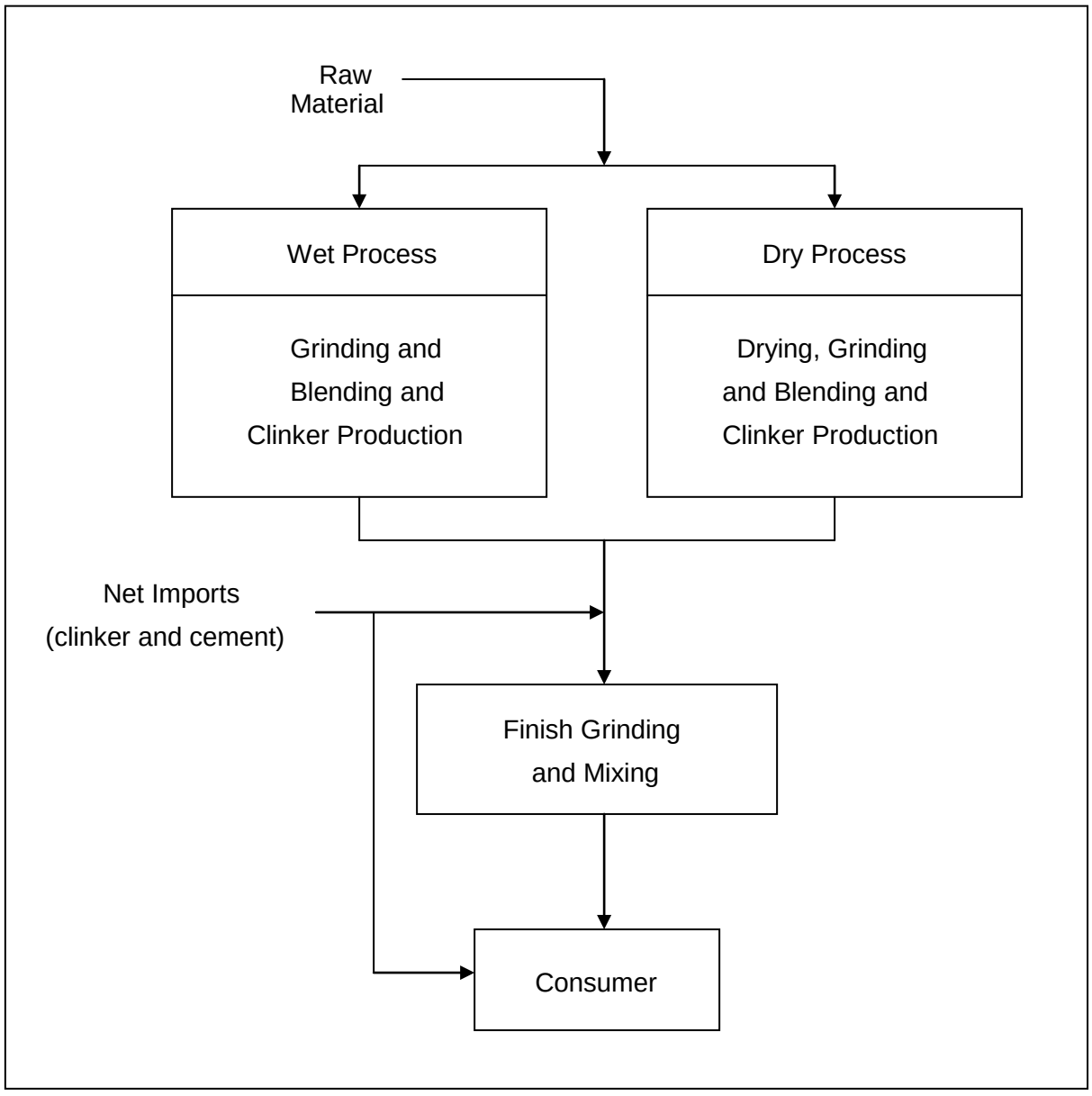


Figure 9. Cement Industry Process Flow



Iron and Steel Industry (NAICS 331111)

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

Agglomeration;
Coke making;
Iron making;
Steel making;
Steel casting; and
Steel forming.

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 Module, 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 10 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.

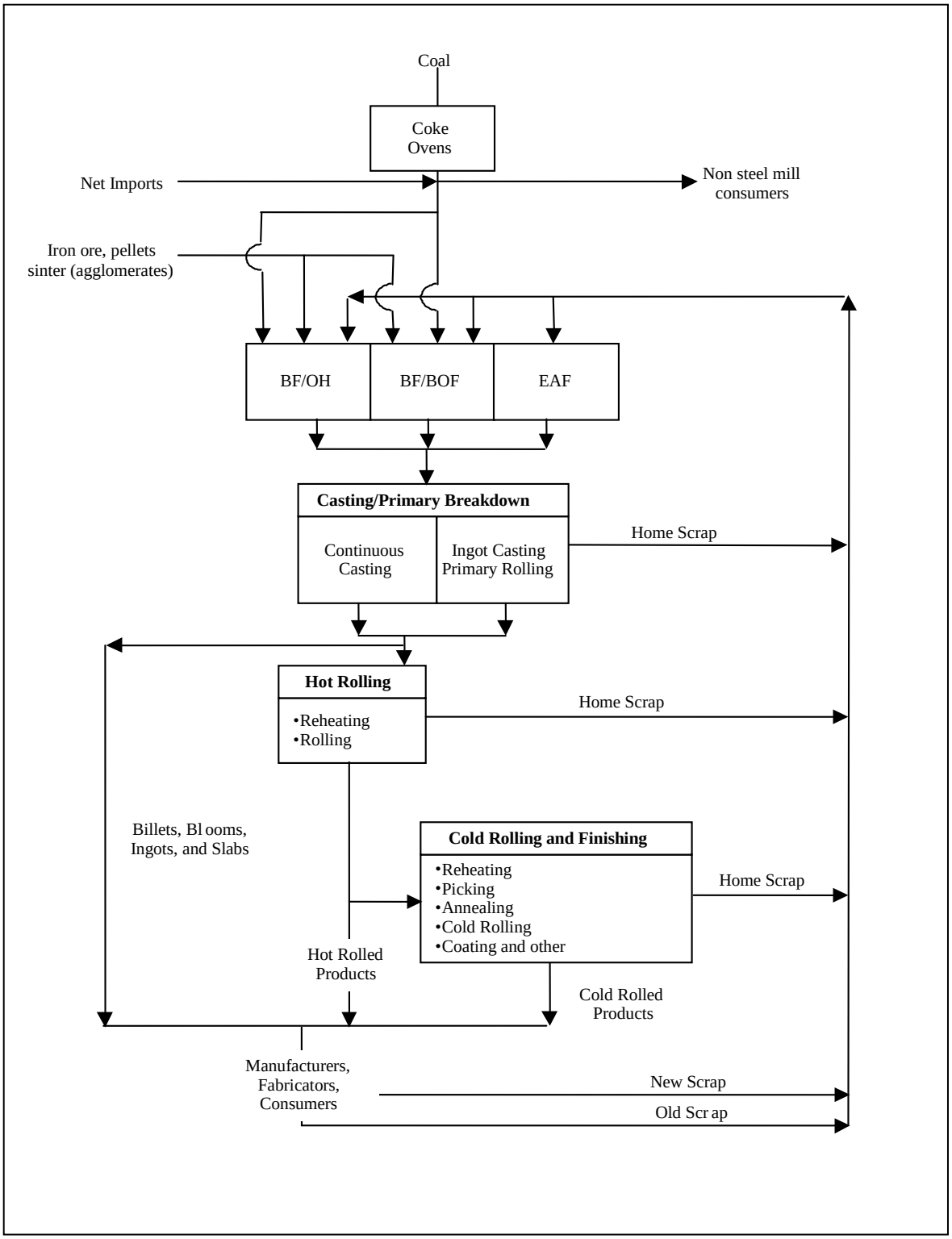
Iron is produced in the Blast Furnace (BF), which is then charged into a Basic Oxygen Furnace (BOF) or Open Hearth (OH) to produce raw steel. The OH is now obsolete in the United States and is not included in new facilities modeled in the Industrial Module. The Electric Arc Furnace (EAF) is utilized to produce raw steel from an all scrap (recycled materials) 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 B13.

Figure 10. Iron and Steel Industry Process Flow



Aluminum Industry (NAICS 3313)

The U.S. aluminum industry consists of two majors sectors: the primary aluminum sector, which is dependent on alumina as raw materials; and the secondary sector, which is largely dependent on the collection and processing of aluminum scrap. The primary and secondary aluminum industries have historically catered to different markets but these distinctions are fading. Traditionally, the primary industry bought little scrap and supplied wrought products, including sheet, plate and foil. The secondary industry is scrap-based and has historically supplied foundries that produce die, permanent mold and sand castings. More recently, secondary aluminum smelters have started supplying wrought (sheet) stock. In addition, in the past decade, the primary producers have been moving aggressively into recycling aluminum, especially used beverage cans, into wrought products. Figure 11 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:

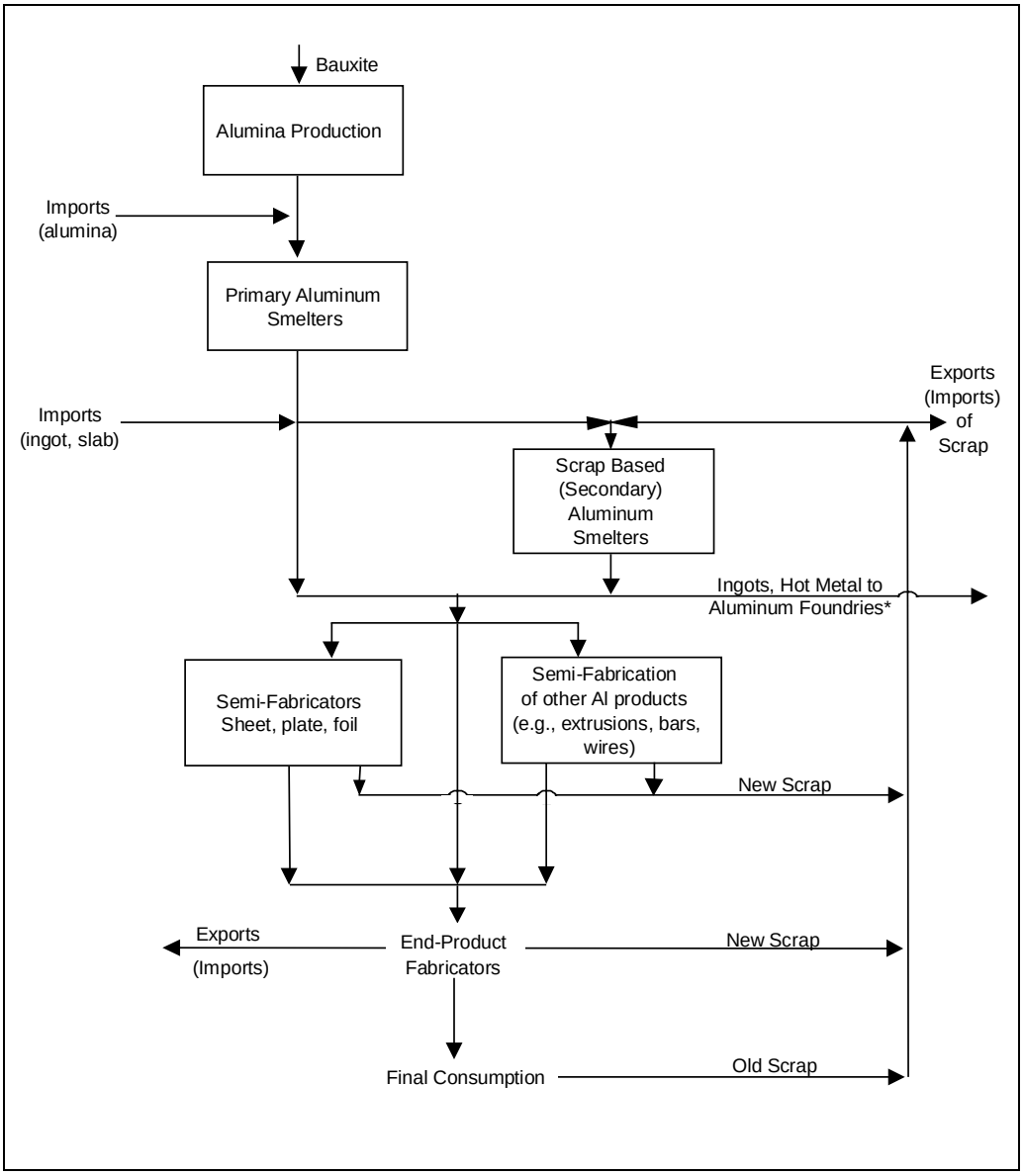
Alumina Refining (NAICS 331311)
Primary Aluminum Production (NAICS 331312)
Secondary Smelting and Alloying of Aluminum (NAICS 331314)
Aluminum Sheet, Plate, Foil Manufacturing (NAICS 331315) and
Aluminum Semi-fabrication of products such as extrusions, tube, cable, and wire (found in NAICS 3316 and NAICS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

Note: 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 B13.

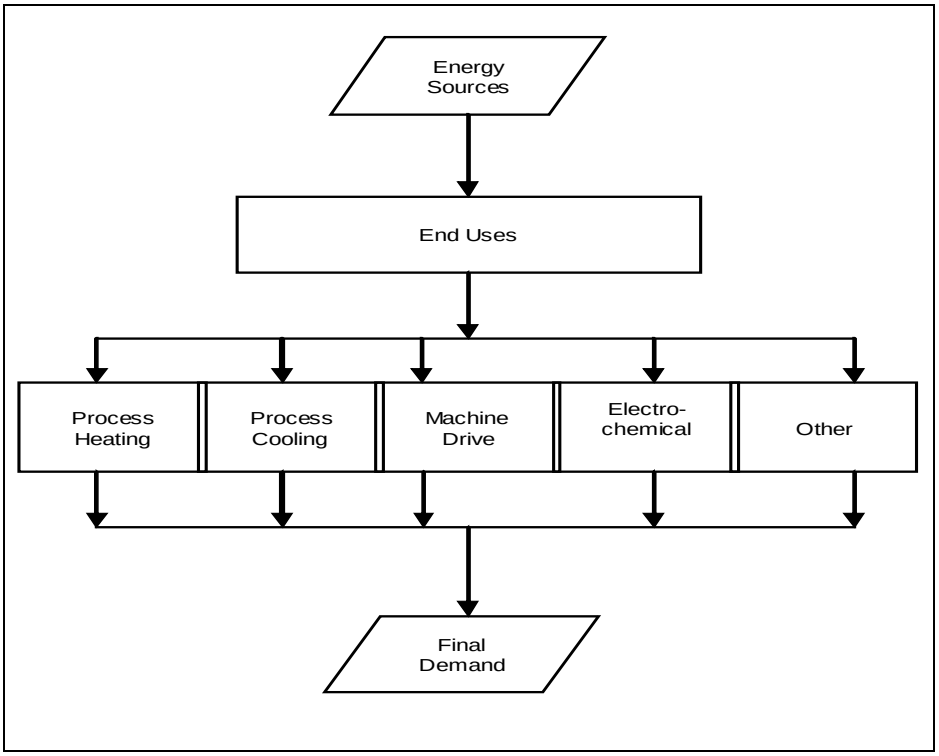
Figure 11. Aluminum Industry Process Flow



Metal-Based Durables Industry (NAICS 332-336)

This industry group consists of industries engaged in the manufacture of fabricated metals, industrial machinery and equipment, electronics and other electric equipment, transportation equipment, and instruments. Typical processes found in this group include re-melting 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 Manufacturing Energy Consumption Survey 2002 (MECS2002).[12] These end uses are shown in Figure 12.

Figure 12. Metal-Based Durables Industry End Uses



The metal-based durables group has been disaggregated into five component sectors (Table 6). In 2002, the metal-based durables industry consumed 1.3 quadrillion Btu of energy.[12] A motor stock model, which is described later in this document, calculates electricity consumption for the machine drive end use. Unit energy consumption values for the other end uses in the PA component for the metal-based durables industry are given in Table 6. Unit energy consumption parameters for the metal-based durables' end uses in the PA component are given in Table B10.

Table 6. Components of Metal-Based Durables Manufacturing

Sectors	NAICS	2002 Unit Energy Consumption (thousand Btu per dollar)	Shipments Growth Rate, Percent (2002-2030)
Fabricated Metals	332	1.582	1.7
Machinery	333	0.693	2.6
Computers and Electronics	334	0.482	4.9
Transportation Equipment	336	0.609	2.2
Electrical Machinery	335	1.853	2.7
Total Metal-Based Durables		0.799	2.1

Other Non-Energy-Intensive Manufacturing Industry

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. Data limitations and lack of a dominant energy user limit disaggregation of these industries. Using the MECS2002 data, wood products (NAICS 321) and plastics manufacturing (NAICS 326) have been separately specified (Table 7). Wood products manufacturing is of interest because the industry derives 60 percent of its energy from biomass in the form of wood waste and residue. The plastics manufacturing industry produces goods by processing plastic materials (it does not produce the plastic). Half of plastics manufacturing's energy is electricity. Together, these two industries account for about 700 trillion Btu of energy (4 percent of manufacturing) and 7 percent of manufacturing value of shipments. The remaining industries are aggregated into "Balance of Manufacturing" as a catchall category.

Table 7. Components of Other Non-Energy-Intensive Manufacturing

Sectors	NAICS	2002 Unit Energy Consumption (thousand Btu per dollar)	Shipments Growth Rate, Percent (2002-2030)
Wood Products	321	3.945	0.8
Plastics and Rubber Products	326	1.994	1.8
Balance of Manufacturing	NA	2.182	1.7
Total		2.041	1.8

In 2002, the other non-energy-intensive manufacturing industry consumed 2.6 quadrillion Btu of energy.[12] A motor stock model, which is described later in this document, calculates electricity consumption for the machine drive end use. Unit energy consumption parameters for the other end uses in the PA component of the balance of manufacturing group are given in Table B11.

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.

[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.

The mining industry is divided into three sectors in the Industrial Demand Module – 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 Module and the physical quantities were converted to Btu for use in NEMS.

There is only one construction sector included in the Industrial Demand Module. 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 2004*,[16] the *2002 Manufacturing Energy Consumption Survey*,[17] *Fuel Oil and Kerosene Sales 2002*,[18] and a recent publication of energy use in agriculture.[19] 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 B12 for the non-manufacturing industries.

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

Future energy improvements were estimated for old (retrofit) and new processes/facilities. The energy improvements for grouped old facilities 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/facilities were estimated using engineering judgment on how much energy savings could be reasonably achieved in each industry. The estimated annual energy savings for each energy conservation measure are modest (up to 0.5 percent per year).

Unit energy consumption values for the state-of-the-art (SOA) and advanced technologies are also estimated. SOA technologies are the latest proven technologies that are available at the time a commitment is made to build a new plant. These values are then compared to the 2002 unit energy consumption values to develop an index of relative energy intensity (REI). Relative

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[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 2003* (Washington, DC, October 2006).
[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).
[19] Outlaw, Collins, and Duffield, *Agriculture as a Producer and Consumer of Energy*, CABI Publishing (Cambridge, MA, 2005)

energy intensity is defined as the ratio of energy use in a new or advanced process compared to 2002 average energy use (Table B14).

The efficiency improvement for new facilities assumes the installation includes the SOA technologies available for that industry. A second and often more important set of substantial improvements are often realized when advanced technologies become available for a specific 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 energy saving potential and the likelihood for such savings to be realistically achieved. All energy improvements in the Industrial Module are based on 2002 energy usage.

Additionally, even SOA technologies and advanced technologies can sometimes be expected to improve after development 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 facilities are assumed to be able to economically justify some retrofits and, for other reasons listed above, show slow improvements over time in their unit energy consumption. It is assumed that by 2035, old equipment (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 equipment operating in the year 2035 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 B14. 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 B15. The list of SOA and advanced technologies considered in the analysis is presented in Table B16.

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 annual 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:

$$Enpint_{v,f,s} = EnpintLag_{v,f,s} * (1 + TPCRate_{v}) \quad (1)$$

where:

$Enpint_{v,f,s}$ = Unit energy consumption of fuel *f* at process step *s* for vintage *v*;
$EnpintLag_{v,f,s}$ = Previous year's 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, $BCSC_{v,f,s}$.

$$X = TPCPrat^{TPCBeta}$$

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

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

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 increases for vintage *v*; and
$BCSC_{v,f,s}$	=	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*,[20] a report produced for the U.S. Department of Energy's Office of Industrial Technologies (Table B17). Section 313 of *The Energy Independence and Security Act of 2007* (EISA2007) increased the minimum efficiency of motors to reflect National Electrical Manufacturers Associations Premium Efficiency requirements, effective no later than 2011. These revised standards simplify the model code since only premium efficiency motors can be purchased.

The motor stock model can be broken down into five 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 B18).

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

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

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.

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 B19). 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. 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, 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, rewound motors, and surviving motors.

5. 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.[21] 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 B20) 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 requirement from conventional boilers.

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:

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

where i is the i^{th} fuel (coal, petroleum, and natural gas). The P_i are the fuel prices relative to 2002 prices; α_i are sensitivity parameters, assumed equal to -1.5 for all i; and the β_i are calibrated to reproduce the 2002 fuel shares using the relative prices that prevailed in 2002. The byproduct

[21]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.

fuels are consumed before the quantity of purchased fuels is estimated. The boiler fuel shares are assumed to be those estimated using MECS2002 and exclude waste and byproducts.

Cogeneration capacity, generation, fuel use, and thermal output are determined from exogenous data and new additions are simulated as determined necessary 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 2008, with planned additions (units under construction) through 2012.[22]

The data is processed outside the model to separate industrial cogeneration from commercial sector cogeneration, cogeneration from refineries and enhanced oil recovery operations, and offsite cogeneration. Offsite cogenerators are primarily merchant power plants selling to the grid and often supplying relatively small amounts of thermal energy. The remainder, or onsite industrial cogeneration portion, 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 2009, under the assumption that planned units under construction cover only some of the likely additions through 2012. 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.

