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

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Update Information

This is the 15th edition of the *Model Documentation Report: Industrial 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 2011*. These changes include:

- Updated benchmarks to annual data sets including:
    - The State Energy Data System (*SEDS2008*)
    - The Annual Energy Review (*AER2009*)
    - The Manufacturing Energy Consumption Survey (*MECS2006*)
    - The Economic Census (2007)
    - The Census of Agriculture (2007)
- Updated Combined Heat and Power (CHP) system characteristics
- Enhanced decision making for CHP to include discount rate and acceptance curves updated to reflect this change
- Updated base dollar year to 2005 to maintain consistency with the Bureau of Economics (BEA) national accounts
- Updated agriculture energy consumption to include collection of forest residues
- Updated bulk chemical feedstock consumption approach used to forecast the shares of ethylene, propylene, and butadiene feedstock requirements to use linear regression equations relating the feedstock shares with petroleum naphtha prices and Natural Gas Liquids (NGL) prices

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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 (IDM). 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 Demand Module for model analysts, users, and the public. Second, this report meets the legal requirement of the Energy Information Administration (EIA) to provide adequate documentation in support of its models (Public Law 94-385, section 57.b2). Third, it facilitates continuity in model development by providing documentation from which energy analysts can undertake model enhancements, data updates, and parameter refinements in future projects.

Model Summary

The NEMS Industrial Demand 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 IDM 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 IDM receives fuel prices, employment data, and the value of industrial shipments. Based on the values of these variables, the IDM passes back to the NEMS system estimates of consumption by fuel types.

The NEMS Industrial Demand 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 IDM 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 2008*.[1] The national-level values reported in *Annual Energy Review 2009*[2] were allocated to the Census Divisions using the *State Energy Data Report 2008*.[3]

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[1] Issued June 30, 2010, http://www.eia.doe.gov/emeu/states/_seds.html

[2] Energy Information Administration, *Annual Energy Review 2009*, DOE/EIA-384(2009), August 2010, 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), except the non-manufacturing industries (agriculture, construction, and mining), all of which do not include a buildings component. 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 2011*.

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Organization of this Report

Chapter 2 discusses the purpose of the NEMS Industrial Demand Module, detailing its objectives, input and output variables, and the relationship of the IDM to the other modules of the NEMS system. Chapter 3 describes the rationale behind the IDM 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 IDM. Appendix A is a bibliography of data sources and background materials used in model development. Appendix B provides the input data for *AEO2011*. Appendix C is the model abstract. Appendix D provides industrial group descriptions.

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 IDM 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 other components of NEMS, the IDM receives fuel prices, employment data, and the value of shipments, which are expressed in 2005 dollars, for industrial activity. Based on the values of these variables, the IDM 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 IDM projects energy consumption at the four Census Region levels; energy consumption is allocated to the Census Division levels based on State Energy Data System (SEDS) data.[5]

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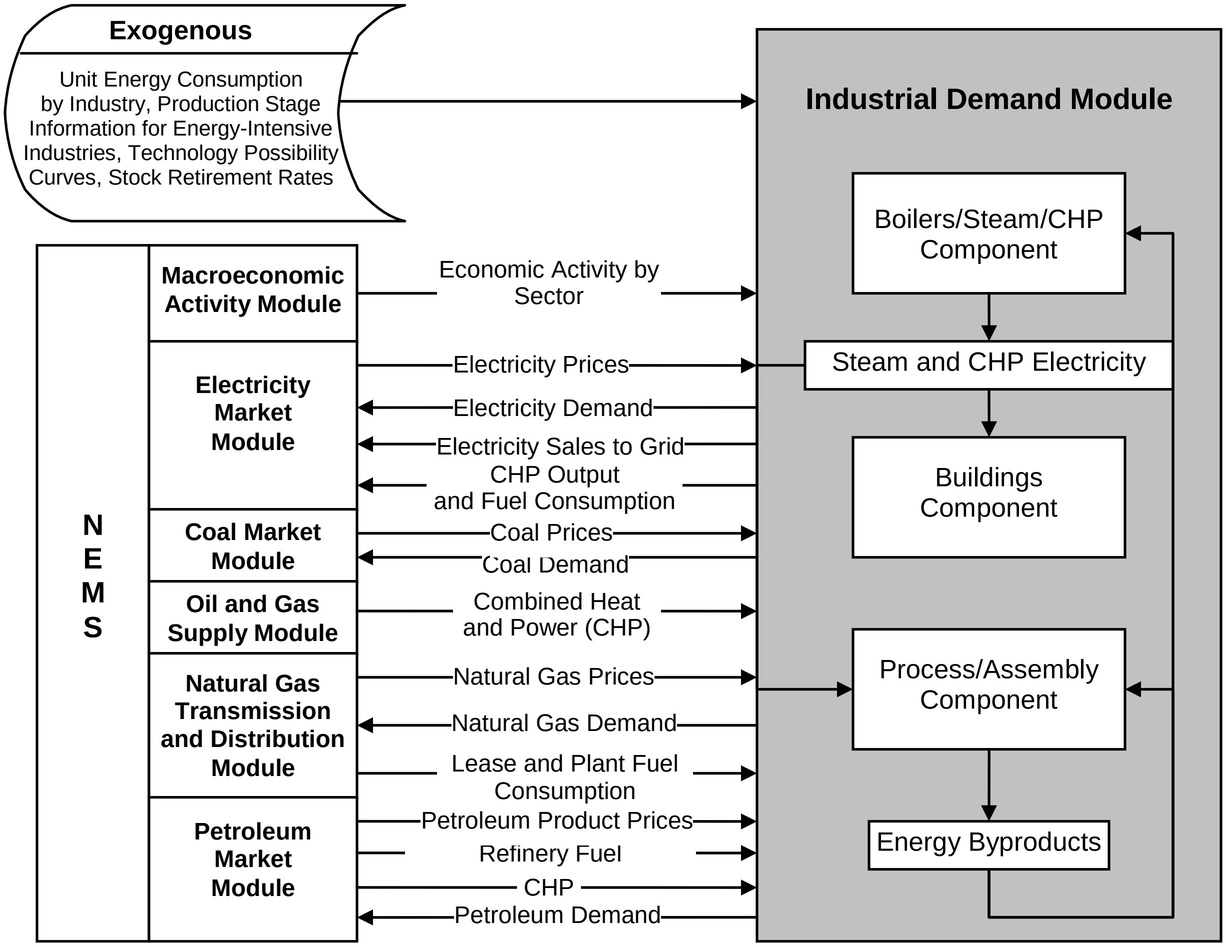
[4] Executive Office of the President, Office of Management and Budget, *North American Industry Classification System, United States, 2007*. Washington, DC, 2007.

[5] *State Energy Data Report 2008,* http://www.eia.doe.gov/emeu/states/_seds.html.

Figure 1. Industrial Demand Module Interactions Within NEMS



The NEMS Industrial Demand 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 IDM 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 IDM uses "technology bundles" to characterize global 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 2006). The “New 2006 UEC” is the intensity expected to prevail for a new, greenfield installation in 2006. Similarly, the “New 2035 UEC’ is the intensity expected to prevail for a new, greenfield 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 IDM inputs from and outputs to other NEMS modules. Note that all inter-module interactions must pass through the integrating module. For the IDM, the Macroeconomic Activity Module (MAM) is critical. MAM supplies industry value of shipments and employment for the IDM 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 Demand Module can be characterized as a dynamic accounting model, combining economic and engineering data and knowledge. Its architecture brings together the disparate industries[6], and uses of energy in those industries, and combines them in an understandable and cohesive framework. An explicit representation of the varied uses of energy in the industrial sector is used as the framework upon which to base the dynamics of the model.

One of the overriding characteristics of 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.

Modeling Approach

A number of considerations have been taken into account in building the Industrial Demand 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 Demand 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 IDM 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.

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[6] According to the 2007 North American Industry Classification System, there are596 industries classified as industrial by NEMS.

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

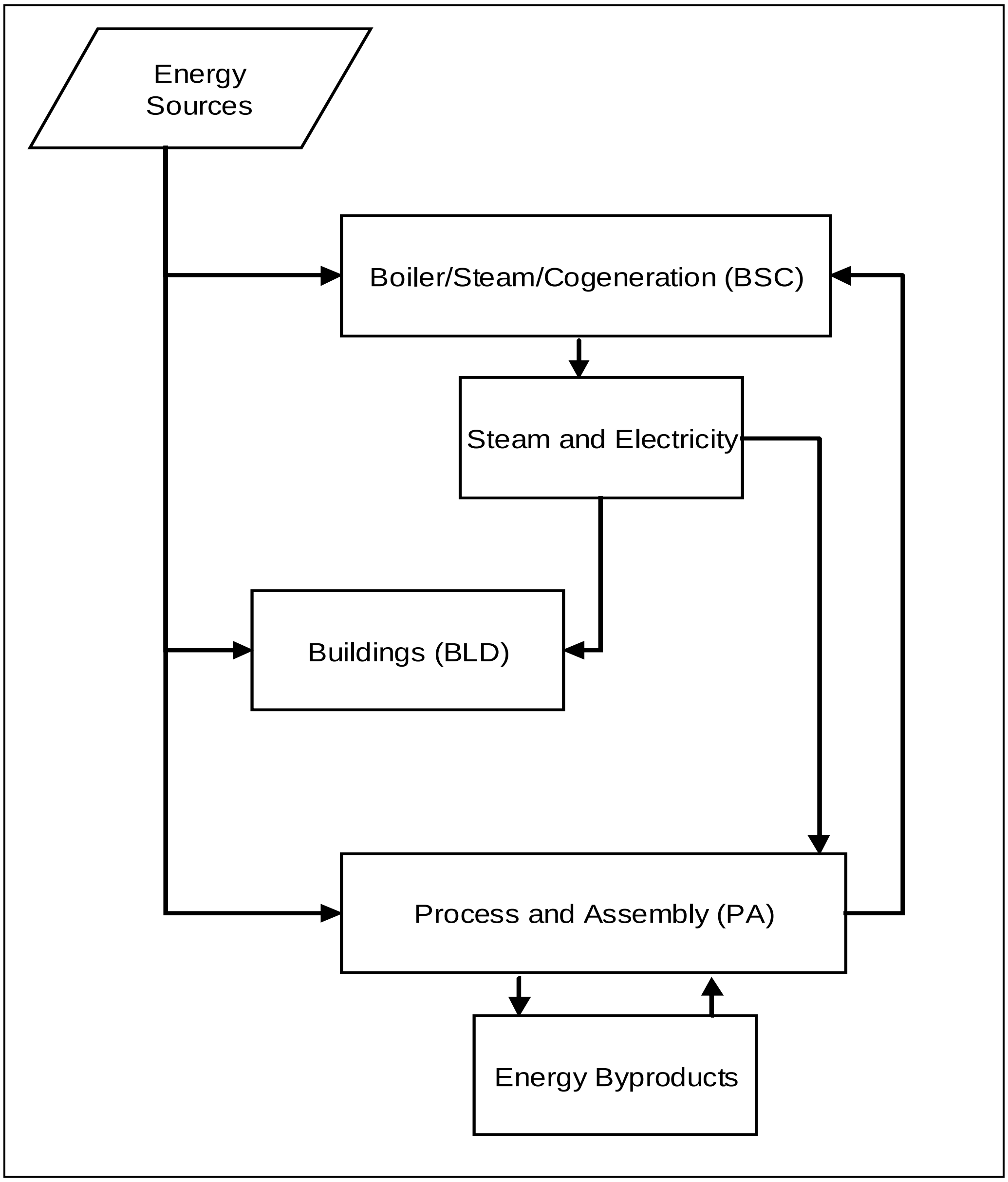
Fundamental Assumptions

The industrial sector consists of numerous heterogeneous industries. The IDM 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, of which seven are modeled in the IDM. 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 reported in the Industrial Sector energy consumption totals.

For each industry, the flow of energy among the three model components is represented by the arrows in Figure 2. 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 IDM 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 2005 dollars) produced by each industry group. The value of shipments by NAICS classification is provided to the IDM 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 Demand 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 2006 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 Demand 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.[7] 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. 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 Demand Module estimates energy consumption by 21 industries for 14 fuels. The fuels modeled in the IDM are:

- Electricity
- Natural Gas
- Steam Coal
- Distillate Oil
- Residual Oil
- Liquefied Petroleum Gas (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.

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[7] 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 Demand 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 assumed to be the most important source of energy-related changes in the IDM. 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 current level of disaggregation in the IDM. Instead, the IDM is designed to incorporate overall changes in energy use on a more aggregate and long term basis using the autonomous technical change parameters.

Buildings Component UEC

Buildings are estimated to account for 6 percent of allocated heat and power energy consumption in manufacturing industries.[8] Estimates of 2006 manufacturing sector building energy consumption are presented in Table B 1 and Table B 2. 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 designed primarily for workers rather than machines. However, since value of shipments tend to grow, it is likely that conditioned floor space also grows. The IDM uses an average to account for the contrasting trends in employment and shipment growth rates.

Process and Assembly Component UEC

The process and assembly component (PA) accounted for the largest share, 62 percent, of direct energy consumption for heat and power in 2006. Of the PA total, natural gas accounted for 34 percent and electricity accounted for 32 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 2006 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 durables, and the balance of manufacturing (excluding petroleum refining that is modeled in the Petroleum Market Module of NEMS).

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[8] Computed from Energy Information Administration, *2006 Manufacturing Energy Consumption Survey*, (http://www.eia.doe.gov/emeu/mecs/), June 2009. Note that byproduct and non-energy use of combustible fuels are excluded from the computation because they are not allocated in the MECS tables.

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 of energy use by generic process unit as a percentage of total energy use in the PA component. This is 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)

In 2006, the food products industry accounted for 8 percent ($541 billion) of manufacturing value of shipments and consumed approximately 1,186 trillion Btu of energy.[9] Energy use in the food products industry for the PA component was estimated for each of four major end-use categories:

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

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

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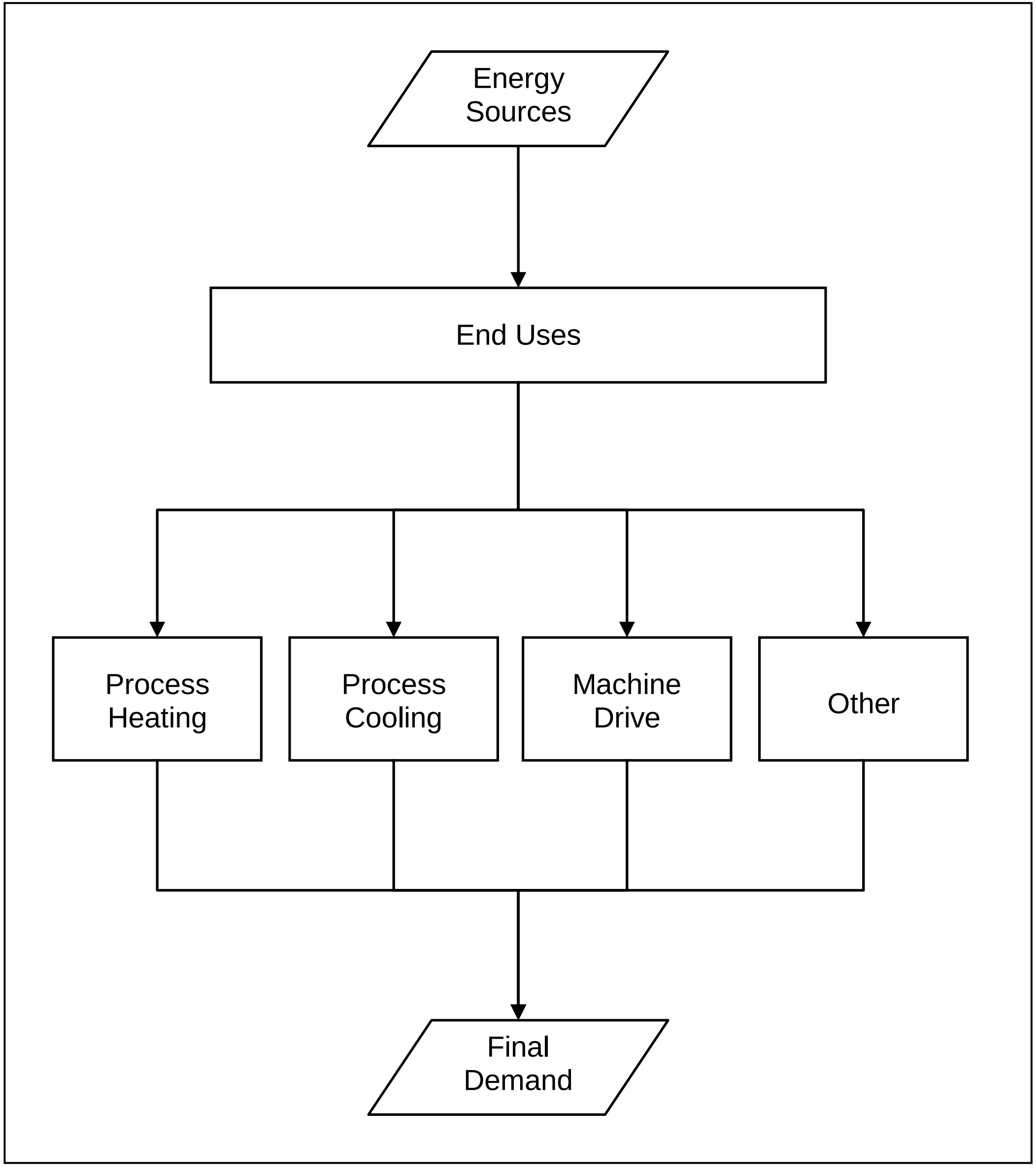
[9] Energy Information Administration (EIA), *2006 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/, June 2009. Note that the IDM's energy consumption projection for 2006 may vary slightly from the *MECS2006* values due to the inclusion of data from the electricity data forms and model dynamics.

are provided in Table B 3. The dominant end use was direct heat, which accounted for 50 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 2006, 96 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, it is estimated 48 percent was produced with the Kraft chemical process, 3.5 percent from semi-chemical pulping, 4.5 percent from mechanical (ground wood) pulping, and 44 percent from waste fibers. The unit energy consumption estimates for this industry are provided in Table B 4. 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 34 percent and 42 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 B 13**.** 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 24 percent (5.0 quadrillion Btu) of the total energy consumed in the manufacturing sector, while accounting for 7 percent ($321 billion) of manufacturing value of shipments.[10] This industry is a major energy feedstock user and a major producer of cogeneration power.