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

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 B21). 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 B22; the high technology case uses the characteristics in Table B23):

      i. Net electric generation capacity in kilowatts

      ii. Total installed cost, in 2005 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 B24). 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 often cursory). The Industrial Module 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 Module. 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 Module for the various industries are listed in Table B14.

Existing old and middle vintage production is reduced by the retirement rate of capital through the equations below. The retirement rate is posited to be a positive function of energy prices.

For years after 2002, the RetirePrat is calculated as the greater of 1 or the ratio of the current year's average industrial energy price to the average price in 2002.

$$X = RetirePrat^{RetireBeta}$$

$$RetirePriceFactor = 2 * \frac{X}{(1+X)} \quad (4)$$

$$RetireRate_s = RetirePriceFactor * ProdRetr_s$$

where:

RetirePrat	=	Maximum (1, 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 Module. 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 pulping 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 Module. These implications fall into three categories: coke oven standards; efficiency standards for boilers, furnaces, and electric motors; and industrial process technologies. The Industrial Module assumes the leakage standards for coke oven doors do not reduce the efficiency of producing coke, or increase unit energy consumption. The Industrial Module 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. The EISA2007 increases the motor efficiency standard for all motors up to 500 horsepower purchased after 2011. All motors available in the motor model are at least as efficient as the standards for a given projection year. The Industrial Module 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 currently included in the model. When regulations are promulgated, their estimated impact could be modeled in NEMS. However, cement modeling does include the capability to increase the amount of blended component in the clinker mix.

Section 1321 of EPACT2005 extends the Section 29 Production Tax Credit (PTC) for non-conventional fuels 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 facilities 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. To parallel assumptions in the NEMS electricity market module, capital costs for cogeneration plants have been increased by 15 percent to reflect higher material costs. These assumptions are introduced into the model through a spreadsheet file. The cogeneration assumptions used for the *AEO2010* are presented in Table B21, Table B22, Table B23, and Table B24.

Benchmarking

The Industrial Module energy demand projections are benchmarked to values presented in *Annual Energy Review 2008*. The national-level values reported in *Annual Energy Review 2008* were allocated to the Census Divisions using the *State Energy Data Report 2007*. The benchmark factors are based on the ratio of the SEDS value of consumption for each fuel to the consumption calculated by the model at the Census Division level. EIA has comprehensively reviewed and revised how it collects, estimates, and reports fuel use for facilities producing electricity.[23] The specific impacts on reported industrial energy consumption are discussed in U.S. Energy Information Administration, *Annual Energy Outlook 2003*, pp. 32-34.[24] Additional calibration for the years 2009-2010 are performed to conform to the *Short-Term Energy Outlook.*

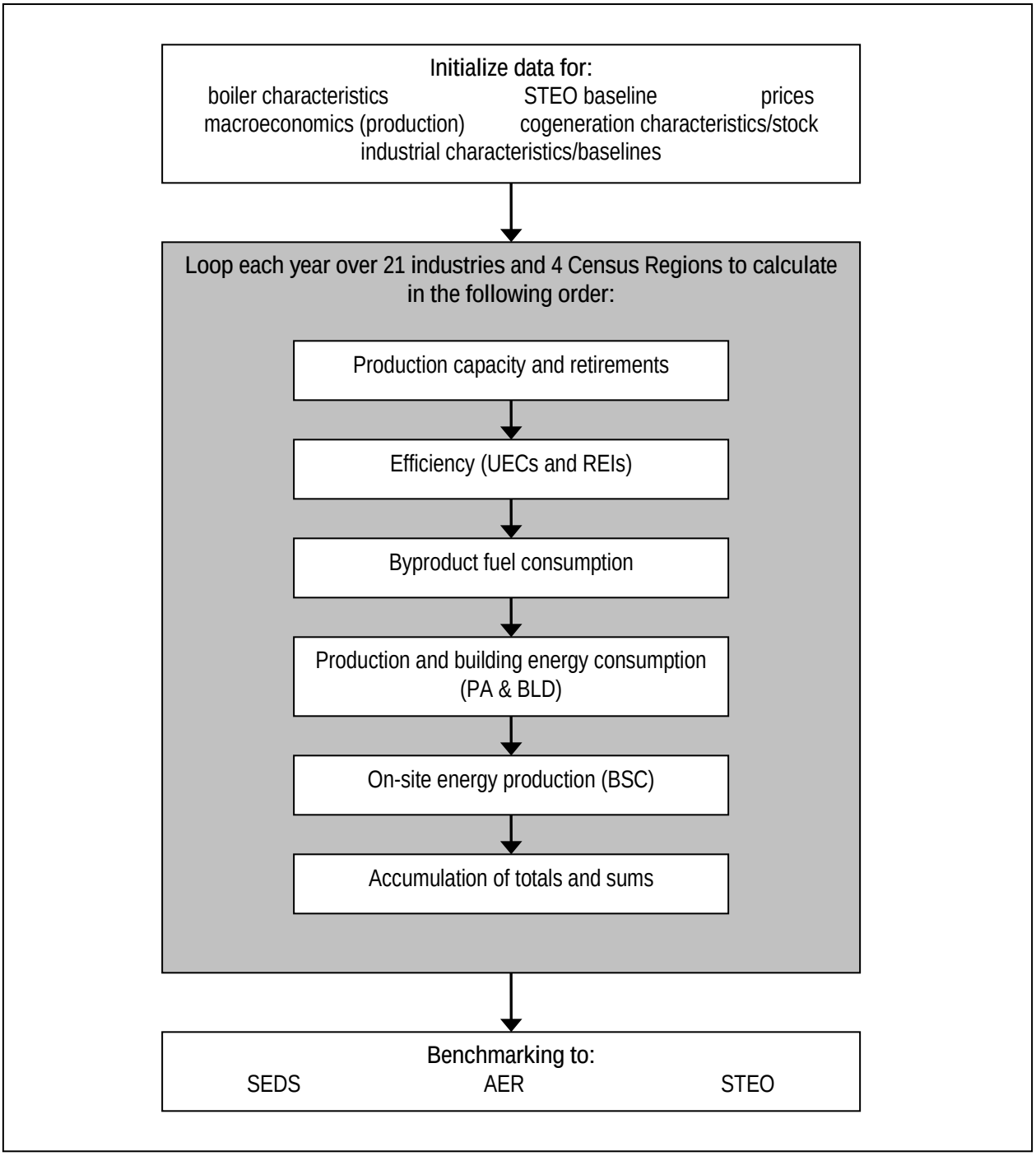
[23]For a detailed discussion, see Energy Information Administration, *Annual Energy Review 2001*, DOE/EIA-0384 (2001), November 2002, Appendix H, "Estimating and Presenting Power Sector Fuel Use in EIA Publications and Analyses," web site site http://tonto.eia.doe.gov/FTPROOT/multifuel/038401.pdf.
[24]Energy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

A flow diagram of the Industrial Demand Module solution is provided in Figure 13. The solution outline that follows provides some elaboration of the items in Figure 13. This section is followed by a section covering each subroutine of the solution outline in detail.

Figure 13. Flow diagram of module solution



First Year: Initialize Data

- RCNTL: Read Control Options
- IRCOGEN: Read cogeneration data files (called from IND)
- MecsLess860B: Calculate 2002 boiler fuel by subtracting Form 906 cogeneration fuel from 2002 MECS indirect fuels.
- REXOG: Assign exogenous macroeconomic and energy price variables that come from NEMS.
- 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.
- MECS2002: Read PRODFLOW.TXT containing process/assembly step definitions and flow rates from most recent MECS data (2002)
- UECTPC: Read ITECH.TXT file with MECS-based UEC rates and the TPC assumptions
- 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 21 industry groups, including 6 non-manufacturing, 7 energy-intensive and 8 non-energy-intensive -manufacturing industries. For each industry, loop through each of 4 census regions

- RDBIN: Read memory management file with previous year's data for this industry, region
- CALPROD: Compute revised productive capacity and throughput by process/assembly step and vintage; implement retirement and vintaging assumptions.
- CALCSC: Conservation Supply Curve: Evaluate changes in UECs based on Technological Possibility
- CALBYPROD: Calculate consumption of byproduct fuels
- CALPATOT: Compute consumption of energy in the process assembly component
    - ICHEM: Compute bulk chemical industry consumption of energy in the process assembly component
    - MOTORS: Compute consumption of electricity for machine-drive for end-use industries
- CALBTOT: Compute consumption of energy in the buildings component
- 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:
    - COGENT: Read cogeneration assumptions spreadsheet (first year)
    - SteamSeg: Assign fraction of steam load in current load segment for current industry
    - COGINIT: Initialize the cogeneration data arrays with capacity, generation, and fuel use data
    - EvalCogen: Evaluate investment payback of a cogeneration system in a given year
- CALBSC: Estimate boiler fuel shares as a function of changing boiler fuel prices.

- CALSTOT: Compute energy consumption in the Boiler-Steam-Cogeneration (BSC) component
- WRBIN: Write memory management file with data on current industry, region
- INDTOTAL: Accumulate total energy consumption for the industry

National Summaries

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

Apply exogenous adjustments and assign values to global variables

WEXOG

- SEDS Benchmarking:
    - SEDS years (through 2007: calculate regional benchmark factors as the ratio of actual consumption to model consumption for each fuel in four Census Regions.
    - Post SEDS Years (2008-on): Optionally, multiply model consumption by the SEDS benchmark factors.
- Disaggregate energy consumption from 4 Census Regions to 9 Census Divisions using shares from SEDS
- Calibrate regional energy consumption to match the latest year of national-level history data (from the STEO file).
- STEO Benchmarking
    - STEO years: calculate national benchmark factors as the ratio of model consumption for each fuel to the STEO projection for each fuel.
    - Post-STEO years: Optionally, over the period 2009 to 2010, 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 Module. 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 Activity Module (MAM) is processed. Employment is also obtained from

MAM 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 Module energy demand projections are benchmarked to values presented in *Annual Energy Review 2008* in subroutine WEXOG. The national-level values reported in *Annual Energy Review 2008* were allocated to the Census Divisions using the *State Energy Data Report 2007*. Because detailed data for the Industrial Module 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.

$$PRCX_{elec,r} = \frac{\sum_{d=1}^{Num_r} DPRCX_{elec,r} * QSELIN_{d,2007}}{\sum_{d=1}^{Num_r} QSELIN_{d,2007}} \quad (5)$$

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
$QSELIN_{d,2004}$ = SEDS consumption of electricity in Census Division *d* in 2007.

IND calls two subroutines: ISEAM, the subroutine that guides the Industrial Module 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 Module calculations and initiates some 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 the 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 Module. 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 MAM for use in the Industrial Module. 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 Module 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 output conversion 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.

$$PHDRAT_{i,r} = \frac{PHYSICAL_{i,r}}{PRODVX_{i,r}} \quad (6)$$

where:

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

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

$$PRODX_{i,r} = PRODVX_{i,r} * PHDRAT_{i,r} \quad (7)$$

where:

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

$PHDRAT_{i,r}$ = Ratio of physical units to value of shipments in industry *i* and Census Region *r*, 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.

$$PRODX_{i,r} = PRODVX_{i,r} \quad (8)$$

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.

A linkage is defined as a link between one or more process steps. Five energy-intensive industries have process steps: paper, glass, cement, steel, and aluminum. The remaining 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 industries is equal to 1. 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 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 pass through the bleaching process.
Y_3 = Number of tons of material to pass through the waste fiber pulping process.
Y_4 = Number of tons of material to pass through the mechanical pulping process.
Y_5 = Number of tons of material to pass through the semi-mechanical pulping process.
Y_6 = Number of tons of material to pass through the Kraft pulping process.
Y_7 = Number of tons of material to pass through the wood preparation process.

Then, we have the following:

Y_1 = Output, in tons
Y_2 = $0.502\ Y_1$
Y_3 = $0.317\ Y_1 + 0.317\ Y_2$

$Y_4 = 0.041\ Y_1 + 0.041\ Y_2$

$Y_5 = 0.028\ Y_1 + 0.028\ Y_2$

$Y_6 = 0.377\ Y_1 + 0.377\ Y_2$

$Y_7 = 1.689\ Y_4 + 1.689\ Y_5 + 1.689\ Y_6$

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 paper making 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 Module, 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 or before 2002. 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, HVAC, 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 2005. 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 the industrial technology data file (ITECH.TXT) to update the initial ENPROD.TXT data file with 2002 values of UECs and TPCs. The second half of ITECH.TXT is reserved for use side cases.

IFINLCALC

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

CALBYPROD

The Industrial Module consumes all byproduct fuels prior to purchasing any fuels. This subroutine calculates the energy savings or the 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 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 is the greater of this ratio and 1.0. As a result, TPC is an increasing function of TPCPrat:

$$X = TPCPrat^{TPCBeta}$$

$$TPCPriceFactor = \frac{X}{(1+X)} \qquad (9)$$

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

where:

TPCPrat	=	Maximum (1.0, 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*, and

$BYPCSC_{v,f,s}$ = Initial TPC for vintage *v*, fuel *f*, and step *s*.

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

$$BYPINT_{v,f,s} = (BYPINTLag_{v,f,s})^{TPCRate_v} \quad (10)$$

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 multiplier on TPC rate due to energy price increases 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.

$$BYPINT_{mid,f,s} = \left(\frac{\left(PRODLag_{mid,f,s} * BYPINTLag_{mid,f,s} \right)}{\left(PRODLag_{mid,s} + PRODLag_{new,s} \right)} + \frac{\left(PRODLag_{new,s} * BYPINTLag_{new,f,s} \right)}{\left(PRODLag_{mid,s} + PRODLag_{new,s} \right)} \right)^{TPCRate_{mid}} \quad (11)$$

where:

$PRODLag_{new,s}$ = Prior year's production from new vintage capacity at process step *s*,

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

$PRODLag_{mid,s}$ = Prior year's production from middle vintage capacity at process step *s*,

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

$TPCRate_{mid}$ = TPC multiplier on TPC rate due to energy price increases for middle vintage.

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

$$BYPQTY_{v,f,s} = PRODCUR_{v,s} * BYPINT_{v,f,s} \quad (12)$$

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*.

Note that $PRODCUR_{v,s}$ is production by a vintage at a step and is not fuel-specific. The rate of byproduct fuel production is then converted from millions of Btu to trillions of Btu. Byproduct fuel production is subdivided into three categories: main fuels, intermediate fuels, and renewable fuels.

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

$$ENBYPM_{f,v} = \sum_{s=1}^{MPASTP} BYPQTY_{v,f,s} \quad (13)$$

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 (PA) 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.

$$ENPQTY_{v,f,s} = PRODCUR_{v,s} * ENPINT_{v,f,s} \quad (14)$$

where:

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

Consumption of each fuel is converted to trillions of Btu. Energy consumption is subdivided into main fuels, intermediate fuels, and renewable fuels. Main fuels include the following:[25]

Electricity,

Core and non-core natural gas,

Natural gas feedstocks,

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

Steam coal,
Coking coal (including net coke imports),
Residual oil,
Distillate oil,
Liquid petroleum gas for heat and power,
Liquid petroleum gas for feedstocks,
Motor gasoline,
Still gas,
Petroleum coke,
Asphalt and road oil,
Petrochemical feedstocks,
Other petroleum feedstocks, and
Other petroleum.

Intermediate fuels include the following:

Steam,
Coke oven gas,
Blast furnace gas,
Other byproduct gas,
Waste heat, and
Coke.

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

Hydropower,
Biomass--wood,
Biomass--pulping liquor,
Municipal solid waste,
Geothermal,
Solar,
Photovoltaic, and
Wind.
.

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.

$$ENPMQTY_f = \sum_{s=1}^{MPASTP} \sum_{v=1}^{3} ENPQTY_{v,f,s} \quad (15)$$

where:

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

The impact of increased corn-based on ethanol production on energy used in agriculture and in producing nitrogenous fertilizer is projected as follows:

$$CORNFUEL_f = \sum_{f=1}^{6} CORNFAC_f * CORNINCR \quad (16)$$

where:

$CORNFUEL_f$	=	Consumption of fuel *f* in agricultural production for ethanol feedstocks,
$CORNFAC_f$	=	Thousand Btu of fuel, *f*, to produce 1 bushel of corn, and
CORNINCR	=	Incremental corn production in a Census region.

The fuels, *f*, are electricity, natural gas, distillate, LPG, motor gasoline, and natural gas used for additional fertilizer production.

The increased fuel requirements are then added to the energy projections for the agricultural crops industry (NAICS 111), and, for fertilizer, to the agricultural chemicals industry (NAICS 3253). The values for $CORNFAC_f$ are given Table B25.

Energy consumption for coke imports is calculated as the difference between coke consumption and coke production. In the current Industrial Module, 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.

$$ENPMQTY_{coke} = ENPIQTY_{coke} - \left(PRODCUR_{total,co} * \frac{24.8}{10^6} \right) \quad (17)$$

where:

$ENPMQTY_{coke}$	=	Quantity 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.

ICHEM

ICHEM calculates the total energy consumption from the process and assembly (PA) component of the bulk chemical industry. The new bulk chemical industry model was implemented for the first time for the *AEO2010*. The major calculations are:

- Chemical production projections,
- Chemical process projections, and
- Energy consumption projections (for heat/power and feedstocks).

For the chemical production projections, the equations below were used. These equations represent the basic equations used to forecast chemical production, indexed to 2002.

Subscripts are:

indreg = census region
ibyr = 2002
curcalyr = year calculated
y = curcalyr-2001

Organic Chemicals

Ethylene

Ethylene production directly follows the total bulk chemicals value of shipments trend.

$$OrganicPRodIdxUnc_{1,r} = \frac{ChemShip_{5,r,yr}}{ChemShip_{5,r,2002}} * 100.00 \quad (18)$$

where:

$ChemShip_{5,r,yr}$ = Total bulk chemicals value of shipments for region *r* in year *yr*, and
$OrganicPRodIdxUnc_{1,r}$ = Ethylene production for region *r* indexed to 2002.

Propylene

Propylene production is a function of ethylene production.

$$OrganicPRodIdxUnc_{2,r} = \exp(PRIntercept) * (OrganicPRodIdxUnc_{1,r})^{0.64307} * (y^{0.079787}) \quad (19)$$

where:

$PRIntercept$ = Calculated regression intercept based on 2002 data, and
$OrganicPRodIdxUnc_{2,r}$ = Propylene production for region *r* indexed to 2002.

Butadiene

Butadiene production is a function of ethylene production.

$$OrganicPRodIdxUnc_{3,r} = \exp(BUIntercept) * (OrganicPRodIdxUnc_{1,r})^{1.302607} * (y^{0.047119}) \quad (20)$$

where:

$BUIntercept$ = Calculated regression intercept based on 2002 data, and
$OrganicPRodIdxUnc_{3,r}$ = Butadiene production for region *r* indexed to 2002.

Acetic Acid

Acetic acid production is a function of vinyl acetate production.

$$OrganicPRodIdxUnc_{4,r} = OrganicPRodIdxUnc_{31,r} \quad (21)$$

where:

$OrganicPRodIdxUnc_{4,r}$ = Acetic acid production for region *r* indexed to 2002, and
$OrganicPRodIdxUnc_{31,r}$ = Vinyl acetate production for region *r* indexed to 2002.

Acrylonitrile

Acrylonitrile production is a function of butadiene production.

$$OrganicPRodIdxUnc_{5,r} = \exp(ACIntercept) * (OrganicPRodIdxUnc_{3,r})^{0.56996} * (y^{-0.062598}) \quad (22)$$

where:

ACIntercept = Calculated regression intercept based on 2002 data, and
$OrganicPRodIdxUnc_{5,r}$ = Acrylonitrile production for region *r* indexed to 2002.

Ethylbenzene

Ethylbenzene production is a function of ethylene production.

$$OrganicPRodIdxUnc_{6,r} = \exp(EBIntercept) * (OrganicPRodIdxUnc_{1,r})^{1.1870531} * (y^{-0.04729}) \quad (23)$$

where:

EBIntercept = Calculated regression intercept based on 2002 data, and
$OrganicPRrodIdxUnc_{6,r}$ = Ethylbenzene production for region *r* indexed to 2002.

Ethylene Dichloride

Ethylene dichloride production is a function of vinyl chloride production.

$$OrganicPRodIdxUnc_{7,r} = RESINSPRodIdxUnc_{5,r} \quad (24)$$

where:

$OrganicPRrodIdxUnc_{7,r}$ = Ethylene dichloride production for region *r* indexed to 2002, and
$RESINSPRodIdxUnc_{5,r}$ = Vinyl chloride production for region *r* indexed to 2002.

Ethylene Oxide

Ethylene oxide production is a function of ethylene production.

$$OrganicPRodIdxUnc_{9,r} = \exp(EOIntercept) * (OrganicPRrodIdxUnc_{1,r})^{0.951344} * (y^{-0.06138}) \quad (25)$$

where:

EOIntercept	= Calculated regression intercept based on 2002 data, and
$OrganicPRodIdxUnc_{9,r}$	= Ethylene oxide production for region *r* indexed to 2002.

Ethylene Glycol

Ethylene glycol production is a function of ethylene oxide production.

$$OrganicPRodIdxUnc_{8,r} = \exp(EGIntercept) * (OrganicPRodIdxUnc_{9,r})^{1.000592} * (y^{0.027261}) \quad (26)$$

where:

EGIntercept	= Calculated regression intercept based on 2002 data, and
$OrganicPRodIdxUnc_{8,r}$	= Ethylene glycol production for region *r* indexed to 2002.

Formaldehyde

Formaldehyde production is a function of wood and printing industry production (value of shipments).

$$OrganicPRodIdxUnc_{10,r} = \exp(FDIntercept) * \left(\frac{chemwood}{chemwood2002} * 100\right)^{0.488691} * \left(\frac{chempr\,int}{chempr\,int\,2002} * 100\right)^{0.165717} * \left(y^{0.027899}\right) \quad (27)$$

where:

FDIntercept	= Calculated regression intercept based on 2002 data,
Chemwood	= Wood industry value of shipments for current year,
Chemwood2002	= Wood industry value of shipments for 2002,
Chemprint	= Printing industry value of shipments for current year,
Chemprint2002	= Printing industry value of shipments for 2002, and
$OrganicPRodIdxUnc_{10,r}$	= Formaldehyde production for region *r* indexed to 2002.

Methanol

<u>Methanol Demand</u>

Methanol demand follows formaldehyde production trends.

$$MethanolDemUnc_r = MethanolHistDem_{r,2002} * \left(OrganicPRodIdxUnc_{10,r}\right) \quad (28)$$

where:

$MethanolHistDem_{r,2002}$	= Calculated factor based on 2002 data, and
$MethanolDemUnc_r$	= Methanol demand for region *r* indexed to 2002.

Methanol Imports

Methanol imports are a function of methanol demand and natural gas prices.

$$MethimpShareUnc_r = \exp(MEIntercept) * \left(\frac{MethanolDemUnc_r}{MethanolHistDem_{r,2002}} * 100 \right)^{-0.498699} * (MEGasPR)^{0.303922} * (y^{0.329169}) \quad (29)$$

where:

$MEIntercept$	= Calculated regression intercept based on 2002 data,
$MEGasPR$	= Natural gas wellhead price adjusted to current year dollar, and
$MethimpShareUnc_r$	= Methanol imports for region *r* indexed to 2002.

Methanol Domestic Production

Methanol domestic production is the difference between total methanol demand and total methanol imports.

$$OrganicPRodIdxUnc_{11,r} = \left(\frac{MethanolDemUnc_r * (1 - MethimpShareUnc_r)}{OrganicHistPRod_{11,r,2002}} \right) * 100 \quad (30)$$

where:

$OrganicHistPRod_{11,r,2002}$	= Methanol production in 2002 for region *r*, and
$OrganicPRodIdxUnc_{11,r}$	= Methanol production for region *r* indexed to 2002.

Styrene

Styrene production is a function of ethylbenzene production.

$$OrganicPRodIdxUnc_{12,r} = \exp(STIntercept) * (OrganicPRodIdxUnc_{6,r})^{1.03554} * (y^{0.02}) \quad (31)$$

where:

$STIntercept$	= Calculated regression intercept based on 2002 data, and
$OrganicPRodIdxUnc_{12,r}$	= Styrene production for region *r* indexed to 2002.

Vinyl Acetate

Vinyl acetate production is a function of ethylene production.

$$OrganicPRodIdxUnc_{13,r} = \exp(VAIntercept) * (OrganicPRodIdxUnc_{1,r})^{1.112169} * (y^{-0.01494}) \quad (32)$$

where:

VAIntercept = Calculated regression intercept based on 2002 data, and

$OrganicPRodIdxUnc_{13,r}$ = Vinyl acetate production region *r* indexed to 2002.

Ethanol

Ethanol production is a function of total organic chemicals production (value of shipments).

$$OrganicPRodIdxUnc_{14,r} = \frac{ChemShip_{2,r,yr}}{ChemShip_{2,r,2002}} * 100.00 \quad (33)$$

where:

$ChemShip_{2,r,yr}$ = Organic chemicals value of shipments for region *r* in year *yr*, and

$OrganicPRodIdxUnc_{14,r}$ = Ethanol production for region *r* indexed to 2002.

On-Purpose Propylene

On-purpose propylene production is an exogenous projection (Table 8) based on limited situations where typical pricing or availability do not apply to certain chemical operators. This production also results in byproduct ethylene production, which is 53% (0.53) of the on-purpose propylene production.

Table 8. Exogenous Projection of On-Purpose Propylene

Year	Billion Pounds
2002	0.0000
2003	0.0000
2004	0.0000
2005	0.0000
2006	0.0000
2007	0.0000
2008	0.0000
2009	0.0000
2010	0.0000
2011	0.1443
2012	0.2886
2013	0.4329
2014	0.5772
2015	0.7214

Year	Billion Pounds
2016	0.8657
2017	1.0100
2018	1.1543
2019	1.2986
2020	1.4429
2021	1.5872
2022	1.7315
2023	1.8758
2024	2.0200
2025	2.1643
2026	2.3086
2027	2.4529
2028	2.5972
2029	2.7415
2030	2.8858
2031	3.0301
2032	3.1744
2033	3.3187
2034	3.4629
2035	3.6072

Other Organic Chemicals

Other (misc.) organic chemicals production is a function of total organic chemicals production (value of shipments).

$$OrganicPRodIdxUnc_{15,r} = \frac{ChemShip_{2,r,yr}}{ChemShip_{2,r,2002}} * 100.00 \quad (34)$$

where:

$OrganicPRodIdxUnc_{15,r}$ = Other organic chemicals production for region *r* indexed to 2002.

Inorganic Chemicals

Acetylene

Acetylene production is a function of vinyl acetate production.

$$InorganicPRodIdxUnc_{1,r} = OrganicPRodIdxUnc_{13,r} \quad (35)$$

where:

$InorganicPRodIdxUnc_{1,r}$ = Acetylene production for region *r* indexed to 2002.

Chlorine

Chlorine production is a function of paper industry production (value of shipments).

$$InorganicPRodIdxUnc_{2,r} = \frac{ChemPaper}{ChemPaper2002} * 100.00 \quad (36)$$

where:

ChemPaper	= Paper industry value of shipments for current year,
ChemPaper2002	= Paper industry value of shipments for 2002, and
$InorganicPRodIdxUnc_{2,r}$	= Chlorine production for region *r* indexed to 2002.

Oxygen

Oxygen production is a function of vinyl acetate production.

$$InorganicPRodIdxUnc_{3,r} = OrganicPRodIdxUnc_{13,r} \quad (37)$$

where:

$InorganicPRodIdxUnc_{3,r}$	= Oxygen production for region *r* indexed to 2002.

Sulfuric Acid

Sulfuric acid production is a function of phosphoric acid production.

$$InorganicPRodIdxUnc_{4,r} = \exp(SAIntercept) * (AgrichemPRodIdxUnc_{2,r})^{0.554257} * (y^{-0.04926}) \quad (38)$$

where:

SAIntercept	= Calculated regression intercept based on 2002 data,
$AgrichemPRodIdxUnc_{2r}$	= Phosphoric acid production for region *r* indexed to 2002, and
$InorganicPRodIdxUnc_{4,r}$	= Sulfuric acid production for region *r* indexed to 2002.

Hydrogen

Hydrogen production is a function of total inorganic chemicals productions (value of shipments).

$$InorganicPRodIdxUnc_{5,r} = \frac{ChemShip_{1,r,yr}}{ChemShip_{1,r,2002}} * 100.00 \quad (39)$$

where:

$ChemShip_{1,r,yr}$	= Inorganic chemicals value of shipments for region *r* in year *yr*, and
$InorganicPRodIdxUnc_{5,r}$	= Hydrogen production for region *r* indexed to 2002.

Other Inorganic Chemicals

Other (misc.) inorganic chemicals production is a function of total inorganic chemicals production (value of shipments).

$$InorganicPRodIdxUnc_{6,r} = \frac{ChemShip_{1,r,yr}}{ChemShip_{1,r,2002}} * 100.00 \quad (40)$$

where:

$InorganicPRodIdxUnc_{6,r}$ = Other inorganic chemicals production for region *r* indexed to 2002.

Plastic Resins

Polyethylene

Polyethylene production is a function of total plastic resins production (value of shipments).

$$RESINSPRodIdxUnc_{2,r} = \frac{ChemShip_{3,r,yr}}{ChemShip_{3,r,2002}} * 100.00 \quad (41)$$

where:

$ChemShip_{3,r,yr}$ = Plastic resins value of shipments for region *r* in year *yr*, and
$RESINSPRodIdxUnc_{2,r}$ = Polyethylene production for region *r* indexed to 2002.

Polyvinyl Chloride (PVC)

PVC production is a function of construction industry production (value of shipments) and polyethylene production.

$$\begin{aligned} RESINSPRodIdxUnc_{1,r} = {} & \exp(PVCIntercept) \\ & * \left(\frac{chemconst}{chemconst2002} * 100 \right)^{0.470265} \\ & * \left(RESINSPRodIdxUnc_{2,r} \right)^{0.59181} \\ & * (y^{-0.08928}) \end{aligned} \quad (42)$$

where:

$PVCIntercept$ = Calculated regression intercept based on 2002 data,
$ChemConst$ = Construction industry value of shipments for current year,
$ChemConst2002$ = Construction industry value of shipments for 2002, and
$RESINSPRodIdxUnc_{1,r}$ = PVC production for region *r* indexed to 2002.

Polystyrene

Polystyrene production is a function of styrene production and PVC production.

$$RESINSPRodIdxUnc_{3,r} = \exp(PSIntercept) * (OrganicPRodIdxUnc_{12,r})^{0.323791} * (RESINSPRodIdxUnc_{1,r})^{0.068003} * (y^{0.026836}) \quad (43)$$

where:

PSIntercept = Calculated regression intercept based on 2002 data, and
RESINSPRodIdxUnc$_{3,r}$ = Polystyrene production for region *r* indexed to 2002.

Styrene-Butadiene-Rubber (SBR)

SBR production is a function of butadiene production.

$$RESINSPRodIdxUnc_{4,r} = OrganicPRodIdxUnc_{3,r} \quad (44)$$

where:

RESINSPRodIdxUnc$_{4,r}$ = SBR production for region *r* indexed to 2002.

Vinyl Chloride

Vinyl chloride production is a function of PVC production.

$$RESINSPRodIdxUnc_{5,r} = RESINSPRodIdxUnc_{1,r} \quad (45)$$

where:

RESINSPRodIdxUnc$_{5,r}$ = Vinyl chloride production for region *r* indexed to 2002.

Other Plastic Resins

Other (misc.) plastic resins production is a function of total plastic resins production (value of shipments).

$$RESINSPRodIdxUnc_{6,r} = \frac{ChemShip_{3,r,yr}}{ChemShip_{3,r,2002}} * 100.00 \quad (46)$$

where:

RESINSPRodIdxUnc$_{6,r}$ = Other plastic resins production for region *r* indexed to 2002.

Agricultural Chemicals

Ammonia

Ammonia production is a function of total agricultural chemicals production (value of shipments).

$$AgrichemPRodIdxUnc_{1,r} = \frac{ChemShip_{4,r,yr}}{ChemShip_{4,r,2002}} * 100.00 \quad (47)$$

where:

$ChemShip_{4,r,yr}$	= Agricultural chemicals value of shipments for region *r* in year *yr*, and
$AgrichemPRodIdxUnc_{1,r}$	= Polyethylene production for region *r* indexed to 2002.

Phosphoric Acid

Phosphoric acid production is a function of ammonia production.

$$AgrichemPRodIdxUnc_{2,r} = \exp(PAIntercept) * (AgrichemPRodIdxUnc_{1,r})^{0.15298} * (y^{-0.06125}) \quad (48)$$

where:

$PAIntercept$	= Calculated regression intercept based on 2002 data, and
$AgrichemPRodIdxUnc_{2,r}$	= Phosphoric acid production for region *r* indexed to 2002.

Other Agricultural Chemicals

Other (misc.) agricultural chemicals production is a function of total agricultural chemicals production (value of shipments).

$$AgrichemPRrodIdxUnc_{3,r} = \frac{ChemShip_{4,r,yr}}{ChemShip_{4,r,2002}} * 100.00 \quad (49)$$

where:

$AgrichemPRodIdxUnc_{3,r}$	= Other agricultural chemicals production for region *r* indexed to 2002.

The above results are benchmarked to the known historical production from 2002 to 2008. Thus for each year (2002 to 2008) and each chemical, a benchmark factor is estimated. The benchmark factor equation is given as (an organic chemical is given as an example):

$$OrganicBench_{ic,ir} = \frac{OrganicHistPRodIdx_{ic,r}}{OrganicPRodIdxUnc_{ic,r}} \quad (50)$$

where:

$OrganicBench_{ic,r}$	= Benchmark factor for chemical *ic* in region *r* for a given year (2002 to 2008),
$OrganicHistPRodIdx_{ic,r}$	= Historical production of chemical *ic* in region *r* for the year, indexed to 2002, and
$OrganicPRodIdxUnc_{ic,r}$	= Calculated production from model equation of chemical *ic* in region *r* for the year, indexed to 2002.

The benchmark factor $OrganicBench_{ic,r}$ is then multiplied by the unbenchmarked production (e.g., $OrganicPRodIdxUnc_{ic,r}$) to calculate the final indexed production ($OrganicPRodIdxCal_{ic,r}$ in this example).

$$OrganicPRodIdxCal_{ic,r} = OrganicPRodIdxUnc_{ic,r} * OrganicBench_{ic,r} \quad (51)$$

The average benchmark factor from 2002 to 2008 is the benchmark factor applied for calculations starting in model year 2009. The final production value in physical units (billion pounds of chemical) is calculated as (an organic chemical is given as an example):

$$OrganicPRodCal_{ic,r} = OrganicPRodIdxCal_{ic,r} * OrganicPRodCal2002_{ic,r} \quad (52)$$

where:

$OrganicPRodCal_{ic,r}$ = Final production in billion lbs of chemical *ic* in region *r* for a given year,

$OrganicPRodCal2002_{ic,r}$ = Historical production in billion lbs of chemical *ic* in region *r* for 2002, and

$OrganicPRodIdxCal_{ic,r}$ = Production of chemical *ic* in region *r* for a given year indexed to 2002.

The choice of process used to produce a chemical product is not generally driven just by energy prices. Thus, the shares of processes used to produce a chemical are mostly exogenous to the model (see Table 5). The exceptions are those processes that use significant amounts of energy feedstocks, such as ethylene, propylene and butadiene. These chemicals are sensitive to energy prices, and as such, the model includes a feedstock switching response to changing energy prices. For the rest of the chemicals in the model, production by process is determined by the following equation (an organic chemical is used as an example):

$$OrganicPRocPRod_{ic,ip,r} = OrganicPRodCal_{ic,r} * OrganicPRocShr_{ip,r} \quad (53)$$

where:

$OrganicPRocPRod_{ic,ip,r}$ = Production in billion lbs of chemical *ic* using process *ip* in region *r*,

$OrganicPRodCal_{ic,r}$ = Production in billion lbs of chemical *ic* in region *r*, and

$OrganicPRocShr_{ip,r}$ = Exogenous share of process *ip* over total production of chemical *ic*.

To forecast energy consumption for the production of ethylene, propylene, and butadiene, feedstock/process shares are calculated first, followed by the calculation of energy consumption given the projected chemical production and the feedstock/process shares.

Feedstock Shares Calculations

The main approach used to forecast the shares of ethylene, propylene and butadiene feedstock is linear regression equations relating the feedstock shares with oil and natural gas prices. Naphthas and gas oils are petrochemical feedstocks and ethane, propane and butane are natural gas liquids (NGL) or liquefied petroleum gas (LPG). Thus, the relative values of natural gas and oil prices are key drivers for the choice between using oil-based feedstocks and gas-based ones.

In the model, the shares of total natural gas liquids (NGL includes ethane, propane, butane) and total petrochemical feedstocks (includes naphthas and gas oils) are determined by natural gas and crude oil price trends.

$$NGLShr = NGLIntercept_r + (-0.00681 * y) + (0.004943 * NGLOil\,\mathrm{Pr}) + (-0.02787 * NGLGas\,\mathrm{Pr}) \quad (54)$$

and,

$$NGLShr = \min(1.0, NGLShr) \quad (55)$$

where:

NGLShr	= Share of natural gas liquids feedstock,
$NGLIntercept_r$	= Calculated regression intercept based on 2002 data in region *r*,
y	= Current year minus 2001 (serves as an index),
NGLOilpr	= Crude oil (low sulfur light) price in current year $/barrel, and
NGLGaspr	= Natural gas price (wellhead) in current year $/1000 cf.

After calculating the share of natural gas liquids feedstock, the share of petrochemical feedstock is calculated.

$$PeFShr = 1 - NGLShr - BioShr \quad (56)$$

and,

$$PeFShr = \max(PeFshr, 0.36) \quad (57)$$

where:

PeFshr	= Petrochemical feedstock share, which is limited to 36% of capacity based on current data, and
BioShr	= Share of biomass feedstock, which is currently assumed to be zero.

For the high world oil price and low world oil price scenarios, limits are imposed on the shares of petrochemical feedstocks and NGL because of theoretical bounds. For the high world oil price case the share of petrochemical feedstocks is never lower than 3.0 percent, and for the low world oil price case the share of petrochemical feedstocks is never lower than 4.5 percent.

After the shares of NGL and petrochemical feedstocks are determined, the model calculates the shares of propane and ethane based also on the natural gas and oil prices.

$$EthShr = EthIntercept_r + (0.009968 * EthOil\,\mathrm{Pr}) + (-0.023380 * EthGas\,\mathrm{Pr}) + (0.582766 * EthShrLag_r) \quad (58)$$

and,

$$EthShr = \min(1.0, EthShr) \quad (59)$$

where:

EthShr	= Ethane share of natural gas liquids,
$EthIntercept_r$	= Calculated intercept for region *r* based on 2002 data,
$EthShrlag_r$	= Lag value of *EthShr* from previous year,
EthOilPr	= Crude oil (low sulfur light) price in current year $/barrel,

and

EthGasPr = Natural gas price (wellhead) in current year $/1000 cf.

After calculating the share of ethane feedstock, the share of propane feedstock, *ProShr*, is calculated.

$$\text{Pr}oShr = 1.0 - EthShr \tag{60}$$

Butane share is determined separately using a regression equation relating butane share with oil prices.

$$BtnShr = BtnIntercept_r + (0.002840 * BtnOil\ \text{Pr}) + (0.002342 * y) \tag{61}$$

and,

$$BtnShr = \min(1.0, BtnShr) \tag{62}$$

where:

BtnShr = Butane share of natural gas liquids,

$BtnIntercept_r$ = Calculated regression intercept for region *r* using 2002 data,

y = Current year minus 2001 (serves as an index), and

BtnOilPr = Crude oil (low sulfur light) price in current year $/barrel.

Also, since butane-based capacity is only located in Census Region 3, BtnShr = 0.0 for all regions except Census Region 3. There is also a limit to the share and use of butane for ethylene production in Census Region 3, and this limit is 5 percent. Therefore,

$$BtnShr = \max(0.05, BtnShr) \tag{63}$$

To allocate the total oil-based feedstock to naphthas and gas oils, the 2002 shares between the two feedstocks are maintained throughout the projection period.

$$GasOilSubShr = 0.1207 \tag{64}$$

and,

$$Naphthsubshr = 1 - GasOilSubShr \tag{65}$$

where:

GasOilSubShr = Gas oil share of total petrochemical feedstocks, and

NaphthaSubShr = Napthas share of total petrochemical feedstocks.

Since ethylene, propylene, and butadiene are co-produced, careful accounting of energy and feedstock consumed to produce each chemical is necessary. Given the feedstock shares already calculated using the equations above, these shares are applied to ethylene processes first.

There are six feedstocks for ethylene: ethane, propane, butane, naphtha, gas oil, and biomass. These shares were calculated above. Combining all the equations, let *OrganicPRocShr* represent the feedstock shares for ethylene as:

Ethylene Butane share

$$OrganicPRocShr_{5,r} = BtnShr \tag{66}$$

Ethylene Gas oil share

$$OrganicPRocShr_{3,r} = PeFShr * GasOilSubShr \tag{67}$$

Ethylene Naphtha share

$$OrganicPRocShr_{4,r} = PeFShr * NaphthSubShr \tag{68}$$

Ethylene Biomass share

$$OrganicPRocShr_{6,r} = BioShr \tag{69}$$

Ethylene Ethane share

$$\begin{aligned} OrganicPRocShr_{1,r} = EthShr * [1 - (&OrganicPRocShr_{3,r} + \\ &OrganicPRocShr_{4,r} + OrganicPRocShr_{5,r} \\ &+ OrganicPRocShr_{6,r})] \end{aligned} \tag{70}$$

Ethylene Propane share

$$\begin{aligned} OrganicPRocShr_{2,r} = [1 - (&OrganicPRocShr_{3,r} + OrganicPRocShr_{4,r} \\ &+ OrganicPRocShr_{5,r} + OrganicPRocShr_{6,r})] \\ &- OrganicPRocShr_{1,r} \end{aligned} \tag{71}$$

Since each type of feedstock has different production rates for ethylene, propylene and butadiene, the process or feedstock shares used for propylene and butadiene are based on the shares for ethylene but are adjusted to take these rates into account. Thus, the feedstock shares for propylene are:

$$\begin{aligned} sum = &(OrganicPRocShr_{1,r} * 3.0) + (OrganicPRocShr_{2,r} * 50.0) \\ &+ (OrganicPRocShr_{3,r} * 55.0) + (OrganicPRocShr_{4,r} * 50.0) \\ &+ (OrganicPRocShr_{5,r} * 40.0) \end{aligned} \tag{72}$$

Propylene Ethane share

$$OrganicPRocShr_{7,r} = (OrganicPRocShr_{1,r} * 3.0) / sum \tag{73}$$

Propylene Propane share

$$OrganicPRocShr_{8,r} = (OrganicPRocShr_{2,r} * 50.0) / sum \tag{74}$$

Propylene Gas Oil share

$$OrganicPRocShr_{9,r} = (OrganicPRocShr_{3,r} * 55.0) / sum \tag{75}$$

Propylene Naphtha share

$$OrganicPRocShr_{10,r} = (OrganicPRocShr_{4,r} * 50.0) / sum \quad (76)$$

Propylene Butane share

$$OrganicPRocShr_{11,r} = \min(0.08, (Organic\,\Pr ocShr_{5,indreg} * 40.0 / sum)) \quad (77)$$

Note that butane share has a limit and this limit is similarly based on the limit for ethylene. If the limit is reached, then the remainder is added to propane share.

$$OrganicPRocShr_{8,r} = OrganicPRocShr_{8,r} + [(OrganicPRocShr_{5,r} * 40.0) / sum) - OrganicPRocShr_{11,r}] \quad (78)$$

The shares for butadiene are:

Butadiene Catalytic dehydrogenation of butane share

$$OrganicPRocShr_{17,r} = OrganicHistPRocShr_{17,r} \quad (79)$$

where:

$OrganicHistPRocShr_{17,r}$ = Historical share of catalytic dehydrogenation of butane based on 2002 data.