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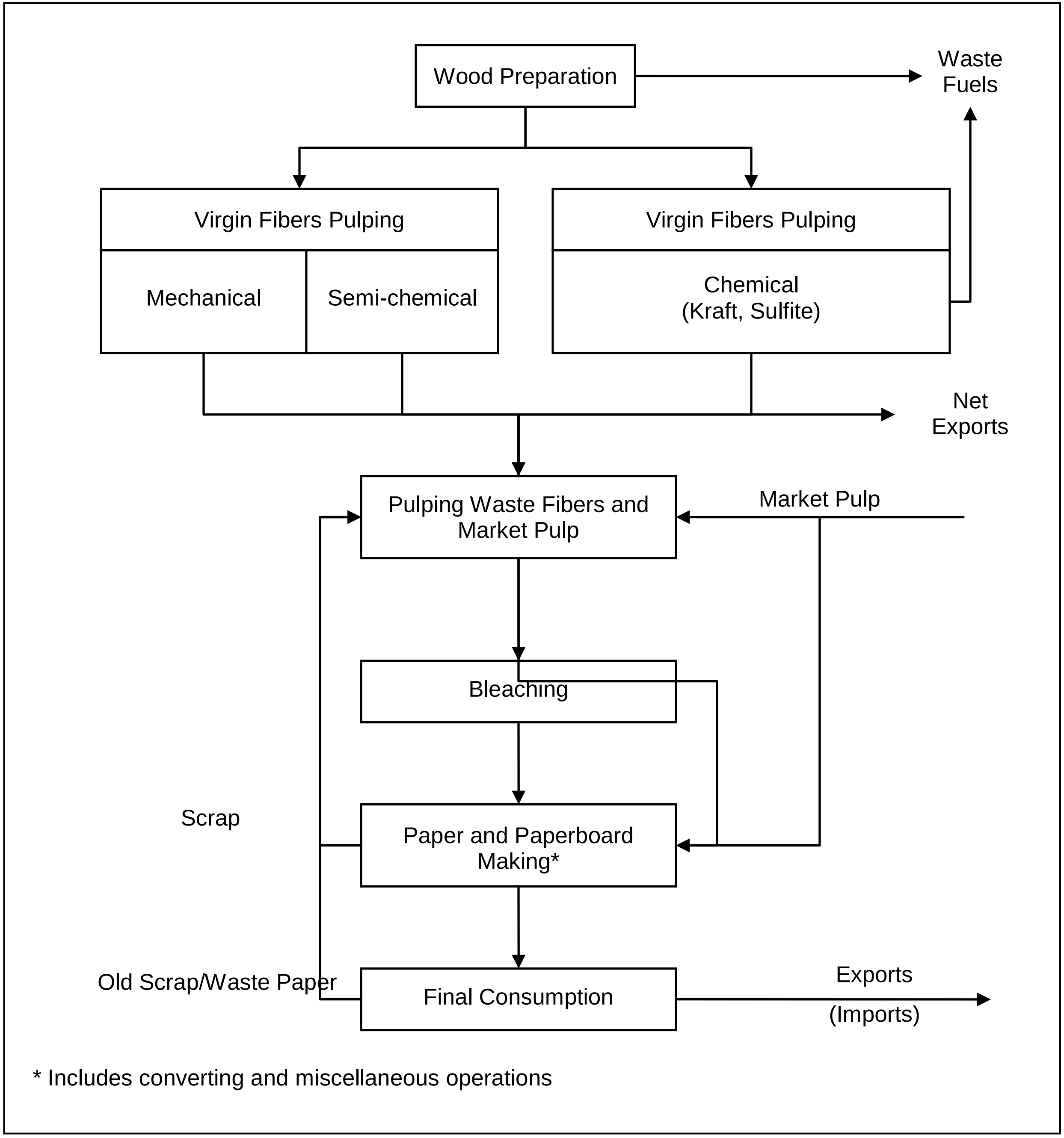
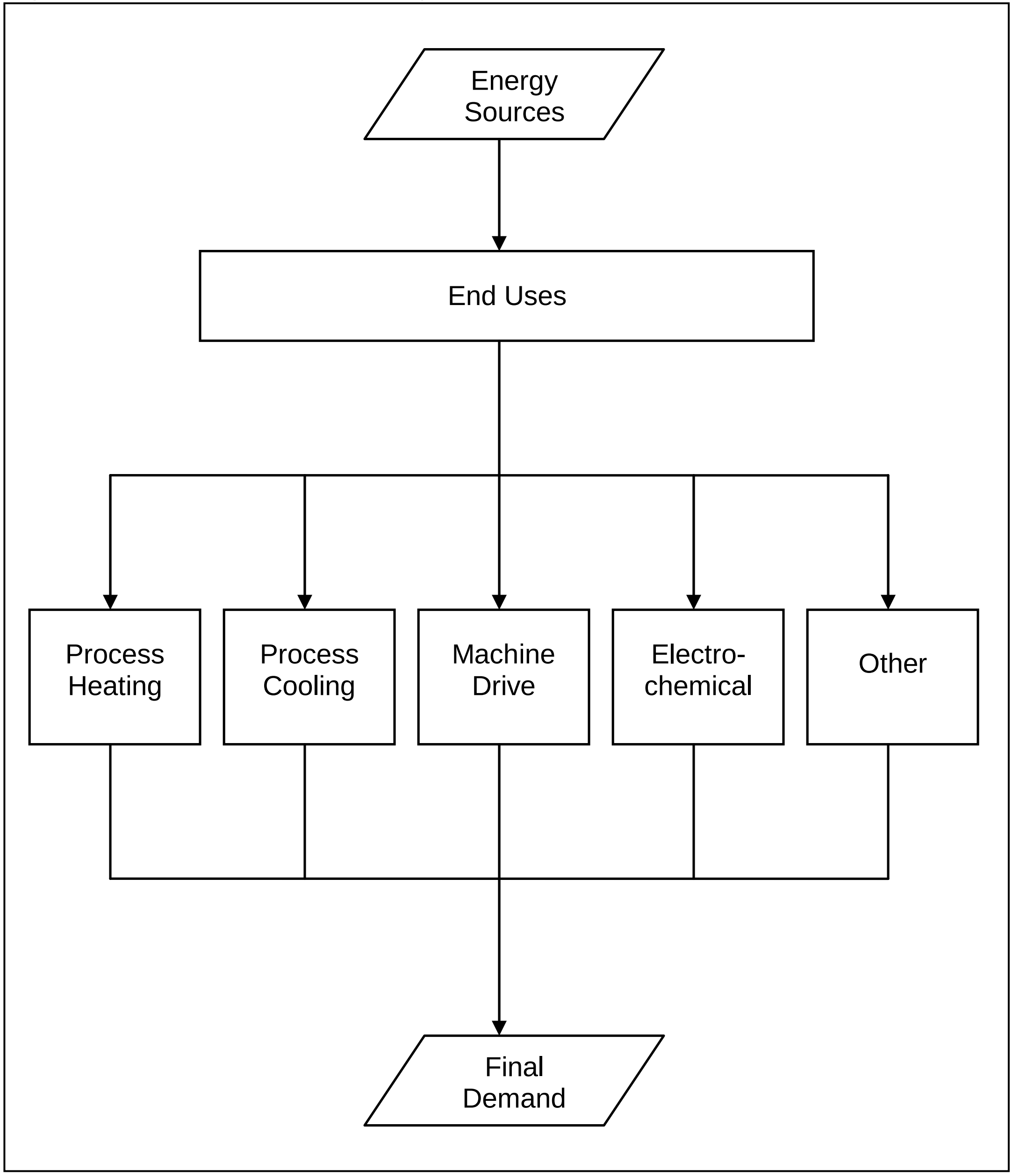
[10] This *MECS2006* value does not include 1.1 quadrillion Btu of petrochemical feedstocks which are not assigned directly to the chemical industry.