Butadiene Catalytic dehydrogenation of n-butane share

$$OrganicPRocShr_{18,r} = OrganicHistPRocShr_{18,r} \quad (80)$$

where:

$OrganicHistPRocShr_{18,r}$ = Historical share of catalytic dehydrogenation of n-butane based on 2002 data.

Butadiene Ethane share

$$OrganicPRocShr_{12,r} = (1 - OrganicPRocShr_{17,r} - OrganicPRocShr_{18,r}) * (OrganicPRocShr_{1,r} * 2.0) / sum \quad (81)$$

where:

$$sum = (OrganicPRocShr_{1,r} * 2.0) + (OrganicPRocShr_{2,r} * 5.0) + (OrganicPRocShr_{3,r} * 17.0) + (OrganicPRocShr_{4,r} * 15.0) + OrganicPRocShr_{5,r} * 9.0) \quad (82)$$

Butadiene Propane share

$$OrganicPRocShr_{13,r} = (1 - OrganicPRocShr_{17,r} - OrganicPRocShr_{18,r}) * (OrganicPRocShr_{2,r} * 5.0) / sum \quad (83)$$

Butadiene Gas Oil share

$$OrganicPRocShr_{14,r} = (1 - OrganicPRocShr_{17,r} - OrganicPRocShr_{18,r}) * (OrganicPRocShr_{3,r} * 17.0) / sum \quad (84)$$

Butadiene Naphtha share

$$OrganicPRocShr_{15,r} = (1 - OrganicPRocShr_{17,r} - OrganicPRocShr_{18,r}) * (OrganicPRocShr_{4,r} * 15.0) / sum \quad (85)$$

Butadiene Butane share

$$OrganicPRocShr_{16,r} = (1 - OrganicPRocShr_{17,r} - OrganicPRocShr_{18,r}) * (OrganicPRocShr_{5,r} * 9.0) / sum \quad (86)$$

To avoid double/triple-counting when the model calculates energy consumption to produce these chemicals, each feedstock is assigned only to one of the three chemical products. Thus, the calculation of ethylene energy consumption is based only on the calculation of energy requirements using ethane and biomass as a feedstock. The calculation of propylene energy consumption is based on the calculation of the energy requirements using propane, gas oil, and naphthas as feedstocks, and for butadiene, the calculations are based on butane.

The assignments done in the calculations are only to avoid double/triple counting of energy consumption. It would be erroneous to imply that energy consumption using ethane and biomass feedstocks determines total energy consumption to produce ethylene. Ethylene is produced using ethane and biomass, but also propane, gas oils, naphthas, and butane. As such, to calculate total energy consumption to produce ethylene (or propylene or butadiene), it is important to sum all the energy consumption.

The final step is the calculation of energy consumption for each chemical/chemical group in Table 1. Unit energy requirements for fuel sources (steam, electricity, fuel), for each of the 14 energy services are assumed to change as energy prices change. The calculated total steam consumption is passed to the BSC Component.

Thus, the steps performed in this component for each chemical/chemical group are the following:

Step 1. Calculate the steam, fuel and electricity demand for each energy service and for each process without incorporating energy conservation effects from energy price changes. Thus, for each chemical (an organic chemical is presented as an example),

$$OrganicEnServ_{ic,ip,ie,if,r} = (OrganicPRodCal_{ic,r} * Organic\,Pr\,ocShr_{ip,r} * OrganicEn\,Re\,q_{ip,ie,if}) / 1000 \quad (87)$$

where:

$OrganicEnServ_{ic,ip,ie,if,r}$ = Energy consumption for energy service *ie* from fuel source *if* using process *ip* to manufacture chemical *ic* in region *r*,

$OrganicProdCal_{ic,r}$ = Production in billion lbs of chemical *ic* in region *r*,

$OrganicProcShr_{ip,r}$ = Share of process *ip* in region *r*, and

$OrganicEnReq_{ip,ie,if}$ = Unit energy requirement of fuel source *if* for energy

service *ie* using process *ip*.

where energy service categories are:

Process water cooling (*ie* = 1),
Pumping (*ie* = 2),
Compression (*ie* = 3),
Motive force (*ie* = 4),
Direct clean heat (*ie* = 5),
Indirect heat (*ie* = 6),
Indirect drying (*ie* = 7),
Concentration (*ie* = 8),
Distillation (*ie* = 9),
Electrolysis (*ie* = 10),
Feedstock (*ie* = 11),
Reforming (*ie* = 12),
Fuel from feed (*ie* = 13), and
Byproduct adjustment (*ie* = 14).

Step 2. Calculate total energy consumption for process cooling, electrolysis, machine drive, process heat, for each chemical, process, and fuel source by region.

Process Cooling

$$OrganicPC_{ic,ip,if,r} = OrganicEnServ_{ic,ip,1,if,r} \quad (88)$$

Machine Drive

$$\begin{aligned} OrganicMD_{ic,ip,if,r} &= OrganicEnServ_{ic,ip,2,if,r} \\ &+ OrganicEnServ_{ic,ip,3,if,r} \\ &+ OrganicEnServ_{ic,ip,4,if,r} \end{aligned} \quad (89)$$

Electrolysis

$$OrganicEY_{ic,ip,if,r} = OrganicEnServ_{ic,ip,10,if,r} \quad (90)$$

Process Heat

$$
\begin{aligned}
OrganicHT_{ic,ip,if,r} = {} & OrganicEnServ_{ic,ip,5,if,r} \\
& + OrganicEnServ_{ic,ip,6,if,r} \\
& + OrganicEnServ_{ic,ip,7,if,r} \\
& + OrganicEnServ_{ic,ip,8,if,r} \\
& + OrganicEnServ_{ic,ip,9,if,r} \\
& + OrganicEnServ_{ic,ip,12,if,r} \\
& + OrganicEnServ_{ic,ip,13,if,r} \\
& + OrganicEnServ_{ic,ip,14,if,r}
\end{aligned}
\tag{91}
$$

Step 3. Update energy demand calculated in step 2 by incorporating energy conservation for each service and fuel source, in which is driven by energy prices. Thus, the update starts with the calculation of the price change:

$$rat = price_{if,y} / price_{if,y-1} \tag{92}$$

where:

rat	= Ratio of current price over lag price, and
$price_{if,y}$	= Price of fuel source *if* in year *y*.

Given, the calculated price change *rat*, the savings rate is estimated:

$$SaveRt_{if,r} = SaveRt2002_{if,r} - (1 - (rat^{Elas_{if}})) \tag{93}$$

where:

$SaveRt_{if,r}$	= Savings rate for fuel source *if* in region *r*,
$SaveRt2002_{if,r}$	= Historical savings rate for fuel source *if* in region *r*, and
$Elas_{if}$	= Price elasticity of fuel source *if*.

After determining the savings rate, the total process cooling, machine drive, electrolysis, and process heat demands are adjusted to incorporate the savings. Using an organic chemical as an example, the equations used to calculate the demands are:

Process Cooling

$$OrganicTotPC_{ic,if,r} = OrganicTotPC_{ic,if,r} * (1 + SaveRt_{if,r}) \tag{94}$$

Machine Drive

$$OrganicTotMD_{ic,if,r} = OrganicTotMD_{ic,if,r} * (1 + SaveRt_{if,r}) \tag{95}$$

Electrolysis

$$OrganicTotEY_{ic,if,r} = OrganicTotEY_{ic,if,r} * (1 + SaveRt_{if,r}) \tag{96}$$

Process Heat

$$OrganicTotHT_{ic,if,r} = OrganicTotHT_{ic,if,r} * (1 + SaveRt_{if,r}) \tag{97}$$

Step 4. Allocate total process heat requirements by fuel type (natural gas, residual fuel oil, distillate fuel oil, coal, electricity).

For the *AEO2010*, it is assumed that the fuel shares are kept constant at 2002 values. This assumption is deemed reasonable since natural gas is the primary fuel for this application and switching to fuel oils, coal, and electricity would add more costs and have more regulatory barriers.

Step 5. Calculate final feedstock consumption. There are several chemicals in the model that consume energy as a raw material or feedstock:

- Ethylene/propylene/butadiene (LPG/NGL, petrochemical feedstocks, biomass)
- Acetic acid (natural gas, biomass)
- Ethylbenzene (petrochemical feedstocks)
- Methanol (natural gas, coal, biomass)
- On-purpose propylene (petrochemical feedstocks)
- Other organic chemicals (LPG/NGL, petrochemical feedstocks)
- Acetylene (natural gas)
- Hydrogen (natural gas, coal, biomass)
- Ammonia (natural gas, coal, petroleum coke)

Apart from ethylene/propylene/butadiene, the feedstock consumption is calculated using the unit energy requirements for the feedstock energy service and the production value. Total feedstock consumption for a particular fuel type (e.g., natural gas) is calculated as the sum of natural gas feedstock consumption of the chemicals that consume this (acetic acid, methanol, acetylene, hydrogen, ammonia).

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 *Energy Independence and Security Act of 2007* increased motor efficiency standards effective no later than 2011. The motor model has been revised to reflect the fact that the EPAC92 standards no longer apply. 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 program life 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:

$$TotalMotorEnergy_{i,s,r,y} = MotorStock_{i,s,r,y} * \left(MotorEnergy_{i,s,r,y} * \frac{3412}{10^{12}} \right) \qquad (98)$$

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).

$MotorStock_{i,s,r,y}$ 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:

$$ReplacePrPrem_{i,s} = PEListPrice_s * (1 - DealerDisc) - RewindCost_{i,s} \qquad (99)$$

where:

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

$PEListPrice_s$ = The manufacturers' list price for an EISA efficiency motor in size group *s*,

$DealerDisc$ = The average dealer discount offered on purchases of EISA efficiency

motors, and

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

The energy expenditure savings are calculated as follows:

$$ReplaceAnnSav_{i,s,r,y} = MotorHP_{i,s} * HPtoKW * MotorOpHr_{i,s} * IndElecPrice_{r,y} * \left[\left(\frac{1}{RewoundEff_{i,s}} \right) - \left(\frac{1}{PEPctEff_{i,s}} \right) \right] \quad (100)$$

where:

$ReplaceAnnSav_{i,s}$ = The expected annual savings from the replacing a 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*,

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

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

$IndElecPrice_{r,y}$ = The industrial electricity price for Census 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

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

The simple payback period in years is:

$$ReplacePayback_{i,s,r,y} = \frac{ReplacePrPrem_{i,s}}{ReplaceAnnSav_{i,s,r,y}} \quad (101)$$

where:

$ReplacePayback_{i,s,r,y}$ = Payback period, 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*.

$ReplacePrPremi_{,s}$ 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 EISA minimum efficiency motors and the number of failed motors that are repaired. 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 five acceptance rates, and the payback period for the motor size group:

$$ReplaceAccept_{i,s,r,y} = Acceptance\left(PremAccept,5,ReplacePayback_{i,s,r,y}\right) \quad (102)$$

where:

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

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

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

The number of failed motors is given by:

$$FailedMotors_{i,s,r,y} = MotorStock_{i,s,r,y-1} * FailurePct_{i,s} \quad (103)$$

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

$$RepMotorFlow_{i,s,r,y} = FailedMotors_{i,s,r,y} * ReplaceAccept_{i,s,r,y} \quad (104)$$

where:

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

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

Motor stock changes are then summarized by:

$$TotalMotorFlow_{i,s,r,y} = MotorStock_{i,s,r,y-1} * IndShipGr_{i,r,y} + RepMotorFlow_{i,s,r,y} \quad (105)$$

where:

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

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

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

The new motor stock is then:

$$MotorStock_{i,s,r,y} = MotorStock_{i,s,r,y-1} - FailedMotors_{i,s,r,y} + RewoundMotors_{i,s,r,y} + TotalMotorFlow_{i,s,r,y} \quad (106)$$

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

$$RewoundMotors_{i,s,r,y} = FailedMotors_{i,s,r,y} * RepMotFlow_{i,s,r,y} \quad (107)$$

where:

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

$FailedMotors_{i,s,r,y-1}$ and $RepMotorFlow_{i,s,r,y}$ 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:

$$RewoundEff_{i,s,r,y} = MotAvgEff_{i,s,r,y-1} - MotRewDrop_{i,s} \quad (108)$$

where:

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

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

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

The efficiency of new motors is calculated as a weighted average efficiency of the motors purchased:

$$NewMotorEff_{i,s,r,y} = \left(PEPctEff_{i,s} * PremMotorFlow_{i,s,r,y}\right) / RepMotFlow_{i,s,r,y} \quad (109)$$

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*.

$PEPctEff_{i,s}$, $PremMotorFlow_{i,s,r,y}$, *and* $RepMotFlow_{i,s,r,y}$ are defined above.

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

$$NewMotorEnergy_{i,s,r,y} = MotAdjEnergy_{i,s,r,y-1} * \left(1 - \frac{\left(NewMotorEff_{i,s,r,y} - MotAvgEff_{i,s,r,y-1}\right)}{NewMotorEff_{i,s,r,y}}\right) \quad (110)$$

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, and

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

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

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

$$RewMotorEnergy_{i,s,r,y} = MotAdjEnergy_{i,s,r,y-1} * \left(1 - \frac{\left(RewoundEff_{i,s,r,y} - MotAvgEff_{i,s,r,y-1}\right)}{RewoundEff_{i,s,r,y}}\right) \quad (111)$$

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, and

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

$RewoundEff_{i,s}$ *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:

$$MotAvgEnergy_{i,s,r,y} = \frac{\left(\begin{array}{l} MotAdjEnergy_{i,s,r,y-1} * \\ \left(MotorStock_{i,s,r,y-1} - FailedMotors_{i,s,r,y}\right) \\ + \left(TotalMotorFlow_{i,s,r,s} * NewMotorEnergy_{i,s,r,y}\right) \\ + \left(RewoundMotors_{i,s,r,y} * RewMotorEnergy_{i,s,r,y}\right) \end{array}\right)}{MotorStock_{i,s,r,y}} \quad (112)$$

where:

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

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

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

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

$$RewoundEff_{i,s,r,y} = MotAvgEff_{i,s,r,y-1} - MotRewDrop_{i,s} \quad (113)$$

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*.

$RewoundEff_{i,s,r,y}$ and $MotRewDrop_{i,s}$ are defined above.

The energy efficiency of motor systems is affected not only by the efficiency of the motors themselves, but also by the efficiency of the systems in which the motors are used. 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 as a percentage:

$$SystemSavingsR_{i,s} = \frac{\left(\begin{array}{l}\left(PumpAppPct_{i,s} * PumpSavPct_{i,s}\right) \\ +\left(FanAppPct_{i,s} * FanSavPct_{i,s}\right) \\ +\left(CompAppPct_{i,s} * CompSavPct_{i,s}\right)\end{array}\right)}{MotSysLife_{i,s}} \quad (114)$$

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:

$$MotAdjEnergy_{i,s,r,y} = MotAvgEnergy_{i,s,r,y} * \left(1 - SystemSavingsR_{i,s}\right) \quad (115)$$

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.

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

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

$$TotalMotorEnergy_{i,s,r,y} = \left(MotorStock_{i,s,r,y} * MotorAveEnergy_{i,s,r,y}\right) * \frac{3412}{10^{12}} \quad (116)$$

where:

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

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

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

$$TotalAdjMotorEnergy_{i,s,r,y} = \left(MotorStock_{i,s,r,y} * MotorAdjEnergy_{i,s,r,y}\right) * \frac{3412}{10^{12}} \qquad (117)$$

where:

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

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

CALBTOT

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

$$ENBQTY_{e,f} = \left(\begin{array}{l} EWeight * \left[EMPLX_{i,r} * ENBINT_{e,f} \right] \\ + PWeight * \left[ProdVX_{i,r} * ONBINT_{e,f} \right] \end{array} \right) * BldPFac \qquad (118)$$

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 (0.7),
PWeight = Weight for output unit energy consumption (0.3), 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:

$$BldPFac = BldPRat^{BldElas} \qquad (119)$$

where:

BldPRat = Ratio of current year's average industrial energy price to 2002 price, and
BldElas = Assumed elasticity, currently -0.5.

CALGEN

Subroutine CALGEN accounts for electricity generation from cogeneration by combining existing and planned cogeneration with new cogeneration 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 each industry. Generation for own use and electricity sales to the grid are calculated from the share of sales to the grid from EIA-860B data.[26]

CALGEN begins by computing total steam demand as the sum of steam use in buildings (HVAC being the only system using steam) and steam use from the process and assembly component.[27]

$$STEMCUR = ENBQTY_{hvac,steam} + ENPIQTY_{steam} \quad (120)$$

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:

$$NonCogSteam = STEMCUR - CogSteam_{i,r} \quad (121)$$

where:

$NonCogSteam$ = Non-cogenerated steam based on existing cogeneration capacity,
$STEMCUR$ = Total steam demand, and
$CogSteam_{i,r}$ = Steam met by existing cogenerators as of the last data year, for each industry *i* and Census Region *r*.

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 the function $SteamSeg_{i,loadsegment}$. It is assumed for this purpose that steam loads are distributed in the same proportions as boiler capacity:

$$AggSteamLoad_{loadsegment} = NonCogSteam + SteamSeg_{i,loadsegment} \quad (122)$$

where:

$AggSteamLoad_{loadsegment}$ = Aggregate steam load for a load segment,
$NonCogSteam$ = Non-cogenerated steam based on existing cogeneration capacity, and
$SteamSeg_{i,loadsegment}$ = The fraction of total steam in each of eight boiler firing ranges, in million Btu/hour, ranges are 1.5-3, 3-6.5, 6.5-10, 10-50, 50-100,

[26]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.
[27]This subroutine also calculates the amount of steam produced by byproduct fuels, which reduces the amount of steam required to be produced by purchased fuels.

100-250, 250-500, and >500.

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

$$AveHourlyLoad_{loadsegment} = \frac{AggSteamLoad_{loadsegment}}{0.008760} \quad (123)$$

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) this calculation is:

$$TechPot_{loadsegment} = AvgHourlyLoad_{loadsegement} * PowerSteam_{isys} \quad (124)$$

where:

$TechPot_{loadsegment}$ = Technical potential for cogeneration, in megawatts, for a 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):

$$EconPot_{loadsegement} = TechPot_{loadsegment} * EconFrac_{loadsegment} \quad (125)$$

where:

$EconPot_{loadsegment}$ = Economic potential for cogeneration in megawatts,

$TechPot_{loadsegment}$ = Technical potential for cogeneration, in megawatts, for a load segment if all cogeneration was adopted, irrespective of the economics, and

$EconFrac_{loadsegment}$ = 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:

$$CapAddMW_{loadsegment} = EconPot_{loadsegment} * PenetrationRate \quad (126)$$

where:

$CapAddMW_{loadsegment}$ = Cogeneration capacity added, in megawatts, for a load segment in the current model year,

$EconPot_{loadsegment}$ = Economic potential for cogeneration in 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 are 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 used 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 Census Division (nine), year, industry, and fuel. Since the model runs at the four 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:

$$COGGEN_{d,y,i,ngas} = COGGEN_{d,y,i,ngas} + CAPADDGWH * DSHR \quad (127)$$

$$COGCAP_{d,y,i,ngas} = COGCAP_{d,y,i,ngas} + CAPADDGWH * DSHR \quad (128)$$

$$COGTHR_{d,y,i,ngas} = COGTHR_{d,y,i,ngas} + STMADDTRIL * DSHR \quad (129)$$

$$COGELF_{d,y,i,ngas} = COGELF_{d,y,i,ngas} + \left(\left(CAPADDGWH*AVEHTRT \Big/ 10^6 \right) - \left(STMADDTRIL \Big/ 0.8 \right) \right) * DSHR \quad (130)$$

where:

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

Cogeneration from biomass (*BIO*) for the pulp and paper industry is also directly related to the amount of biomass available for that industry (calculated in subroutine CALBYPROD), which is calculated as follows:

$$BIO = Max\left(0, \frac{BioAvail_{r,y} - BioAvail_{r,y-1}}{HeatRate}\right) \quad (131)$$

where:

$BioAvailr_{r,y}$	=	Biomass available in Census Region *r*, in the current model year *y*,
$BioAvail_{r,y-1}$	=	Biomass available in Census Region *r*, in the previous model year *y*-1, 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 by the following calculation (incremental assignment shown):

$$COGGEN_{d,y,i,biomass} = COGGEN_{d,y,i,biomass} + BIO * DSHR \quad (132)$$

where:

$COGGEN_{d,y,i,biomass}$ = Total biomass cogeneration by Census Division *d*, year *y*, and industry *i*, and

DSHR = Factor to share Census Region addition to Census Divisions such that each division gets an equal share.

BIO is defined above.

The biomass capacity, thermal output, and electricity-related fuel use associated with the generation (*BIO*), are 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 component 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 $COGGRD_{d,y,i,f}$. 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 (2008). For the 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:

$$NEWGEN = CapAddGWH * DSHR \quad (133)$$

$$OLDGRD = COGGEN_{d,y,i,f} + COGGRD_{d,y,i,f} \quad (134)$$

$$NEWGRD = NEWGEN + COGGRDNEW_i \quad (135)$$

$$COGGRD_{d,y,i,f} = \frac{(OLDGRD + NEWGRD)}{(COGGEN_{d,y,i,f} + NEWGEN)} \quad (136)$$

where:

NEWGEN = Generation from the capacity additions (*CapAddGWH*) equally shared (*DSHR*) to Census Divisions in a region,

OLDGRD = Generation sold to the grid, prior to adjusting the sales and generation to reflect the new additions,

NEWGRD = Portion of new capacity generation (*NEWGEN*) sold to the grid, and

$COGGRDNEW_i$ = Assumed grid share for new capacity additions by industry.

CapAddGWH, DSHR, $COGGEN_{d,y,i,f}$, and $COGGRD_{d,y,i,f}$ are defined above.

Electricity generation for own use is then calculated as follows:

$$ELOWN_{y,i} = \sum_d \sum_f \left(COGGEN_{d,y,i,f} * COGGRD_{d,y,i,f} \right) \quad (137)$$

where:

$ELOWN_{y,i}$ = Electricity generation for own use for industry *i* and year *y*.

OLDGRD, $COGGEN_{d,y,i,f}$, and $COGGRD_{d,y,i,f}$ are defined 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 >500. The corresponding steam output, or steam load, is determined from the average boiler capacity using the following:

$$SteamLoad_{loadsegment} = AveBoilSize_{loadsegment} * EboilEff_{loadsegment} \quad (138)$$

where:

$SteamLoad_{loadsegment}$ = Steam output of average boiler in the load segment, in million Btu per hour,

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

$EboilEff_{loadsegment}$ = Assumed boiler efficiency.

A candidate cogeneration system is pre-selected 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* cogeneration systems (8) are used, with the system number, *isys* subscript, ranging from 1 to *nsys*. These characteristic variables are as follows:

$CogSizeKW_{isys}$ = 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 converted to useful heat and power.

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

$ElecGenEff_{isys}$ = Fraction of input energy converted to electric energy, or electric energy efficiency,
≈ 3412 / $CHeatRate_{isys}$

$ElecSizeMWh_{isys}$ = Electric generation from the cogeneration plant in megawatthours,
≈ $CogSizeKW_{isys}$ * 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, and
≈ $ElecGenEff_{isys}$ / ($OverAllEff_{isys}$ - $ElecGenEff_{isys}$)

$SteamOutput_{isys}$ = Thermal output of the cogeneration system in mmBtu/hr.
≈ $CogSizeKW_{isys}$ * 0.003412 / $PowerSteam_{isys}$

The system number pre-selected 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 with lower thermal output than the next largest system):

$$SteamOutput_{isys} \le SteamLoad_{loadsegment} < SteamOutput_{isys+1} \quad (139)$$

where:

$SteamOutput_{isys}$ = Steam output of the pre-selected cogeneration system, and
$SteamLoad_{loadsegment}$ = Matching thermal output in the load segment.

Next, the investment payback period must recover the prototypical cogeneration investment for each load segment ($Cpayback_{loadsegment}$). This is determined by 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 the user-specified fraction of the industrial electricity rate (10 percent). 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:

$$FuelCost_{loadsegment} = FuelUse_{isys} * CogFuelPrice \quad (140)$$

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

$$ExistFuelUse_{loadsegment} = \frac{SteamOutput_{isys} * 8.76 * CapFac_{isys}}{EboilEff_{loadsegment}} \quad (141)$$

$$ExistFuelCost_{loadsegment} = ExistFuelUse_{loadsegment} * CogFuelPrice \quad (142)$$

Determine incremental fuel cost and the value of cogenerated electricity:

$$IncrFuelCost_{loadsegment} = FuelCost_{loadsegment} - ExistFuelCost_{loadsegment} \quad (143)$$

$$ElecValue_{loadsegment} = ElecSizeMWh_{isys} * CogElecPrice * 0.003412 \quad (144)$$

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

$$OperProfit_{loadsegemnt} = ElecValue_{loadsegment} - IncrFuelCost_{loadsegment} \quad (145)$$

Determine the investment capital cost and the investment payback period:

$$Investment_{loadsegment} = CogSizeKW_{isys} * CogCapCostKW_{isys} \quad (146)$$

$$CPayBack_{loadsegment} = Investment_{loadsegment} / OperProfit_{loadsegment} \quad (147)$$

Given the payback for the prototype system evaluated for each load segment, the model estimates the fraction of total technical potential considered economical. 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 containing 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 the calculation is:

$$EconFrac_{loadsegment} = Acceptance\left(AcceptFrac,13,CPayBack_{loadsegment}\right) \quad (148)$$

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 this 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 0.8. Thus, total cogeneration system fuel use, $FuelSys_f$, is given by:

$$FuelSys_f = \sum_d COGELF_{d,y,i,f} + (COGOTHR_{d,y,i,f} / 0.8) \quad (149)$$

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

The steam that must be met through fossil-fired boilers is the total non-cogenerated steam (*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. Sharing this total to fuels in a manner consistent with MECS data is difficult. The MECS data indicate only the total amounts of indirect fuels associated with boilers and cogeneration, so we cannot directly compute fuel-specific boiler use from MECS alone. Since we take our cogeneration fuel use and thermal output from 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:

$$Estimated = NonCogFosSteam / 0.8$$

$$Implied = \sum_f BOIL2002_{i,r,f}$$

$$CALIB2002_FOS_{i,r} = Implied / Estimated$$

where:

Estimated = Trial value for fossil fuel use from conventional boilers,
Implied = Conventional boiler fuel use,
$BOIL2002_{i,r,f}$ = Difference between MECS and form 860b for each boiler fuel *f*, industry *i*, and Census Region *r*, and
$CALIB2002_FOS_{i,r}$ = 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:

$$NonCogFosFuel = \left(\frac{NonCogFosSteam}{0.8} \right) * \left(CALIB2002_FOS_{i,r} \right) \quad (150)$$

where:

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

cogeneration data.

NonCogFosSteam and $CALIB2002_FOS_{i,r}$ are defined above.

Conventional boiler fuel use ($FuelFos_{steam}$) is allocated to fuels based on fuel shares adjusted for price changes since 2002. The fuel shares (*BSSHR*) are estimated in subroutine CALBSC:

$$FuelFos_{steam} = NonCogFosFuel * BSSSHR_{f} \quad (151)$$

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

$$ENSQTY_{f} = CogBoilFuel_{f} * FosFuelSteam_{f} \quad (152)$$

where:

$CogBoilFuel_f$ = Fossil fuel consumption for cogeneration by fuel *f*, and
$FosFuelSteam_f$ = Fossil fuel consumption for conventional boilers by fuel *f*.

INDTOTAL

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

$$QTYMAIN_{r,f} = ENPMQTY_{f} + ENBQTY_{total,f} + ENSQTY_{f} + BYPBSCM_{f} \quad (153)$$

where:

$QTYMAIN_{r,f}$ = Consumption of fuel *f* in Census Region *r*,
$ENPMQTY_f$ = Consumption of fuel *f* in the PA component,
$ENBQTY_{total,f}$ = Consumption of fuel *f* for all building end uses,
$ENSQTY_f$ = Consumption of fuel *f* to generate steam, and
$BYPBSCM_f$ = Byproduct consumption of 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 as follows:

$$QTYMAIN_{r,elec} = ENPMQTY_{elec} + ENBQTY_{total,elec} - ELOWN \quad (154)$$

where:

$QTYMAIN_{r,elec}$ = 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:

$$TQMAIN_{r,f} = \sum_{i=1}^{INDMAX} QTYMAIN_{r,f} \quad (155)$$

where:

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

CONTAB

CONTAB is responsible for reporting consumption values for individual industries. National consumption values 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.[28] All other industries have similar equations.

$$FOODCON_f = \sum_{f=1}^{NUM_f} QTYMAIN_{5,f} \quad (156)$$

where:

$FOODCON_f$ = Total consumption of fuel *f* in the food products industry,
NUM_f = Number of fuels, and
$QTYMAIN_{5,f}$ = Consumption of fuel *f* for 4 Census Regions and the US (5).

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 time, but change over industry. This binary file also contains data that do not change over time, but change over process. 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 21 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*).

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

$$
\begin{aligned}
CGINDCAP_{d,y,f,grid} &= \sum_{i}^{ind\,max}\left(COGCAP_{d,y,i,f} * COGGRD_{d,y,i,f}\right)\\
CGINDCAP_{d,y,f,ownuse} &= \sum_{i}^{ind\,max}\left(COGCAP_{d,y,i,f} * \left(1 - COGGRD_{d,y,i,f}\right)\right)\\
CGINDGEN_{d,y,f,grid} &= \sum_{i}^{ind\,max}\left(COGGEN_{d,y,i,f} * COGGRD_{d,y,i,f}\right)\\
CGINDGEN_{d,y,f,ownuse} &= \sum_{i}^{ind\,max}\left(COGGEN_{d,y,i,f} * \left(1 - COGGRD_{d,y,i,f}\right)\right)\\
CGINDQ_{d,y,f,grid} &= \sum_{i}^{ind\,max}\left(COGELF_{d,y,i,f} * COGGRD_{d,y,i,f}\right)\\
CGINDQ_{d,y,f,ownuse} &= \sum_{i}^{ind\,max}\left(COGELF_{d,y,i,f} * \left(1 - COGGRD_{d,y,i,f}\right)\right)
\end{aligned}
\qquad (157)
$$

where:

$CGINDCAP_{d,y,f,u}$ = Cogeneration capacity by Census Division *d*, year *y*, fuel *f*, and use *u* (grid or own-use),

$CGINDGEN_{d,y,f,u}$ = Cogeneration generation by Census Division *d*, year *y*, fuel *f*, and use *u*,

$CGINDQ_{d,y,f,u}$ = Cogeneration fuel use, electricity portion, by Census Division *d*, year *y*, fuel *f*, and use *u*,

$COGGRD_{d,y,i,f}$ = Share of cogeneration sold to the grid by Census Division *d*, year *y*, industry *i*, and fuel *f*,

$COGCAP_{d,y,i,f}$ = Cogeneration capacity by Census Division *d*, year *y*, industry *i*, and fuel *f*,

$COGGEN_{d,y,i,f}$ = Cogeneration generation by Census Division *d*, year *y*, industry *i*, and fuel *f*, and

$COGELF_{d,y,i,f}$ = Cogeneration fuel use, electricity portion, by Census Division *d*, year, industry *i*, and fuel *f*.

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 (history) year, and thereafter are calibrated to the Short Term Energy Outlook (STEO) projection 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.[29]

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

$$BMAIN_{f,r} = TQMAIN_{f,r} + QELRF_r \quad (158)$$

where:

$BMAIN_{f,r}$ = Consumption of fuel *f* (electricity) in Census Region *r*,
$TQMAIN_{f,r}$ = Consumption of fuel *f* (electricity) in Census Region *r*, and
$QELRF_r$ = Refinery consumption of fuel *f* (electricity) in Census Region *r*.

The equation for total industrial natural gas consumption is:

$$BMAIN_{f,r} = TQMAIN_{f,r} + QNGRF_r + CGOGQ_{s,r} + CGOGQ_{o,r} \quad (159)$$

where:

$BMAIN_{f,r}$ = Consumption of fuel *f* (natural gas) in Census Region *r*,
$TQMAIN_{f,r}$ = Consumption of fuel *f* (natural gas) in Census Region *r*,
$QNGRF_r$ = Consumption of natural gas from Refining in Census Region *r*,
$CGOGQ_{s,r}$ = Consumption of natural gas from cogeneration of electricity for sales to the grid in enhanced oil recovery *s* in Census Region *r*, input from Oil and Gas Module, and
$CGOGQ_{o,r}$ = Consumption of natural gas from cogeneration of electricity for own use in enhanced oil recovery *o* by Census Region *r*, input from Oil and Gas Module.

Total industrial consumption for other fuels is calculated similarly.

SEDS benchmark factors are calculated as follows:

$$SEDSBF_{f,r} = \frac{SEDS4_{f,r}}{BMAIN_{f,r}} \quad (160)$$

where:

$SEDSBF_{f,r}$ = Current SEDS data year benchmark factors by fuel *f* and Census Region *r*,
$SEDS4_{f,r}$ = Current SEDS data year consumption aggregated from the Census Division level to the Census Region level *r* by fuel *f*, and
$BMAIN_{f,r}$ = Total Industrial consumption of fuel *f* in Census Region *r*.

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

$$BENCH_{f,r} = SEDSBF_{f,r} * BMAIN_{f,r} \quad (161)$$

where:

$BENCH_{f,r}$ = Benchmarked total industrial consumption of fuel *f* by Census Region *r*.

$SEDSBF_{f,r}$ and $BMAIN_{f,r}$ are defined above.

STEO benchmark factors are calculated as follows:

$$STEOBF_f = \frac{STEO_{f,y}}{\sum_f \sum_r BENCH_{f,r}} \quad (162)$$

where:

$STEOBF_f$ = STEO benchmark factor, which equals each fuel's share of the total SEDS benchmarked industrial consumption, by fuel *f* (note that these factors are applied post SEDS data years),

$STEO_{f,y}$ = STEO projected industrial consumption by fuel *f* for each STEO projection year *y*, and

$BENCH_{f,r}$ = Benchmarked total industrial consumption by fuel *f* and Census Region *r*.

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

$$BENCH_{f.r} = STEOBF_f * BENCH_{f,r} \quad (163)$$

STEO benchmark factors are faded to zero beginning in the first year after the STEO projection year through 2011.

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.

$$DSRENW_{f,d} = \frac{OUTIND_{13,d} + OUTIND_{11,d}}{\sum_{d=1}^{NUM_r} \left(OUTIND_{13,d} + OUTIND_{11,d}\right)} \quad (164)$$

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 (*i* = 13) in Census Division *d*,

$OUTIND_{11,d}$ = Gross value of output for the lumber and wood products industry (*i* = 11) in Census Division *d*, and

NUM_r Number of Census Divisions in Census Region *r*.

The benchmark factor for biomass is computed as follows:

$$BENCHFAC_{bm,d} = \frac{BIOFUELS_d}{\sum_{f=2}^{3} DQRENW_{f,d}} \quad (165)$$

where:

$BENCHFAC_{bm,d}$ = Benchmark factor for biomass *bm* 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*.

where renewable fuel consumption is calculated:

$$DQRENW_{f,d} = TQRENW_{f,r} * DSRENW_{f,d} \quad (166)$$

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.

$$QELIN_{d,y} = BENCH_{elec,r} * SEDSHR_{elec,r,d} \quad (167)$$

where:

$QELIN_{d,y}$ = Industrial consumption of electricity in Census Division *d* and year *y*,

$BENCH_{elec,r}$ = Consumption of electricity in Census Region *r*, and

$SEDSHR_{elec,r,d}$ = SEDS Census Region *r* share of electricity in Census Division *d*.

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

$$QGFIN_{d,y} = BENCH_{ngas,r} * SEDSHR_{ngas,r,d} * \left[\frac{TQMAIN_{cng,r} + TQMAIN_{fds,r}}{BMAIN_{ngas,r}} \right] \quad (168)$$

where:

$QGFIN_{d,y}$ = Industrial consumption of core natural gas in Census Division *d* and year *y*,

$BENCH_{ngas,r}$ = Benchmarked consumption of total natural gas in Census Region *r*,

$SEDSHR_{ngas,r,d}$ = SEDS Census Region *r* share of natural gas in Census Division *d*,

$TQMAIN_{cng,r}$ = Consumption of core natural gas in Census Region *r*, from Subroutine NATTOTAL,

$TQMAIN_{fds,r}$ = Consumption of feedstock natural gas in Census Region *r*, from Subroutine NATTOTAL, and

$BMAIN_{ngas,r}$ = Total un-benchmarked consumption of natural gas in Census Region *r*.

$$QGIIN_{d,y} = QNGIN_{ngas,r} - QGFIN_{d,y} \quad (169)$$

where:

$QGIIN_{d,y}$ = Industrial consumption of non-core natural gas in Census Division *d* by year *y*,

$QNGIN_{ngas,d}$ = Consumption of natural gas in Census Division *d*, and

$QGFIN_{d,y}$ = Industrial consumption of core natural gas in Census Division *d* by year *y*.

Industrial consumption of biomass is calculated in the following equation:

$$QBMIN_{d,y} = \left[\sum_{f=2}^{3} DQRENW_{f,d}\right] + \left[\sum_{u=1}^{2} CGOGO_{d,y,bm,u}\right] + QBMRF_{d,y} \quad (170)$$

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 in enhanced oil recovery *u* 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 renewable fuels is calculated through the following equation. Currently, only biomass (including pulping liquor), hydropower, and municipal solid waste (MSW) are nonzero.

$$QTRIN_{d,y} = QHOIN_{d,y} + QBMIN_{d,y} + QGEIN_{d,y} + QSTIN_{d,y} + QPVIN_{d,y} + QWIIN_{d,y} + QMSIN_{d,y} \quad (171)$$

where:

$QTRIN_{d,y}$ = Total industrial consumption of renewable fuels 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 B14). The retirement rate is posited to be a positive function of energy prices. For years after 2002, *RetirePrat* is calculated as the greater of 1 and the ratio of the current year's average industrial energy price to the average price in 2002.

$$X = RetirePrat^{RetireBeta}$$

$$RetirePriceFactor = \frac{X}{(1+X)} \qquad (172)$$

$$RetireRate_s = 2*RetirePriceFactor*ProdRetr_s$$

where:

RetirePrat	=	Maximum (1, 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*.

$$PRODCUR_{old,s} = (PRODCUR_{old,s} + IDLCAP_{old,s}) * (1 - RetireRate_s) \qquad (173)$$

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 process step *s*.

$$PRODCUR_{mid,s} = PRODCUR_{mid,s} + PRODCUR_{new,s} \quad (174)$$

where:

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

$$PRODX_{i,r} = PHDRAT * PRODVX_{i,r} \quad (175)$$

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 ($\mathbf{D_1}$ is equivalent to *PRODX*), and
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:

$$(\mathbf{I} - \mathbf{A}) * \mathbf{X} = \mathbf{D} \quad (176)$$

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

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1} * \mathbf{D} \quad (177)$$

Since the **A** coefficients for old and new capacity differ, there are two such arrays: $\mathbf{A_{old}}$ and $\mathbf{A_{new}}$. The corresponding "technology" matrices ($\mathbf{I-A_{old}}$) and ($\mathbf{I-A_{new}}$) will be referred to as $\mathbf{IA_{old}}$ and $\mathbf{IA_{new}}$.

Likewise, $\mathbf{X_{old}}$ and $\mathbf{X_{new}}$ 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 $\mathbf{X_{old}}$ and the portion of that capacity that survives to a given year is called $\mathbf{X_{surv}}$. The portion that is retired is called $\mathbf{X_{ret}}$. Therefore, total productive capacity ($\mathbf{X_{tot}}$) is given by:

$$\mathbf{X_{tot}} = \mathbf{X_{surv}} + \mathbf{X_{new}}$$
$$or \quad (178)$$
$$\mathbf{X_{tot}} = \mathbf{X_{old}} - \mathbf{X_{ret}} + \mathbf{X_{new}}$$

$\mathbf{X_{old}}$ is defined in the base year as follows:

$$\mathbf{IA_{old}} * \mathbf{X_{old}} = \mathbf{D}_{2002}$$
$$or \quad (179)$$
$$\mathbf{X_{old}} = \mathbf{IA_{old}}^{-1} * \mathbf{D}$$

$\mathbf{X_{new}}$ 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:

$$\mathbf{X_{ret}} = \mathbf{X_{old}} * (1 - (1 - R))^{(Year - 2002)} \quad (180)$$

$$\mathbf{X_{surv}} = \mathbf{X_{old}} - \mathbf{X_{ret}} \quad (181)$$

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

$$\mathbf{D_{old}} = \mathbf{IA_{old}} * \mathbf{X_{surv}} \quad (182)$$

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

$$\mathbf{IA_{old}} * \mathbf{X_{surv,\,year}} + \mathbf{IA_{new}} * \mathbf{X_{new,\,year}} = \mathbf{D}_{year} \quad (183)$$

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

$$\mathbf{IA_{new}} * \mathbf{X_{new,\,\mathit{year}}} = \mathbf{D}_{year} - \mathbf{IA_{old}} * \mathbf{X_{surv,\,\mathit{year}}} \quad (184)$$

Therefore,

$$\mathbf{X_{new,\,year}} = \mathbf{IA_{new}}^{-1} * (\mathbf{D}_{\text{year}} - \mathbf{IA_{old}} * \mathbf{X_{surv,\,year}}) \quad (185)$$

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 $\mathbf{IA_{new}}^{-1}$, followed by calls to intrinsic matrix multiplication functions to solve for $\mathbf{X_{new}}$. As a result, the amount of actual code to implement this approach is minimal.

CALCSC

CALCSC computes Unit Energy Consumption (UEC) for all industries. The current UECs for the old and new vintage are 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.

$$ENPINT_{v,f,s} = ENPINTLAG_{v,f,s} * (1 + TPCRate_{v}) \quad (186)$$

where:

$ENPINT_{v,f,s}$ = UEC of process step *s* for fuel *f* and vintage *v*,
$ENPINTLAG_{v,f,s}$ = Lagged UEC of process step *s* for fuel *f* and vintage *v*, and
$TPCRate_{v}$ = Energy intensity decline rate for vintage *v* after accounting for the impact of increased energy prices.

$TPCRate_{v}$ is calculated using the following relationships when *TPCPrat* is greater than 1.0. Otherwise, the default value for the intensity decline rate is used, $BCSC_{v,f,s}$.

$$X = TPCPrat^{TPCBeta}$$
$$TPCPriceFactor = \frac{X}{(1+X)} \quad (187)$$
$$TPCRate_{v} = 2*TPCPriceFactor*BCSC_{v,f,s}$$

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*, and
$BCSC_{v,f,s}$ = Default intensity rate for old and new vintage *v* for each fuel *f* and step *s*.
$TPCRate_{v}$ is defined above.

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

$$ENPINT_{mid,f,s} = \frac{SUMPINT_{f,s}}{CUMPROD_{new,s}} \quad (188)$$

where:

$ENPINT_{mid,f,s}$ = UEC of process step *s* for fuel *f* at middle vintage,
$SUMPINT_{f,s}$ = Cumulative UEC of process step *s* for fuel *f* , 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:

$$ShareFuel_i = \frac{\left(P_i^{\alpha_i} \beta_i\right)}{\sum_{i=1}^{3} P_i^{\alpha_i} \beta_i} \quad (189)$$

where:

$ShareFuel_i$ = Boiler fuel share for fuel *i*,
P_i = Fuel price relative to the 2002 price for fuel *i*,
α_i = Sensitivity parameter for fuel *i*, default value is -2.0, and
$BCSC_{v,f,s}$ = Fuel chares calibrated to 2002 using relative prices that prevailed in that year.

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 byproduct fuels are consumed before the quantity of purchased fuels is estimated using this equation.