Figure 4. Paper Manufacturing Industry Process Flow



* Includes converting and miscellaneous operations

Figure 5. Bulk Chemical Industry End Uses



Previous versions of IDM treated this industry with a simplified end-use approach, as shown in Figure 5. Although this approach was adequate for many years, there was a need for a capability to analyze the impacts of 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, the current bulk chemical industry model, which includes these capabilities, was developed.

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 making these products. Due to the large number of chemical products, the bulk chemical industry model that projects the industry's energy use focuses on energy-intensive chemicals, chemicals that have high production levels, and chemicals that are fast-growing or energy industry-related (e.g., ethanol and hydrogen). For completeness, the model also represents the balance of the chemical industry in simpler form.

In addition to representing each individual chemical in appropriate detail, the bulk chemical industry model simulates the relationships between the basic chemicals and their intermediate and 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 naphtha. These complex relationships between chemicals and feedstocks add to the complexity of modeling the industry.

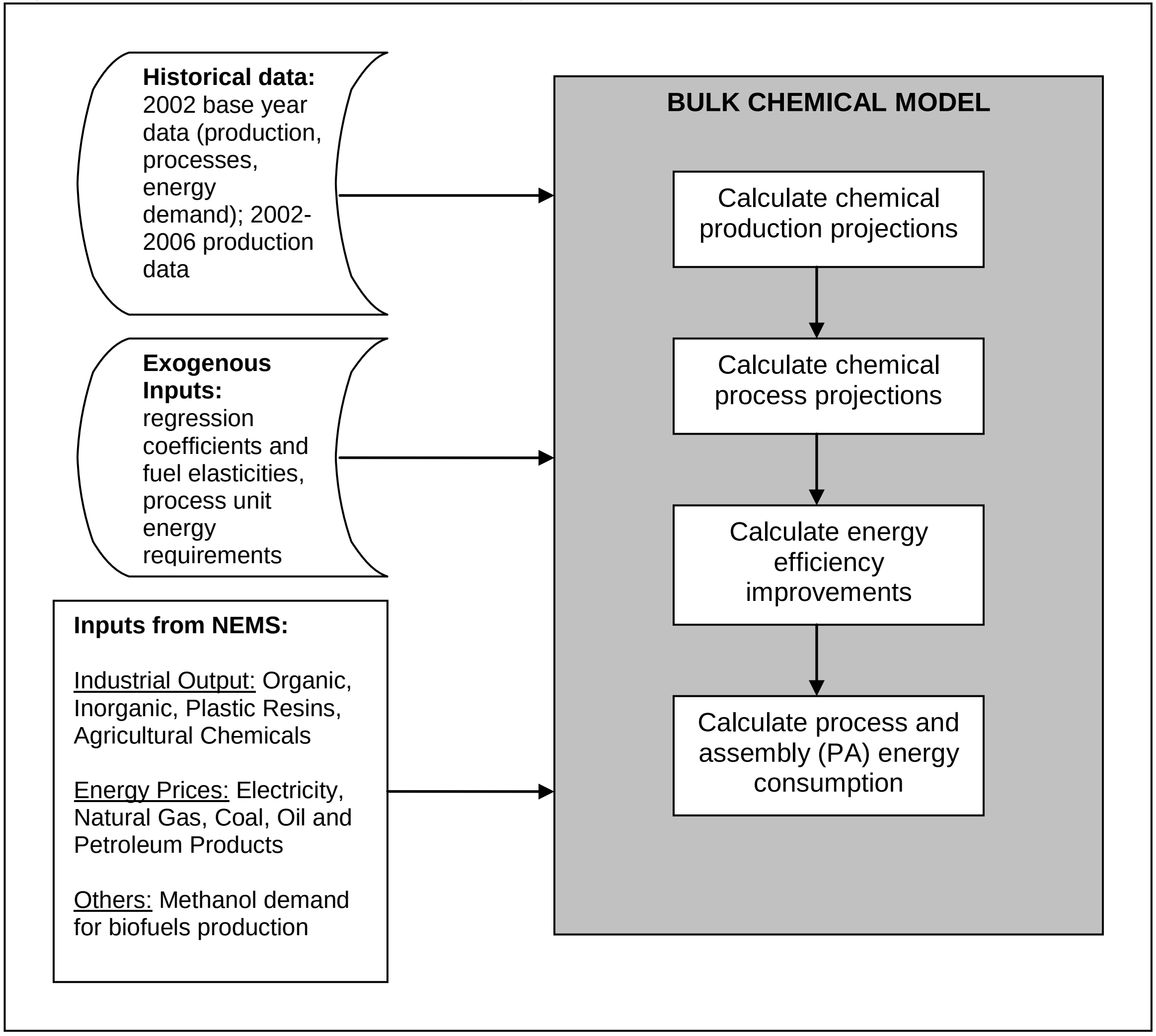
The technologies and processes used to produce a chemical product determine energy use. For some chemicals, there is only one process/technology that is used by the entire industry. For example, in producing sulfuric acid, all producers use the contact process. Thus, the energy use for sulfuric acid would be simple to calculate based on the typical unit energy requirements of the contact process and the demand for sulfuric acid. 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, naphtha, and gas oils). Furthermore, chemical production rate is different for each feedstock.