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Appendix B. Data Inputs

Table B1. Building Component Energy Consumption, Part 1 (trillion Btu)					
		Lighting	Heating, Ventilation, Air Conditioning		
	Region	Electricity	Electricity	Natural Gas	Steam
Food	NE	1.64	1.75	4.05	2.01
	MW	7.25	7.70	16.92	4.42
	SO	5.83	6.19	12.05	5.98
	WE	2.54	2.70	7.46	3.71
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	1.42	1.71	1.31	0.00
	MW	3.06	3.68	2.34	0.00
	SO	13.05	15.69	16.40	0.00
	WE	0.94	1.13	1.14	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
Fabricated Metals	NE	2.21	2.36	7.37	2.10
	MW	7.34	7.82	25.11	7.15
	SO	5.23	5.57	15.19	4.33
	WE	1.41	1.50	3.39	0.97
Machinery	NE	1.94	2.58	4.68	2.36
	MW	5.81	7.75	18.65	9.40
	SO	3.72	4.96	6.91	3.48
	WE	1.04	1.39	2.34	1.18
Computers	NE	5.18	11.27	7.11	8.87
	MW	2.45	5.34	4.11	5.12
	SO	4.22	9.19	2.67	3.32
	WE	5.86	12.75	8.00	9.97
Electrical Equipment	NE	0.93	1.25	3.00	1.28
	MW	2.27	3.02	5.70	2.43
	SO	2.80	3.74	5.47	2.33
	WE	0.40	0.53	1.58	0.67
Transportation Equipment	NE	2.18	2.77	6.63	0.93
	MW	14.65	18.59	36.95	5.20
	SO	7.48	9.49	14.47	2.04
	WE	2.49	3.16	5.78	0.81

Table B1. Building Component Energy Consumption, Part 1 (trillion Btu)					
		Lighting	Heating, Ventilation, Air Conditioning		
	Region	Electricity	Electricity	Natural Gas	Steam
Wood Products	NE	0.30	0.30	0.72	1.14
	MW	0.75	.0.75	2.12	3.34
	SO	2.94	2.94	3.69	5.82
	WE	1.28	1.28	2.23	3.52
Plastic Products	NE	2.15	2.61	3.12	0.00
	MW	5.54	6.73	9.97	0.00
	SO	6.03	7.33	12.42	0.00
	WE	1.24	1.51	1.85	0.00
Balance of Manufacturing	NE	6.91	9.70	6.99	0.00
	MW	15.98	22.43	31.26	0.00
	SO	26.23	36.80	62.36	0.00
	WE	7.78	10.92	16.68	0.00
Source: U.S. Energy Information Administration, Office of Integrated Analysis and Forecasting estimates based on *Manufacturing Consumption of Energy 2002*.					

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	0.34	0.17	0.05	0.01	0.09	0.08	0.57	0.10
	MW	0.73	0.40	0.02	0.05	0.20	0.18	0.17	0.48
	SO	3.11	2.80	0.08	0.31	0.87	1.23	0.83	3.23
	WE	0.22	0.20	0.00	0.00	0.06	0.09	0.00	0.01
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
Fabricated Metals	NE	0.44	0.14	0.09	0.00	0.04	0.04	0.09	0.00
	MW	1.47	0.53	0.09	0.02	0.15	0.13	0.09	0.61
	SO	1.05	0.34	0.05	0.03	0.10	0.09	0.05	1.21
	WE	0.28	0.08	0.00	0.00	0.03	0.02	0.00	0.00
Machinery	NE	0.32	0.16	0.00	0.00	0.04	0.04	0.00	0.00
	MW	0.97	0.61	0.06	0.03	0.12	0.15	0.28	0.29
	SO	0.62	0.22	0.00	0.03	0.08	0.06	0.00	0.29
	WE	0.17	0.08	0.00	0.00	0.02	0.02	0.00	0.00
Computers	NE	2.74	0.35	0.04	0.00	0.08	0.09	0.04	0.00
	MW	1.30	0.20	0.00	0.11	0.04	0.05	0.00	0.11
	SO	2.24	0.13	0.00	0.00	0.06	0.03	0.00	0.00
	WE	3.10	0.40	0.00	0.00	0.09	0.10	0.00	0.00
Electrical Equipment	NE	0.16	0.05	0.00	0.00	0.04	0.05	0.00	0.00
	MW	0.38	0.10	0.00	0.00	0.09	0.10	0.00	0.00
	SO	0.47	0.09	0.00	0.07	0.12	0.09	0.00	0.71
	WE	0.07	0.03	0.08	0.00	0.02	0.03	0.08	0.00
Transportation Equipment	NE	0.50	0.21	0.00	0.00	0.08	0.03	0.00	0.00
	MW	3.38	1.17	0.03	0.13	0.56	0.15	0.58	0.27
	SO	1.73	0.46	0.03	0.07	0.29	0.06	0.58	0.13

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
	WE	0.58	0.19	0.00	0.00	0.10	0.02	0.00	0.00
Wood Products	NE	0.06	0.03	0.11	0.08	0.06	0.03	1.25	0.38
	MW	0.15	0.12	0.06	0.08	0.15	0.12	0.63	0.38
	SO	0.59	0.21	0.22	0.17	0.59	0.21	2.50	0.75
	WE	0.26	0.12	0.17	0.08	0.26	0.12	1.88	0.38
Plastic Products	NE	0.61	0.12	0.00	0.10	0.04	0.03	0.00	0.80
	MW	1.58	0.41	0.00	0.10	0.10	0.10	0.00	0.80
	SO	1.72	0.49	0.10	0.10	0.11	0.12	0.10	0.80
	WE	0.35	0.08	0.00	0.00	0.02	0.02	0.00	0.00
Balance of Manufacturing	NE	1.46	0.63	0.00	0.00	0.00	0.00	1.04	0.57
	MW	3.38	2.86	0.00	0.00	0.00	0.00	1.98	0.02
	SO	5.55	5.75	0.00	0.00	0.00	0.00	1.62	1.27
	WE	1.65	1.49	0.00	0.00	0.00	0.00	2.48	0.97
Source: U.S. 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	444.8	0.019	0.480	0.009	0.002	0.004	0.013	0.962
Refrigeration	444.8	0.150	0.019	0.000	0.005	0.000	0.000	0.000
Machine Drive	444.8	0.300	0.030	0.000	0.007	0.000	0.000	0.000
Other	444.8	0.002	0.009	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, U.S. 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	98.6	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
Paper making	91.1	1.660	0.914	0.160	0.012	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, U.S. 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	Petrochemical Feedstocks
Bulk Chemicals									
End Use									
Direct Heat	198.9	0.144	2.974	0.083	0.003	0.170	0.033	6.459	0.000
Refrigeration	198.9	0.247	0.129	0.000	0.001	0.001	0.000	0.000	0.000
Machine Drive	198.9	1.837	0.089	0.000	0.007	0.002	0.000	0.000	0.000
Electrolytic	198.9	0.564	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	198.9	0.009	0.126	0.000	0.002	0.000	0.002	0.000	0.000
Feedstocks	198.9	0.000	3.056	0.000	0.000	10.198	0.000	0.000	6.147
Inorganic									
End Use									
Direct Heat	30.8	0.102	2.011	0.238	0.005	0.000	0.076	5.002	0.000
Refrigeration	30.8	0.370	0.008	0.000	0.001	0.000	0.000	0.000	0.000
Machine Drive	30.8	4.440	0.000	0.000	0.009	0.002	0.000	0.000	0.000
Electrolytic	30.8	2.024	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	30.8	0.008	0.067	0.000	0.006	0.000	0.015	0.000	0.000
Feedstocks	30.8	0.000	0.908	0.000	0.000	0.427	0.000	0.000	0.256
Organic									
End Use									
Direct Heat	81.5	0.124	3.456	0.088	0.002	0.414	0.013	10.457	0.000
Refrigeration	81.5	0.245	0.291	0.000	0.002	0.003	0.000	0.000	0.000
Machine Drive	81.5	1.344	0.084	0.000	0.008	0.004	0.000	0.000	0.000
Electrolytic	81.5	0.282	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	81.5	0.010	0.248	0.000	0.002	0.000	0.000	0.000	0.000
Feedstocks	81.5	0.000	2.513	0.000	0.000	11.924	0.000	0.000	5.964
Resins									
End Use									
Direct Heat	67.8	0.204	1.537	0.013	0.003	0.001	0.033	4.073	0.000
Refrigeration	67.8	0.242	0.026	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	67.8	1.418	0.038	0.002	0.003	0.000	0.000	0.000	0.000
Electrolytic	67.8	0.396	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	67.8	0.008	0.035	0.001	0.000	0.000	0.000	0.000	0.000
Feedstocks	67.8	0.000	1.004	0.000	0.000	15.407	0.000	0.000	10.758
Agricultural Chemicals									
End Use									
Direct Heat	18.8	0.076	7.623	0.062	0.010	0.000	0.054	0.140	0.000
Refrigeration	18.8	0.076	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	18.8	1.278	0.442	0.000	0.015	0.000	0.000	0.000	0.000
Electrolytic	18.8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	18.8	0.015	0.028	0.000	0.000	0.000	0.000	0.000	0.000
Feedstocks	18.8	0.000	16.290	0.000	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, U.S. 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	0.000	0.000	0.000	0.000	0.000
Melting/Refining	14.6	0.520	5.121	0.018	0.008	0.014	0.200
Scrap							
Batch Prep	2.4	0.190	0.000	0.000	0.000	0.000	0.000
Melting/Refining	2.4	0.420	4.099	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	0.006	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, U.S. 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	0.000
Wet Process	20.2	0.210	0.260	0.013	0.017	0.002	3.056	0.107	0.820
Finish Grinding	98.9	0.220	0.000	0.000	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, U.S. 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	0.000	0.000	36.800	0.000	0.710	2.241
Iron & Steel making									
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	0.000	0.003	0.000	0.000	0.000	0.000
Casting									
Ingot	2.8	0.340	1.532	0.000	0.008	0.068	0.090	0.030	0.000
Continuous	98.2	0.100	0.270	0.000	0.001	0.028	0.000	0.010	0.000
Hot Rolling	105.7	0.400	1.300	0.000	0.009	0.000	0.000	0.020	0.000
Cold Rolling	39.4	0.900	1.532	0.000	0.008	0.000	0.000	1.310	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, U.S. 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	0.000
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	0.000	0.000
Semi-Fabrication							
Sheet, Plate, Foil	4.9	3.200	10.022	0.030	0.048	0.000	0.000
Other	2.3	3.400	5.458	0.016	0.026	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, U.S. Energy Information Administration, Washington, DC, October 2005.

Table B10. Metal-Based Durables PA Component National UECs, 2002
(Thousand Btu/2000$ of Shipments, Unless Otherwise Indicated)

Industry	Ship-ments (Billion 2000$)	Elec-tricity	Natural Gas	Residual	Distillate	LPG	Coal	Petroleum Coke	Steam
Fabricated Metals									
Heating	244.3	0.163	0.585	0.005	0.010	0.002	0.001	0.010	0.000
Refrigeration	244.3	0.026	0.001	0.000	0.001	0.000	0.000	0.000	0.000
Machine Drive	244.3	0.313	0.009	0.000	0.001	0.000	0.000	0.000	0.000
Electrochemical	244.3	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	244.3	0.001	0.001	0.000	0.001	0.000	0.002	0.000	0.000
Machinery									
Heating	252.4	0.024	0.125	0.000	0.000	0.003	0.000	0.000	0.000
Refrigeration	252.4	0.012	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	252.4	0.167	0.008	0.000	0.000	0.000	0.000	0.000	0.000
Electrochemical	252.4	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	252.4	0.001	0.001	0.000	0.002	0.000	0.000	0.000	0.000
Computers and Electronics									
Heating	439.1	0.035	0.022	0.000	0.000	0.000	0.000	0.000	0.000
Refrigeration	439.1	0.028	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	439.1	0.070	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Electrochemical	439.1	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	439.1	0.009	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Electrical Equipment									
Heating	103.6	0.090	0.276	0.000	0.001	0.001	0.000	0.000	0.001
Refrigeration	103.6	0.020	0.003	0.000	0.001	0.000	0.000	0.000	0.000
Machine Drive	103.6	0.169	0.003	0.000	0.001	0.001	0.000	0.000	0.000
Electrochemical	103.6	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	103.6	0.002	0.003	0.000	0.001	0.001	0.000	0.666	0.000
Transportation Equipment									
Heating	640.0	0.027	0.104	0.000	0.000	0.002	0.000	0.000	0.104
Refrigeration	640.0	0.013	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	640.0	0.121	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Electrochemical	640.0	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	640.0	0.003	0.013	0.000	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, U.S. Energy Information Administration, Washington, DC, October 2005 and Office of Integrated Analysis and Forecasting estimates.

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

Industry	Ship-ments (Billion 2000$)	Elec-tricity	Natural Gas	Residual	Distillate	LPG	Coal	Petroleum Coke	Steam
Wood Products									
Heating	91.6	0.048	0.329	0.006	0.006	0.022	0.000	0.000	2.077
Refrigeration	91.6	0.005	0.005	0.000	0.006	0.000	0.000	0.000	0.000
Machine Drive	91.6	0.643	0.012	0.000	0.027	0.005	0.000	0.000	0.000
Electrochemical	91.6	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	91.6	0.005	0.012	0.000	0.006	0.005	0.000	0.000	0.000
Plastic Products									
Heating	173.4	0.150	0.235	0.012	0.002	0.007	0.000	0.000	0.482
Refrigeration	173.4	0.081	0.006	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	173.4	0.533	0.006	0.001	0.002	0.002	0.000	0.000	0.000
Electrochemical	173.4	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	173.4	0.012	0.006	0.000	0.002	0.002	0.000	0.000	0.000
Balance of Manufacturing									
Heating	910.2	0.083	0.515	0.000	0.018	0.008	0.101	0.000	0.440
Refrigeration	910.2	0.044	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	910.2	0.294	0.041	0.000	0.008	0.000	0.000	0.000	0.000
Electrochemical	910.2	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	910.2	0.000	0.012	0.000	0.000	0.000	0.004	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, U.S. Energy Information Administration, Washington, DC, October 2005 and Office of Integrated Analysis and Forecasting estimates.

Table B12. 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	94.4	0.676	0.604	3.177	0.411	0.859	0.000	0.000
Agri-Other	135.5	0.390	0.146	1.286	0.304	0.502	0.000	0.000
Coal Mining	21.3	1.538	0.034	2.086	0.000	0.098	0.267	0.000
Oil & Gas	174.8	0.567	2.768	0.202	0.000	0.056	0.000	0.000
Other Mining	25.8	3.753	2.833	1.754	0.000	0.145	0.210	0.000
Construction	923.6	0.115	0.284	0.501	0.000	0.156	0.000	1.343

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 B13. 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
	Paper making	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, U.S. Energy Information Administration, Washington, DC, October 2005.

Table B14. Coefficients for Technology Possibility Curves and Retirement Rates, Reference Case						
	Existing Facilities		New Facilities			Retirement
Industry/Process Unit	REI 2035	TPC	REI 2002	REI 2035	TPC	Rate (%)
Food Product						
Process Heating	0.883	-0.0038	0.900	0.783	-0.0042	1.7
Process Cooling - electricity	0.854	-0.0048	0.850	0.733	-0.0045	1.7
Process Cooling - fuels	0.883	-0.0038	0.900	0.783	-0.0042	1.7
Other - electricity	0.899	-0.0032	0.915	0.793	-0.0043	1.7
Other - fuels	0.883	-0.0038	0.900	0.783	-0.0042	1.7
Paper & Allied Products						
Wood Preparation	0.792	-0.0071	0.882	0.701	-0.0069	2.3
Waste Pulping	0.936	-0.0020	0.936	0.936	0.0000	2.3
Mechanical Pulping	0.800	-0.0067	0.931	0.622	-0.0121	2.3
Semi-Chemical(a)	0.951	-0.0015	0.971	0.930	-0.0013	2.3
Kraft, Sulfite	0.860	-0.0046	0.914	0.810	-0.0036	2.3
Bleaching	0.780	-0.0075	0.878	0.680	-0.0077	2.3
Paper Making	0.869	-0.0043	0.885	0.852	-0.0012	2.3
Bulk Chemicals						
Process Heating	0.883	-0.0038	0.900	0.783	-0.0042	1.7
Process Cooling - electricity	0.854	-0.0048	0.850	0.733	-0.0045	1.7
Process Cooling - fuels	0.883	-0.0038	0.900	0.783	-0.0042	1.7
Electro-Chemical	0.976	-0.0007	0.950	0.833	-0.0040	1.7
Other - electricity	0.899	-0.0032	0.915	0.793	-0.0043	1.7
Other - fuels	0.780	-0.0075	0.720	0.545	-0.0084	1.7
Glass & Glass Products						
Batch Preparation	0.941	-0.0018	0.882	0.882	0.0000	1.3
Melting/Refining	0.934	-0.0021	0.900	0.868	-0.0011	1.3
Forming	0.984	-0.0005	0.982	0.968	-0.0004	1.3
Post-Forming	0.978	-0.0007	0.968	0.955	-0.0004	1.3
Cement						
Dry Process	0.905	-0.0030	0.900	0.810	-0.0032	1.2
Wet Process(c)	0.944	-0.0017	NA	NA	NA	1.2
Finish Grinding	0.975	-0.0008	0.950	0.950	0.0000	1.2
Iron & Steel						
Coke Oven	0.935	-0.0021	0.902	0.869	-0.0011	2.5
BF/BOF	0.994	-0.0002	0.987	0.987	0.0000	1.5
EAF	0.914	-0.0027	0.990	0.830	-0.0053	1.5
Ingot Casting	1.000	0.0000	NA	NA	NA	2.9
Continuous Casting	1.000	0.0000	1.000	1.000	0.0000	2.9
Hot Rolling	0.816	-0.0061	0.800	0.633	-0.0071	2.9
Cold Rolling	0.717	-0.0100	0.924	0.433	-0.0227	2.9
Aluminum						
Alumina Refinery	0.927	-0.0023	0.900	0.854	-0.0016	1.0
Primary Aluminum	0.890	-0.0035	0.950	0.780	-0.0060	1.0
Secondary Aluminum	0.868	-0.0043	0.850	0.736	-0.0044	1.0
Semi-Fab. Sheet/plate/foil	0.893	-0.0034	0.900	0.786	-0.0041	1.0
Semi-Fab. Other	0.918	-0.0026	0.950	0.836	-0.0039	1.0
Fabricated Metals						
Process Heating	0.688	-0.0113	0.675	0.386	-0.0168	1.3
Process Cooling - electricity	0.622	-0.0143	0.638	0.352	-0.0178	1.3
Process Cooling – fuels	0.688	-0.0113	0.675	0.386	-0.0168	1.3
Electro-Chemical	0.727	-0.0096	0.686	0.385	-0.0174	1.3
Other – electricity	0.688	-0.0113	0.675	0.386	-0.0168	1.3

Table B14. Coefficients for Technology Possibility Curves and Retirement Rates, Reference Case						
	Existing Facilities		New Facilities			Retirement
Industry/Process Unit	REI 2035	TPC	REI 2002	REI 2035	TPC	Rate (%)
Other – fuels	0.688	-0.0113	0.675	0.386	-0.0168	1.3
Machinery						
Process Heating	0.688	-0.0113	0.675	0.291	-0.0252	1.3
Process Cooling - electricity	0.622	-0.0143	0.638	0.260	-0.0268	1.3
Process Cooling – fuels	0.688	-0.0113	0.675	0.291	-0.0252	1.3
Electro-Chemical	0.727	-0.0096	0.686	0.287	-0.0261	1.3
Other – electricity	0.688	-0.0113	0.675	0.291	-0.0252	1.3
Other – fuels	0.688	-0.0113	0.675	0.291	-0.0252	1.3
Computers						
Process Heating	0.780	-0.0075	0.720	0.545	-0.0084	1.3
Process Cooling - electricity	0.729	-0.0095	0.680	0.506	-0.0089	1.3
Process Cooling – fuels	0.780	-0.0075	0.720	0.545	-0.0084	1.3
Electro-Chemical	0.809	-0.0064	0.732	0.549	-0.0087	1.3
Other – electricity	0.780	-0.0075	0.720	0.545	-0.0084	1.3
Other – fuels	0.780	-0.0075	0.720	0.545	-0.0084	1.3
Electrical Equipment						
Process Heating	0.780	-0.0075	0.720	0.545	-0.0084	1.3
Process Cooling - electricity	0.729	-0.0095	0.680	0.506	-0.0089	1.3
Process Cooling – fuels	0.780	-0.0075	0.720	0.545	-0.0084	1.3
Electro-Chemical	0.809	-0.0064	0.732	0.549	-0.0087	1.3
Other – electricity	0.780	-0.0075	0.720	0.545	-0.0084	1.3
Other – fuels	0.780	-0.0075	0.720	0.545	-0.0084	1.3
Transportation Equipment						
Process Heating	0.840	-0.0053	0.765	0.612	-0.0067	1.3
Process Cooling - electricity	0.802	-0.0067	0.723	0.570	-0.0071	1.3
Process Cooling – fuels	0.840	-0.0053	0.765	0.612	-0.0067	1.3
Electro-Chemical	0.862	-0.0045	0.778	0.618	-0.0069	1.3
Other – electricity	0.840	-0.0053	0.765	0.612	-0.0067	1.3
Other - fuels	0.840	-0.0053	0.765	0.612	-0.0067	1.3
Wood Products						
Process Heating	0.688	-0.0113	0.630	0.360	-0.0168	1.3
Process Cooling - electricity	0.622	-0.0143	0.595	0.328	-0.0178	1.3
Process Cooling – fuels	0.688	-0.0113	0.630	0.360	-0.0168	1.3
Electro-Chemical	0.727	-0.0096	0.641	0.359	-0.0174	1.3
Other – electricity	0.688	-0.0113	0.630	0.360	-0.0168	1.3
Other – fuels	0.688	-0.0113	0.630	0.360	-0.0168	1.3
Plastic Products						
Process Heating	0.780	-0.0075	0.675	0.511	-0.0084	1.3
Process Cooling - electricity	0.729	-0.0095	0.638	0.474	-0.0089	1.3
Process Cooling – fuels	0.780	-0.0075	0.675	0.511	-0.0084	1.3
Electro-Chemical	0.809	-0.0064	0.686	0.515	-0.0087	1.3
Other – electricity	0.780	-0.0075	0.675	0.511	-0.0084	1.3
Other – fuels	0.780	-0.0075	0.675	0.511	-0.0084	1.3
Balance of Manufacturing						
Process Heating	0.646	-0.0131	0.675	0.335	-0.0210	1.3
Process Cooling - electricity	0.575	-0.0167	0.638	0.303	-0.0223	1.3
Process Cooling – fuels	0.646	-0.0131	0.675	0.335	-0.0210	1.3
Electro-Chemical	0.729	-0.0112	0.686	0.371	-0.0217	1.3
Other – electricity	0.646	-0.0131	0.675	0.335	-0.0210	1.3
Other – fuels	0.646	-0.0131	0.675	0.335	-0.0210	1.3

Table B14. Coefficients for Technology Possibility Curves and Retirement Rates, Reference Case						
	Existing Facilities		New Facilities			Retirement Rate (%)
Industry/Process Unit	REI 2035	TPC	REI 2002	REI 2035	TPC	
Non-Manufacturing						
Distillate	0.876	-0.0040	0.850	0.697	-0.0060	1.0
Asphalt	0.742	-0.0090	0.850	0.610	-0.0100	1.0
Other Fuels	0.876	-0.0040	0.900	0.738	-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, U.S. Energy Information Administration, Washington, DC, October 2005 and Office of Integrated Analysis and Forecasting estimates; Non-manufacturing: Office of Integrated Analysis and Forecasting estimates.

Table B15. Coefficients for Technology Possibility Curves, High Technology Case				
	Existing Facilities		New Facilities	
Industry/Process Unit	REI 2035	TPC	REI 2035	TPC
Food Products				
Process Heating	0.872	-0.0042	0.762	-0.0050
Process Cooling - electricity	0.840	-0.0053	0.712	-0.0053
Process Cooling - fuels	0.872	-0.0042	0.762	-0.0050
Other - electricity	0.889	-0.0035	0.770	-0.0052
Other - fuels	0.872	-0.0042	0.762	-0.0050
Paper & Allied Products				
Wood Preparation	0.784	-0.0073	0.784	-0.0036
Waste Pulping	0.893	-0.0034	0.876	-0.0020
Mechanical Pulping	0.805	-0.0066	0.805	-0.0044
Semi-Chemical	0.944	-0.0017	0.916	-0.0018
Kraft, Sulfite	0.800	-0.0067	0.700	-0.0080
Bleaching	0.725	-0.0097	0.706	-0.0066
Paper Making	0.725	-0.0097	0.570	-0.0132
Bulk Chemicals				
Process Heating	0.870	-0.0042	0.762	-0.0050
Process Cooling - electricity	0.838	-0.0053	0.713	-0.0053
Process Cooling - fuels	0.870	-0.0042	0.762	-0.0050
Electro-Chemical	0.974	-0.0008	0.812	-0.0047
Other - electricity	0.888	-0.0036	0.771	-0.0052
Other - fuels	0.756	-0.0084	0.516	-0.0100
Glass & Glass Products				
Batch Preparation	0.941	-0.0018	0.882	0.0000
Melting/Refining	0.790	-0.0071	0.580	-0.0132
Forming	0.960	-0.0012	0.920	-0.0020
Post-Forming	0.968	-0.0010	0.936	-0.0010
Cement				
Dry Process	0.770	-0.0079	0.540	-0.0154
Wet Process(c)	0.879	-0.0039	NA	NA
Finish Grinding	0.830	-0.0056	0.660	-0.0110
Iron & Steel				
Coke Oven	0.825	-0.0058	0.635	-0.0106
BF/BOF	0.945	-0.0017	0.885	-0.0033
EAF	0.827	-0.0057	0.655	-0.0124
Ingot Casting	1.000	0.0000	NA	NA
Continuous Casting	1.000	0.0000	1.000	0.0000
Hot Rolling	0.738	-0.0091	0.476	-0.0156
Cold Rolling	0.680	-0.0116	0.400	-0.0251
Aluminum				
Alumina Refinery	0.910	-0.0029	0.820	-0.0028
Primary Aluminum	0.775	-0.0077	0.550	-0.0164
Secondary Aluminum	0.810	-0.0064	0.620	-0.0095
Semi-Fab. Sheet/plate/foil	0.721	-0.0099	0.447	-0.0210
Semi-Fab. Other	0.802	-0.0067	0.605	-0.0136
Fabricated Metals				
Process Heating	0.614	-0.0147	0.306	-0.0237
Process Cooling - electricity	0.545	-0.0182	0.277	-0.0249
Process Cooling - fuels	0.614	-0.0147	0.306	-0.0237
Electro-Chemical	0.614	-0.0147	0.306	-0.0237

Table B15. Coefficients for Technology Possibility Curves, High Technology Case				
	Existing Facilities		New Facilities	
Industry/Process Unit	REI 2035	TPC	REI 2035	TPC
Other - electricity	0.655	-0.0127	0.304	-0.0244
Other - fuels	0.614	-0.0147	0.306	-0.0237
Machinery				
Process Heating	0.614	-0.0147	0.204	-0.0356
Process Cooling - electricity	0.545	-0.0182	0.181	-0.0374
Process Cooling - fuels	0.614	-0.0147	0.204	-0.0356
Electro-Chemical	0.614	-0.0147	0.204	-0.0356
Other - electricity	0.655	-0.0127	0.201	-0.0366
Other - fuels	0.614	-0.0147	0.204	-0.0356
Computers and Electronics				
Process Heating	0.723	-0.0098	0.486	-0.0119
Process Cooling - electricity	0.668	-0.0121	0.450	-0.0125
Process Cooling - fuels	0.723	-0.0098	0.486	-0.0119
Electro-Chemical	0.723	-0.0098	0.486	-0.0119
Other - electricity	0.755	-0.0085	0.488	-0.0122
Other - fuels	0.723	-0.0098	0.486	-0.0119
Electrical Equipment				
Process Heating	0.723	-0.0098	0.486	-0.0119
Process Cooling - electricity	0.668	-0.0121	0.450	-0.0125
Process Cooling - fuels	0.723	-0.0098	0.486	-0.0119
Electro-Chemical	0.723	-0.0098	0.486	-0.0119
Other - electricity	0.755	-0.0085	0.488	-0.0122
Other - fuels	0.723	-0.0098	0.486	-0.0119
Transportation Equipment				
Process Heating	0.797	-0.0068	0.559	-0.0095
Process Cooling - electricity	0.755	-0.0085	0.519	-0.0100
Process Cooling - fuels	0.797	-0.0068	0.559	-0.0095
Electro-Chemical	0.797	-0.0068	0.559	-0.0095
Other - electricity	0.821	-0.0059	0.563	-0.0098
Other - fuels	0.797	-0.0068	0.559	-0.0095
Wood Products				
Process Heating	0.617	-0.0145	0.287	-0.0236
Process Cooling - electricity	0.548	-0.0180	0.260	-0.0248
Process Cooling - fuels	0.617	-0.0145	0.287	-0.0236
Electro-Chemical	0.613	-0.0147	0.288	-0.0234
Other - electricity	0.568	-0.0170	0.281	-0.0246
Other - fuels	0.617	-0.0145	0.287	-0.0236
Plastic Products				
Process Heating	0.725	-0.0097	0.456	-0.0118
Process Cooling - electricity	0.671	-0.0120	0.422	-0.0124
Process Cooling - fuels	0.725	-0.0097	0.456	-0.0118
Electro-Chemical	0.722	-0.0098	0.457	-0.0117
Other - electricity	0.687	-0.0113	0.456	-0.0123
Other - fuels	0.725	-0.0097	0.456	-0.0118
Balance of Manufacturing				
Process Heating	0.569	-0.0169	0.251	-0.0295
Process Cooling - electricity	0.496	-0.0210	0.225	-0.0310
Process Cooling - fuels	0.569	-0.0169	0.251	-0.0295
Electro-Chemical	0.702	-0.0126	0.328	-0.0260

Table B15. Coefficients for Technology Possibility Curves, High Technology Case				
	Existing Facilities		New Facilities	
Industry/Process Unit	REI 2035	TPC	REI 2035	TPC
Other - electricity	0.564	-0.0172	0.253	-0.0293
Other - fuels	0.569	-0.0169	0.251	-0.0295
Non-Manufacturing				
Distillate	0.767	-0.0080	0.571	-0.0120
Asphalt	0.549	-0.0180	0.436	-0.0200
Other Fuels	0.767	-0.0080	0.604	-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, U.S. Energy Information Administration, Washington, DC, October 2005 and Office of Integrated Analysis and Forecasting estimates; Non-Manufacturing: Office of Integrated Analysis and Forecasting estimates.

Table B16. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Sub-process	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 de-barker		1	
		Enzyme-assisted de-barker		1	
		Fine slotted wedge wire baskets	1		
		Improved screening processes	1		
		Ring Style de-barker		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	
		Chemi-mechanical Pulping	1		
		Chemi-Thermo-mechanical Pulping (CTMP)	1		
		Cyclotherm System for Heat Recovery*	1		
		Heat Recovery in TMP*	1		
		Improvements in Chemi-thermo-mechanical pulping	1		
		LCR (low consistency refining)	1		
		PGW-Plus		1	
		Pressurized Ground Wood (PGW)		1	
		Process Control System	1		
		Refiner Improvements	1		
		RTS (short Residence time, elevated Temperature, high speed)		1	
		Super Pressurized ground wood pulping		1	
		Thermo-pulping		1	
		Thermo-Refiner Mechanical Pulping	1		
	Semi-Chemical	See Chemical and Mechanical S-O-A technologies above			
	Waste Paper Pulping Technologies				
		Advanced Deinking	1		

Table B16. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		Advanced Pulping	1		
		Improvements in steam use, computer control, etc.	1		
	Bleaching Oxygen Pre-delignification Technologies				
		Oxygen Bleaching		1	
		Displacement Bleaching	1		
		Bio-bleaching		1	
		Extended cooking (delignification)		1	
		Oxygen pre-delignification		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		
		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 Chemi-mechanical (NSCM) Pulping		1	
		Ontario Paper Co. (OPCO) Process		1	
		Pretreatment of incoming pulp into drying		1	

Table B16. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		section			
		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 Chemi-mechanical (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
		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		

Table B16. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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 Feedstocks	1		1
		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	
		Thermo-chemical Recuperator	1		
		Ultrasonic Bath Agitation/Refining*	1		
	Forming/Post-Forming Technologies				
		Advanced Low-E Coatings	1		1
		Automatic Gob Control	1		
		Improved Glass Strengthening	1		

Table B16. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		Techniques*			
		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/Pre-calciner 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				
		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		

Table B16. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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)					
	Coke making Technologies				
		Carbonization Control	1		
		Coal Moisture Control			
		Coke Dry Quenching (CDQ)*	1		
		Continuous Coke Making		1	
		Non-Recovery Coke Ovens		1	
		Programmed Heating	1		
		Sensible Heat Recovery of Off-Gases*	1		
		Wet Quenching of Coke with Energy Recovery*	1		
	Iron making 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		

Table B16. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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		
	Steel making 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		
	Steel making Technologies (EAF)				
		Bottom Tap Vessels*	1		
		Computerization*	1		
		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	
	Steel casting Technologies				
		Clean Cast Steel			1
		Continuous-Conti-Casting	1		

Table B16. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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	
	Steel forming (Rolling) Technologies				
		Air Preheating*	1		
		Combustion Control*	1		
		Continuous Cold Rolling		1	
		Covered Delay Table*	1		
		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
	Iron making 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

Table B16. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		Submerged Arc Furnace (SAF)		1	
	Steel making 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 tunnel		1	
		Continuous charging of scrap to EAF		1	
		Direct Steel making (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 Steel making	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	
	Steel casting 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				

Table B16. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		Advanced Coating	1		
		Advanced High Intensity Infra-Red Preheating of Steel Strip	1		1
		Automated surface inspection	1		1
		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 Digesters	1		

Table B16. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
	Primary Aluminum Technologies				
		Aluminum Carbo-thermic 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: Electro-dialysis 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 Electro-deionization Technology*	1		1
		Advanced Chlor-Alkali Technology		1	1
	Product Recovery				
		Chloro-silane Recovery from Silicone Production	1		1

Table B16. Advanced and State of the Art Technologies					
Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		Olefin 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, U.S. Energy Information Administration, Washington, DC, October 2005.

Table B17. 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	329907	5326	0.8197	0.65	4082
6 - 20 hp	233030	29476	0.8739	0.65	4910
21 - 50 hp	112516	86578	0.9044	0.65	4873
51 - 100 hp	45837	216594	0.9241	0.65	5853
101 - 200 hp	31509	484522	0.9348	0.65	5868
201 - 500 hp	17108	1132905	0.9333	0.65	6474
> 500 hp	7833	5631554	0.9324	0.65	7566
Metal-Based Durables [a]					
1 - 5 hp	5409080	4121	0.8189	0.62	2804
6 - 20 hp	1463782	19178	0.8704	0.62	3480
21 - 50 hp	371691	55031	0.8992	0.62	3736
51 - 100 hp	57708	120722	0.9198	0.62	3478
101 - 200 hp	38699	329256	0.9348	0.62	5370
201 - 500 hp	4411	717862	0.9367	0.62	2824
> 500 hp	1652	602126	0.9303	0.62	1633
Balance of Manufacturing [b]					
1 - 5 hp	1749537	4108	0.8293	0.62	2881
6 - 20 hp	975489	19069	0.8828	0.62	3359
21 - 50 hp	324188	64797	0.9032	0.62	3844
51 - 100 hp	112315	186951	0.9267	0.62	4906
101 - 200 hp	71728	352241	0.9426	0.62	4801
201 - 500 hp	20041	796960	0.9423	0.62	5131
> 500 hp	6143	2446170	0.9291	0.62	4803

[a] The metal-based durables group includes five sectors that are modeled separately: Fabricated Metals; Machinery; Computers and Electronics; Electrical Equipment; and Transportation Equipment.

[b] The balance of manufacturing group includes three sectors that are modeled separately: Wood Products; Plastic and Rubber Products; and All Other Manufacturing.

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

Table B18. Cost and Performance Parameters for Industrial Motor Choice Model			
Industrial Sector Horsepower Range	2002 Stock Efficiency (%)	Premium Efficiency (%)	Premium Cost (2002$)
Food			
1 - 5 hp	81.3	89.2	601
6 - 20 hp	87.1	92.5	1,338
21 - 50 hp	90.1	93.8	2,585
51 - 100 hp	92.7	95.3	6,290
101 - 200 hp	93.5	95.2	11,430
201 - 500 hp	93.8	95.4	29,991
> 500 hp	93.0	96.2	36,176
Bulk Chemicals			
1 - 5 hp	82.0	89.4	601
6 - 20 hp	87.4	92.6	1,338
21 - 50 hp	90.4	93.9	2,585
51 - 100 hp	92.4	95.4	6,290
101 - 200 hp	93.5	95.3	11,430
201 - 500 hp	93.3	95.5	29,991
> 500 hp	93.2	96.2	36,176
Metal-Based Durables[a]			
1 - 5 hp	81.9	89.2	601
6 - 20 hp	87.0	92.5	1,338
21 - 50 hp	89.9	93.9	2,585
51 - 100 hp	92.0	95.3	6,290
101 - 200 hp	93.5	95.2	11,430
201 - 500 hp	93.7	95.4	29,991
> 500 hp	93.0	96.2	36,176
Balance of Manufacturing[b]			
1 - 5 hp	83.0	89.2	601
6 - 20 hp	88.3	92.5	1,338
21 - 50 hp	90.3	93.9	2,585
51 - 100 hp	92.7	95.3	6,290
101 - 200 hp	94.3	95.2	11,430
201 - 500 hp	94.2	95.4	29,991
> 500 hp	92.9	96.2	36,176

[a] The metal-based durables group includes five sectors that are modeled separately: Fabricated Metals; Machinery; Computers and Electronics; Electrical Equipment; and Transportation Equipment.

[b] The balance of manufacturing group includes three sectors that are modeled separately: Wood Products; Plastic and Rubber Products; and All Other Manufacturing.

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+ 4.0* software database (2007) http://www1.eere.energy.gov/industry/bestpractices/pdfs/mmplus.pdf.

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 B19. 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: U.S. Energy Information Administration, Office of Integrated Analysis and Forecasting.	

Table B20. Energy Consumption in Boilers (trillion Btu)						
Industry	Region	Alpha	Natural Gas	Coal	Oil	Renewables
Food	Northeast	-2.0	28	2	5	2
	Midwest	-2.0	125	154	4	15
	South	-2.0	86	10	3	33
	West	-2.0	53	13	4	6
Pulp and Paper	Northeast	-2.0	56	28	25	87
	Midwest	-2.0	64	75	13	103
	South	-2.0	157	97	61	864
	West	-2.0	48	14	4	164
Bulk Chemicals	Northeast	-2.0	43	3	56	0
	Midwest	-2.0	98	34	46	0
	South	-2.0	685	194	271	0
	West	-2.0	50	1	3	0
Glass	Northeast	-2.0	0	0	6	2
	Midwest	-2.0	1	0	0	1
	South	-2.0	1	0	9	1
	West	-2.0	0	0	0	0
Cement	Northeast	-2.0	0	1	0	0
	Midwest	-2.0	0	2	0	0
	South	-2.0	0	3	0	0
	West	-2.0	0	2	0	0
Steel	Northeast	-2.0	10	7	4	0
	Midwest	-2.0	24	1	67	0
	South	-2.0	9	0	22	0
	West	-2.0	1	0	10	0
Aluminum	Northeast	-2.0	2	0	0	1
	Midwest	-2.0	5	0	0	0
	South	-2.0	10	0	0	8
	West	-2.0	2	0	0	0
Fabricated Metals	Northeast	-2.0	2	0	0	2
	Midwest	-2.0	7	0	1	2
	South	-2.0	5	0	0	0
	West	-2.0	1	0	0	0
Machinery	Northeast	-2.0	2	0	0	1
	Midwest	-2.0	9	1	0	1
	South	-2.0	3	0	0	0
	West	-2.0	1	0	0	0
Computers and Electronics	Northeast	-2.0	10	0	2	0
	Midwest	-2.0	5	0	0	0
	South	-2.0	4	0	0	0
	West	-2.0	11	0	0	0
Electrical Equipment	Northeast	-2.0	1	0	0	0
	Midwest	-2.0	2	0	0	0
	South	-2.0	2	0	0	0
	West	-2.0	1	0	0	0
Transportation Equipment	Northeast	-2.0	5	8	3	8
	Midwest	-2.0	31	0	1	11
	South	-2.0	12	2	2	2
	West	-2.0	5	0	0	1
Wood Products	Northeast	-2.0	1	0	0	11
	Midwest	-2.0	4	0	0	20

Table B20. Energy Consumption in Boilers (trillion Btu)

Industry	Region	Alpha	Natural Gas	Coal	Oil	Renewables
	South	-2.0	7	1	1	142
	West	-2.0	4	0	0	56
Plastic Products	Northeast	-2.0	6	2	2	1
	Midwest	-2.0	21	20	1	1
	South	-2.0	24	0	4	2
	West	-2.0	4	0	0	0
Balance of Manufacturing	Northeast	-2.0	15	9	43	8
	Midwest	-2.0	68	50	16	3
	South	-2.0	137	54	54	7
	West	-2.0	35	7	1	2

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

Table B21. 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 B22. Characteristics of Candidate Combined Heat and Power Systems, Reference Case

		Total Installed Cost per Kilowatt		Total Heat Rate (Btu per kWh)		Overall Efficiency	
System	Size (kilowatts)	2005	2035	2005	2035	2005	2035
1 Engine	1,000	1,373	989	10,200	8,882	0.698	0.740
2 Engine	3,000	1,089	929	9,533	8,302	0.702	0.747
3 Gas Turbine	3,000	1,530	1,265	13,100	11,894	0.690	0.708
4 Gas Turbine	5,000	1,180	979	12,255	10,841	0.702	0.716
5 Gas Turbine	10,000	1,104	959	10,953	9,945	0.704	0.717
6 Gas Turbine	25,000	930	813	9,945	8,798	0.705	0.729
7 Gas Turbine	40,000	808	743	9,220	8,415	0.716	0.734
8 Combined Cycle	100,000	846	787	6,873	6,337	0.697	0.730

Note: Cost given in constant 2005 dollars. Effective as of *AEO2008*, costs increased by 15 percent.
Source: Discovery Insights, *Commercial and Industrial CHP Technology Cost and Performance Data for EIA's NEMS*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, U.S. Energy Information Administration, Washington, DC, January 2006.

Table B23. Characteristics of Candidate Combined Heat and Power Systems, High Technology Case

System	Size (kilowatts)	Total Installed Cost per Kilowatt		Total Heat Rate (Btu per kWh)		Overall Efficiency	
		2005	2035	2005	2035	2005	2035
1 Engine	1,000	1,373	927	10,200	8,220	0.698	0.763
2 Engine	3,000	1,089	918	9,533	7,940	0.702	0.748
3 Gas Turbine	3,000	1,530	1036	13,100	11,347	0.690	0.719
4 Gas Turbine	5,000	1,180	903	12,255	10,281	0.702	0.720
5 Gas Turbine	10,000	1,104	895	10,953	9,590	0.704	0.725
6 Gas Turbine	25,000	930	779	9,945	8,615	0.705	0.736
7 Gas Turbine	40,000	808	728	9,220	8,371	0.716	0.737
8 Combined Cycle	100,000	846	768	6,873	6,143	0.697	0.744

Note: Cost given in constant 2005 dollars. Effective for *AEO2008*, costs increased by 15 percent.

Source: Discovery Insights, *Commercial and Industrial CHP Technology Cost and Performance Data for EIA's NEMS*, unpublished report prepared for the Office of Integrated Analysis and Forecasting, U.S. Energy Information Administration, Washington, DC, January 2006.

Table B24. 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: U.S. Energy Information Administration, Office of Integrated Analysis and Forecasting.