There are also some chemical products that can be made with two or more entirely different processes, such as chlorine. Chlorine can be produced using either the mercury cell process, membrane cell process, or the diaphragm cell process, and the energy requirements of each of these processes differ.

As described below, the bulk chemical model implemented in the Industrial Demand Module provides a good snapshot or representation of these complexities in products, technologies, and processes. Figure 6 provides an overview of this bulk chemical industry model, which 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
- Projects production of several chemicals and chemical groups
- Projects processes involved in producing each chemical and chemical group
- Projects 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
- Projects process energy consumption for machine drive electricity, non-machine drive electricity, feedstocks, steam, and direct process heat fuels
- Projects process energy consumption by chemical and chemical group and by region.

Figure 6. New Bulk Chemical Industry Model



It is important to note that the new chemical model described above represents only 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 methodology used to develop the 2002 base year data is exogenous to the model and incorporates a bottom-up and top-down approach with a final calibration process at the end. The 2002 base year database has information on the bulk chemical industry's production, manufacturing processes, and energy consumption for 26 specific chemicals and 4 aggregate groups of chemicals.[11]

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[11] Energy and Environmental Analysis, Inc, *NEM Industrial Prototype Model Documentation (Draft)*, submitted to Energy Information Administration, August 2008.

Projections of Chemical Production

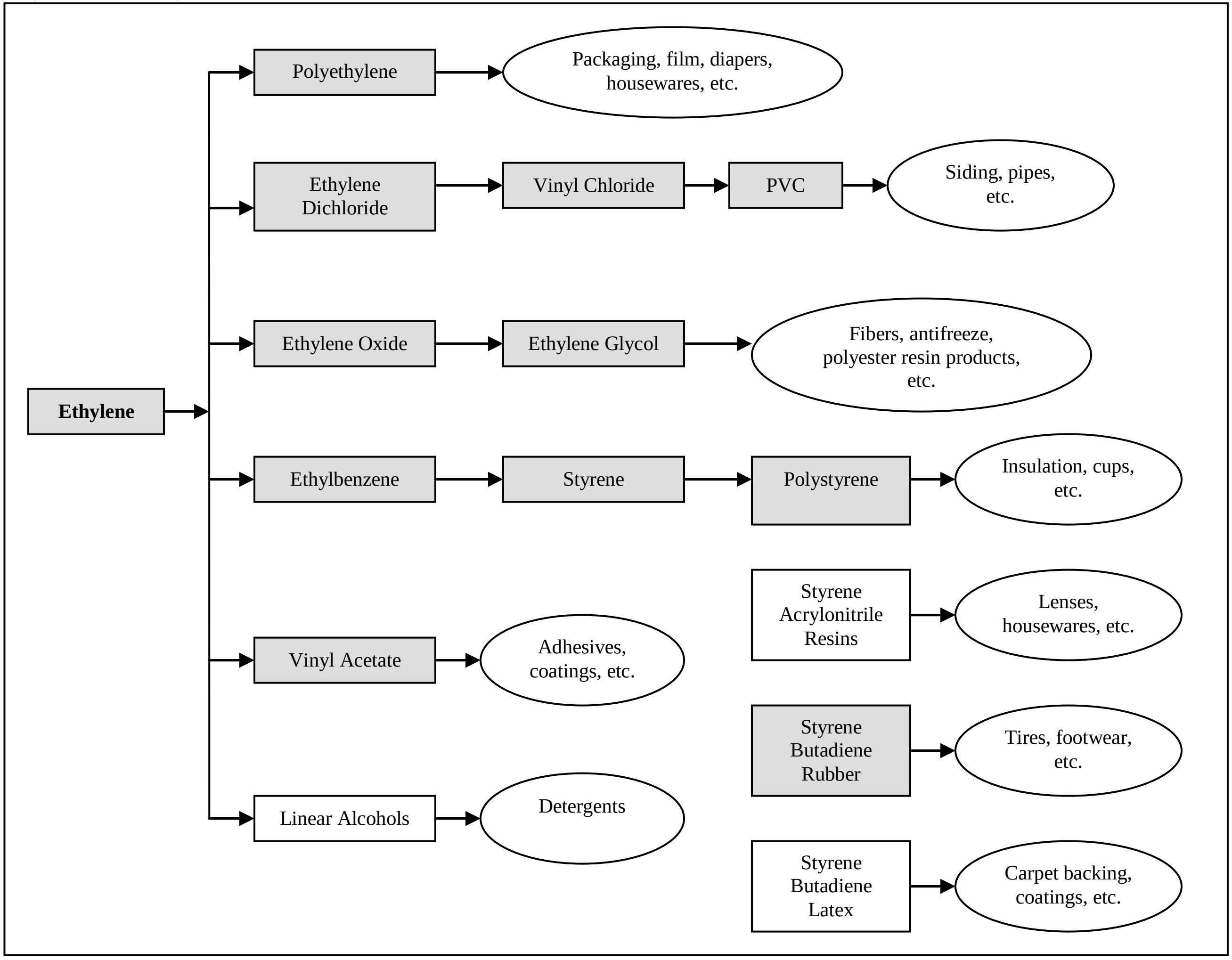
In the bulk chemical industry, there is significant interplay among basic chemicals, intermediate chemicals, and final chemical products. A good understanding of the relationships among these chemicals helps in the development of a reasonable methodology or set of methodologies to forecast the production 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 modeled individually.

The model equations that forecast chemical production reflect the relationships between the chemicals as well as 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. The effects of other drivers such as gross domestic product (GDP), energy prices, and U.S. population are also incorporated. 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 generally assumed that these impacts are already incorporated in the value of shipment model inputs received from the Macroeconomic Module. More detail was needed in the case of methanol, because 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	**MODEL REPRESENTATION**
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
Methanol	Total demand for methanol = *f(formaldehyde production) plus methanol demand for biodiesel production coming from*

CHEMICALS	MODEL REPRESENTATION