Table B25. Fuel Factors for Incremental Corn-Based Ethanol Production	
Fuel	**Thousand Btu per bushel**
Electricity	**1.10**
Natural Gas	**3.05**
Distillate	**6.65**
LPG	**3.32**
Motor Gasoline	**1.64**
Natural Gas for Fertilizer	**23.4**
Source: U.S. Energy Information Administration, Office of Integrated Analysis and Forecasting estimates based on U.S. Department of Agriculture, Economic Research Service, *Commodity Costs and Returns, Energy Use on Major Field Crops in Surveyed States 2001.*	

Table B26. Unit Energy Requirements of Chemical Processes

Main Processes	Proc. Water Cool			Pumping			Compression			Motive Force			Heat: Direct Clean			Heat: Indirect			Drying: Indirect		
	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel
A. Organic Chemicals																					
1- Ethylene																					
Pyrolysis of Ethane	0	28	0	2085	0	0	1880	0	0	0	0	0	75	0	5194	0	0	0	0	0	0
Pyrolysis of Propane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyrolysis of Gas Oil	0	0	0	868	0	0	868	0	0	0	0	0	0	0	0	0	0	0	8750	0	0
Pyrolysis of Naphtha	0	0	0	1074	0	0	1074	0	0	0	0	0	0	0	0	0	0	0	4500	0	0
Pyrolysis of Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass to Ethylene Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2- Propylene																					
Pyrolysis of Ethane	0	28	0	2085	0	0	1880	0	0	0	0	0	75	0	5194	0	0	0	0	0	0
Pyrolysis of Propane	0	0	0	1253	0	0	1253	0	0	0	0	0	0	0	0	0	0	0	12640	0	0
Pyrolysis of Gas Oil	0	0	0	868	0	0	868	0	0	0	0	0	0	0	0	0	0	0	8750	0	0
Pyrolysis of Naphtha	0	0	0	1074	0	0	1074	0	0	0	0	0	0	0	0	0	0	0	4500	0	0
Pyrolysis of Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3- Butadiene																					
Pyrolysis of Ethane	0	28	0	2085	0	0	1880	0	0	0	0	0	75	0	5194	0	0	0	0	0	0
Pyrolysis of Propane	0	0	0	1253	0	0	1253	0	0	0	0	0	0	0	0	0	0	0	12640	0	0
Pyrolysis of Gas Oil	0	0	0	868	0	0	868	0	0	0	0	0	0	0	0	0	0	0	8750	0	0
Pyrolysis of Naphtha	0	0	0	1074	0	0	1074	0	0	0	0	0	0	0	0	0	0	0	4500	0	0
Pyrolysis of Butane	0	0	0	0	0	0	169	0	0	0	0	0	7	0	467	0	0	0	0	0	0
Catalytic dehydrogenation of butane	0	0	0	0	240	0	0	100	0	0	0	0	2775	0	0	0	0	0	0	0	0
Catalytic dehydrogenation of n-butane	0	0	0	0	0	0	0	82	0	0	0	0	0	0	0	0	0	0	0	0	0
4- Acetic Acid																					
N-Butane Oxidation	0	0	0	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	0	0	0
Methanol Carbonylation	0	0	0	0	0	0	0	0	0	0	10	0	0	0	1917	0	0	0	0	0	0
Biomass Fermentation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5- Acrylonitrile																					
Ammoxidation of Propylene	0	0	0	0	0	0	0	0	0	0	60	0	1125	0	0	0	0	0	0	0	0
6- Ethylbenzene																					
Alkylation of Benzene with Ethylene	0	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7- Ethylene Dichloride																					
Catalytic Oxychlorination of Ethylene	0	0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Direct Catalytic Chlorination of Ethylene	0	0	0	0	30	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0
8- Ethylene Glycol																					
Hydration of Ethylene Oxide	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass to Ethylene Glycol Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9- Ethylene Oxide																					
Catalytic Oxidation of Ethylene	0	0	0	0	0	0	0	0	0	0	237	0	0	0	0	0	0	0	2844	0	0
10- Formaldehyde																					
Catalytic Oxidation of Methanol (silver)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	600	0	0	0	0	0	0
Catalytic Oxidation of Methanol (mixed)	0	0	0	0	16	0	448	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dehydrogenation of Methanol (silver)	0	0	0	0	20	0	0	35	0	0	0	0	0	0	0	0	0	0	0	0	0
11- Methanol																					
LP Cat of Reform Natural Gas	0	0	0	0	21	0	0	53	0	0	0	0	0	0	2461	0	0	0	0	0	0

Main Processes	Proc. Water Cool			Pumping			Compression			Motive Force			Heat: Direct Clean			Heat: Indirect			Drying: Indirect		
	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel
LP Synthesis from Partial Oxidation of Resid	0	0	0	0	25	0	0	350	0	0	0	0	0	0	0	0	0	0	0	0	0
HP Cat Conversion of Synthesis Gas	0	0	0	0	20	0	0	150	0	0	0	0	0	0	3000	0	0	0	0	0	0
Coal to Methanol Conversion	0	0	0	0	9	0	0	22	0	0	0	0	84	0	0	0	0	0	0	0	0
Biomass to Methanol Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12- Styrene																					
Catalytic Dehydrogenation of Ethylbenzene	0	0	0	0	7	0	0	0	0	0	0	0	0	0	1465	0	0	0	7250	0	0
Ethylbenzene Hydroperoxidation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13- Vinyl Acetate																					
Catalytic Oxyacetylation of Ethylene	0	0	0	0	40	0	0	0	0	0	12	0	0	0	0	0	0	0	100	0	0
Acetic Acid and Acetylene	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14- Ethanol																					
Dry Milling	0	0	0	0	388	0	0	0	0	0	0	0	870	0	50	0	0	0	0	0	1593
Ethylene Hydration	0	0	0	0	0	0	171	0	0	0	0	0	5400	0	133	0	0	0	0	0	0
15- Other Organics																					
Generic - Region 1	0	0	0	0	0	0	0	0	0	0	35	0	11	0	180	0	0	0	447	0	0
Generic - Region 2	0	0	0	0	0	0	0	0	0	0	75	0	31	0	718	0	0	0	1399	0	0
Generic - Region 3	0	0	0	0	0	0	0	0	0	0	97	0	35	0	2465	0	0	0	1396	0	0
Generic - Region 4	0	0	0	0	0	0	0	0	0	0	20	0	53	0	218	0	0	0	2598	0	0
16- On-Purpose Propylene																					
Generic Process	0	0	0	1074	0	0	1074	0	0	0	0	0	0	0	0	0	0	0	4500	0	0
17- Byproduct Ethylene																					
Generic Process	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B. Inorganic Chemicals																					
1- Acetylene																					
Partial Oxidation of Methane	0	0	0	0	162	0	0	136	0	0	203	0	0	0	5797	0	0	0	824	0	0
Crude Oil Submerged Flame	0	0	0	0	90	0	0	0	0	0	90	0	0	0	0	0	0	0	0	0	0
2- Chlorine																					
Diaphragm Cell	0	0	0	0	102	0	0	52	0	0	2	0	0	0	0	0	0	0	0	0	0
Mercury Cell	0	0	0	0	30	0	0	14	0	0	4	0	0	0	0	0	0	0	0	0	0
Membrane Cell	0	0	0	0	52	0	0	27	0	0	1	0	0	0	0	0	0	0	0	0	0
3- Oxygen																					
Air Liquefaction/Refrigeration	0	0	0	0	18	0	0	257	0	0	0	0	0	0	0	0	0	0	0	0	0
4- Sulfuric Acid																					
Contact Process	0	0	0	0	8	0	31	0	0	0	0	0	0	0	0	0	0	0	14	0	0
5- Hydrogen																					
Steam Methane Reforming - Natural Gas	0	0	0	0	231	0	0	582	0	0	0	0	17906	0	13089	0	0	0	0	0	0
Coal Gasification	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass Gasification	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electrolysis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6- Other Inorganics																					
Generic - Region 1	0	0	0	0	9336	0	0	0	0	0	0	0	0	0	1914	0	0	0	5	0	0
Generic - Region 2	0	0	0	0	20164	0	0	0	0	0	0	0	0	0	2431	0	0	0	13	0	0
Generic - Region 3	0	0	0	0	26072	0	0	0	0	0	0	0	0	0	4414	0	0	0	15	0	0
Generic - Region 4	0	0	0	0	5444	0	0	0	0	0	0	0	0	0	2329	0	0	0	23	0	0

Main Processes	Proc. Water Cool			Pumping			Compression			Motive Force			Heat: Direct Clean			Heat: Indirect			Drying: Indirect		
	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel
C. Plastics and Resins																					
1- Polyvinyl Chloride																					
Suspension Process	0	0	0	0	30	0	0	49	0	394	70	0	0	0	0	0	0	0	319	0	0
2- Polyethylene																					
Slurry Process	0	0	0	0	87	0	0	0	0	308	0	0	0	0	0	0	0	0	530	0	0
Solution Process	0	0	0	0	204	0	0	0	0	0	29	0	0	0	0	0	0	0	0	0	0
Emulsification Process	0	0	0	0	63	0	0	41	0	462	0	0	0	0	0	0	0	0	261	0	0
3- Polystyrene																					
Mass Polymerization of of Styrene	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1298	0	0
4- Styrene Butadiene Rubber																					
Emulsification Process	0	0	0	0	171	0	0	0	0	823	556	0	0	0	0	0	0	0	1807	0	0
Solution Polymerized Solid Rubber	0	0	0	0	175	0	0	0	0	1372	568	0	0	0	0	0	0	0	3012	0	0
5- Vinyl Chloride																					
Pyrolysis of Ethylene Dichloride	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1019	0	0	0	240	0	0
6- Other Plastic Resins																					
Generic - Region 1	0	0	0	0	0	0	0	0	0	0	989	0	0	0	544	0	0	0	168	0	0
Generic - Region 2	0	0	0	0	0	0	0	0	0	0	2135	0	0	0	691	0	0	0	471	0	0
Generic - Region 3	0	0	0	0	0	0	0	0	0	0	2761	0	0	0	1255	0	0	0	536	0	0
Generic - Region 4	0	0	0	0	0	0	0	0	0	0	2761	0	0	0	1255	0	0	0	536	0	0
D. Agricultural Chemicals																					
1- Ammonia																					
Catalytic Synthesis of Methane	0	0	0	117	0	0	1676	0	0	0	0	0	0	0	4070	0	0	0	0	0	0
Partial Oxidation of Coal	0	0	0	166	0	0	2372	0	0	0	0	0	0	0	4841	0	0	0	0	0	0
Coal Gasification	0	0	0	0	1516	0	0	3825	0	0	0	0	243	0	0	0	0	0	0	0	0
Petroleum Coke Gasification	0	0	0	0	1516	0	0	3825	0	0	0	0	243	0	0	0	0	0	0	0	0
2- Phosphoric Acid																					
Wet Process	0	0	0	0	0	0	0	0	0	0	186	0	0	0	0	0	0	0	0	0	0
Electric Furnace Process	0	0	0	0	0	0	0	0	0	0	24	0	0	0	0	0	14509	0	0	0	0
3- Other Agricultural Chemicals																					
Generic - Region 1	0	0	0	0	0	0	0	0	0	0	345	0	0	0	0	0	0	0	0	0	0
Generic - Region 2	0	0	0	0	0	0	0	0	0	0	267	0	0	0	0	0	0	0	0	0	0
Generic - Region 3	0	0	0	0	0	0	0	0	0	0	345	0	0	0	0	0	0	0	0	0	0
Generic - Region 4	0	0	0	0	0	0	0	0	0	0	72	0	0	0	0	0	0	0	0	0	0

Main Processes	Concentration			Distillation			Electrolysis			Feedstocks			Reforming			Fuel From Feed			By-Product Adj.		
	Stm	Elec	Fuel	Stm	Elec	Fuel	Steam	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel
A. Organic Chemicals																					
1- Ethylene																					
Pyrolysis of Ethane	0	0	0	0	0	0	0	0	0	0	0	19600	0	0	0	0	0	0	0	0	-3477
Pyrolysis of Propane	0	0	0	0	0	0	0	0	0	0	0	37632	0	0	0	0	0	0	0	0	0
Pyrolysis of Gas Oil	0	0	0	1950	0	0	0	0	0	0	0	125700	0	0	0	0	0	0	0	0	-60740
Pyrolysis of Naphtha	0	0	0	2400	0	0	0	0	0	0	0	152700	0	0	0	0	0	0	0	0	-50080
Pyrolysis of Butane	0	0	0	0	0	0	0	0	0	0	0	39200	0	0	0	0	0	0	0	0	0
Biomass to Ethylene Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Main Processes	Concentration			Distillation			Electrolysis			Feedstocks			Reforming			Fuel From Feed			By-Product Adj.		
	Stm	Elec	Fuel	Stm	Elec	Fuel	Steam	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel
2- Propylene																					
Pyrolysis of Ethane	0	0	0	0	0	0	0	0	0	0	0	19600	0	0	0	0	0	0	0	0	-3477
Pyrolysis of Propane	0	0	0	2800	0	0	0	0	0	0	0	117300	0	0	0	0	0	0	0	0	-80640
Pyrolysis of Gas Oil	0	0	0	1950	0	0	0	0	0	0	0	125700	0	0	0	0	0	0	0	0	-60740
Pyrolysis of Naphtha	0	0	0	2400	0	0	0	0	0	0	0	152700	0	0	0	0	0	0	0	0	-50080
Pyrolysis of Butane	0	0	0	0	0	0	0	0	0	0	0	39200	0	0	0	0	0	0	0	0	0
3- Butadiene																					
Pyrolysis of Ethane	0	0	0	0	0	0	0	0	0	0	0	19600	0	0	0	0	0	0	0	0	-3477
Pyrolysis of Propane	0	0	0	2800	0	0	0	0	0	0	0	117300	0	0	0	0	0	0	0	0	-80640
Pyrolysis of Gas Oil	0	0	0	1950	0	0	0	0	0	0	0	125700	0	0	0	0	0	0	0	0	-60740
Pyrolysis of Naphtha	0	0	0	2400	0	0	0	0	0	0	0	152700	0	0	0	0	0	0	0	0	-50080
Pyrolysis of Butane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Catalytic dehydrogenation of butane	0	0	0	2500	0	0	0	0	0	0	0	27440	0	0	0	0	0	0	0	0	-6400
Catalytic dehydrogenation of n-butane	0	0	0	0	0	0	0	0	0	0	0	20904	2000	0	0	0	0	2616	0	0	-700
4- Acetic Acid																					
N-Butane Oxidation	0	0	0	1250	0	0	0	0	0	0	0	8756	0	0	0	0	0	5631	0	0	-4766
Methanol Carbonylation	0	50	0	800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-173
Biomass Fermentation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5- Acrylonitrile																					
Ammoxidation of Propylene	0	0	0	9700	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1140
6- Ethylbenzene																					
Alkylation of Benzene with Ethylene	0	0	0	1030	0	0	0	0	0	0	0	8111	0	0	0	0	0	620	0	0	-1000
7- Ethylene Dichloride																					
Catalytic Oxychlorination of Ethylene	0	0	0	550	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Direct Catalytic Chlorination of Ethylene	0	0	0	1240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8- Ethylene Glycol																					
Hydration of Ethylene Oxide	0	0	0	3002	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass to Ethylene Glycol Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9- Ethylene Oxide																					
Catalytic Oxidation of Ethylene	0	0	0	316	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10- Formaldehyde																					
Catalytic Oxidation of Methanol (silver)	60	0	0	0	0	0	0	0	0	0	0	0	620	0	0	0	0	0	0	0	0
Catalytic Oxidation of Methanol (mixed)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dehydrogenation of Methanol (silver)	0	0	0	0	0	0	0	0	0	0	0	0	1000	0	0	0	0	0	0	0	0
11- Methanol																					
LP Cat of Reform Natural Gas	0	0	0	707	0	0	0	0	0	0	0	9458	445	0	0	0	0	0	0	0	0
LP Synthesis from Partial Oxidation of Resid	0	0	0	1250	0	0	0	0	0	0	0	16000	600	0	0	0	0	0	0	0	0
HP Cat Conversion of Synthesis Gas	0	0	0	1250	0	0	0	0	0	0	0	9400	400	0	0	0	0	0	0	0	0
Coal to Methanol Conversion	0	0	0	0	0	0	0	0	0	0	0	39632	0	0	0	0	0	0	-1183	0	0
Biomass to Methanol Conversion	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12- Styrene																					
Catalytic Dehydrogenation of Ethylbenzene	0	0	0	2047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2076
Ethylbenzene Hydroperoxidation	0	0	0	10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1777
13- Vinyl Acetate																					

Main Processes	Concentration			Distillation			Electrolysis			Feedstocks			Reforming			Fuel From Feed			By-Product Adj.		
	Stm	Elec	Fuel	Stm	Elec	Fuel	Steam	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel
Catalytic Oxyacetylation of Ethylene	0	0	0	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-100
Acetic Acid and Acetylene	0	0	0	1200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-250
14- Ethanol																					
Dry Milling	870	0	0	870	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene Hydration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15- Other Organics																					
Generic - Region 1	2	486	0	137	0	0	0	0	0	0	0	5532	51	0	0	0	0	0	0	0	0
Generic - Region 2	6	1698	0	383	0	0	0	0	0	0	0	10227	142	0	0	0	0	0	0	0	0
Generic - Region 3	7	679	0	435	0	0	0	0	0	0	0	2922	162	0	0	0	0	0	0	0	0
Generic - Region 4	10	8	0	662	0	0	0	0	0	0	0	35453	246	0	0	0	0	0	0	0	0
16- On-Purpose Propylene																					
Generic Process	0	0	0	2400	0	0	0	0	0	0	0	30630	0	0	0	0	0	0	0	0	-50080
17- Byproduct Ethylene																					
Generic Process	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B. Inorganic Chemicals											8697										
1- Acetylene																					
Partial Oxidation of Methane	0	0	0	4124	0	0	0	0	0	0	0	56092	0	0	0	0	0	8554	0	0	-48452
Crude Oil Submerged Flame	0	0	0	0	0	0	0	0	0	0	0	141337	0	0	0	0	0	76104	0	0	-119787
2- Chlorine																					
Diaphragm Cell	3267	0	0	0	0	0	0	2351	0	0	0	0	0	0	0	0	0	0	0	0	0
Mercury Cell	0	0	0	634	0	0	0	2351	0	0	0	0	0	0	0	0	0	0	0	0	0
Membrane Cell	402	0	0	0	0	0	0	2022	0	0	0	0	0	0	0	0	0	0	0	0	0
3- Oxygen																					
Air Liquefaction/Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4- Sulfuric Acid																					
Contact Process	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5- Hydrogen																					
Steam Methane Reforming - Natural Gas	0	0	0	0	0	0	0	0	0	0	0	119320	0	0	0	0	0	0	-25730	0	0
Coal Gasification	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biomass Gasification	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electrolysis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6- Other Inorganics																					
Generic - Region 1	723	0	0	46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Generic - Region 2	2025	0	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Generic - Region 3	2303	0	0	148	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Generic - Region 4	3500	0	0	225	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C. Plastics and Resins																					
1- Polyvinyl Chloride																					
Suspension Process	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2- Polyethylene																					
Slurry Process	0	0	0	87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solution Process	0	0	0	828	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Emulsification Process	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3- Polystyrene																					
Mass Polymerization of of Styrene	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Main Processes	Concentration			Distillation			Electrolysis			Feedstocks			Reforming			Fuel From Feed			By-Product Adj.		
	Stm	Elec	Fuel	Stm	Elec	Fuel	Steam	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel	Stm	Elec	Fuel
4- Styrene Butadiene Rubber																					
Emulsification Process	0	0	0	364	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solution Polymerized Solid Rubber	0	0	0	607	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5- Vinyl Chloride																					
Pyrolysis of Ethylene Dichloride	0	0	0	1020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6- Other Plastic Resins																					
Generic - Region 1	0	0	0	192	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Generic - Region 2	0	0	0	539	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Generic - Region 3	0	0	0	613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Generic - Region 4	0	0	0	613	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D. Agricultural Chemicals																					
1- Ammonia																					
Catalytic Synthesis of Methane	0	0	0	0	0	0	0	0	0	0	0	10261	957	0	0	0	0	0	0	0	-565
Partial Oxidation of Coal	0	0	0	0	0	0	0	0	0	0	0	16550	2005	0	0	0	0	0	0	0	-800
Coal Gasification	0	0	0	0	0	0	0	0	0	0	0	16349	0	0	0	0	0	0	0	0	0
Petroleum Coke Gasification	0	0	0	0	0	0	0	0	0	0	0	4256	0	0	0	0	0	0	0	0	0
2- Phosphoric Acid																					
Wet Process	2300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electric Furnace Process	0	13	0	0	0	0	0	0	0	0	0	19966	0	0	0	0	0	0	0	0	0
3- Other Agricultural Chemicals																					
Generic - Region 1	1915	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Generic - Region 2	1684	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Generic - Region 3	1915	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Generic - Region 4	2911	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix C. Model Abstract

Model Name:

Industrial Demand Module

Model Acronym:

None

Description:

The Industrial Demand Module 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 Module 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 Module generates long-term projections of industrial sector energy consumption. The Industrial Module facilitates policy analysis of energy markets, technological development, environmental issues, and regulatory development as they impact industrial sector energy consumption.

Most Recent Model Update:

December 2009.

Part of another Model:

National Energy Modeling System (NEMS)

Model Interfaces:

The Industrial Demand Module 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 Module of the National Energy Modeling System, April 2010.

Archive Media and Installation Manual(s):

The model is archived as part of the National Energy Modeling System production runs used to generate the *AEO2010*.

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, 2008 through 2030.

Modeling Features:

Structure: 15 manufacturing and 6 non-manufacturing industries. The manufacturing industries are further classified as energy-intensive or 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 or end-use 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-906 and predecessor forms: 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 2007, August 2009

Annual Energy Review 2008, June 2009

Computing Environment:

Hardware Used: Intel Xeon CPU

Operating System: Microsoft Windows XP

Language/Software Used: Intel Visual FORTRAN 9.1

Estimated Run Time: 53 seconds for a 2007-2035 run in non-iterating, stand-alone mode.

Special Features: None