	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 the Bulk Chemical Industry Model

CHEMICALS	MANUFACTURING PROCESSES
A. Organic Chemicals	
Ethylene	Pyrolysis (steam cracking) of ethane, propane, gas oil, naphtha, or butane Biomass to ethylene conversion
Propylene	Pyrolysis (steam cracking) of ethane, propane, gas oil, naphtha, or butane
Butadiene	Pyrolysis (steam cracking) of ethane, propane, gas oil, naphtha, or butane Catalytic dehydrogenation of butane or 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 or 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
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

CHEMICALS	MANUFACTURING PROCESSES
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[12]
Byproduct adjustment[13]

Table B 26 provides the unit energy requirements for each chemical, process and energy service represented in the bulk chemical model.

The relative "share" of processes used to produce a particular 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. Because these chemicals are sensitive to energy prices, the model captures the feedstock switching response to changing energy prices. Also, there are chemicals for which only one production process is assumed (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.

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

Table 5. Methodologies for Process Share Projections

CHEMICAL	MODEL REPRESENTATION
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
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; economic assessment of potential for non-natural gas processes reveals 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; economic assessment of potential for non-natural gas processes reveals no market penetration over entire projection period
Phosphoric Acid	Exogenous; assumed fixed to 2002
E. Aggregate Groups	
Other Organic	One generic process considered for this group
Other Inorganic	One generic process considered for this group
Other Plastic Resins	One generic process considered for this group
Other Agricultural Chemicals	One generic process considered for this group

Competition among production processes for chlorine is driven by non-energy-related factors. Environmental issues are creating pressure to phase out the mercury cell process. Simultaneously, 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 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 are fixed to the 2008 value (the last available data on 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 alternatives 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. This issue continues to be studied at EIA and will be updated in future projections as deemed reasonable.

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, and 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) or LPG feedstocks (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 feedstock's usage but also the energy for heat and power requirements to produce the chemicals. For example, the use of naphtha would require more energy than the use of ethane since naphtha is a heavier product and requires 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. Naphtha and gas oils are petroleum refinery products referred to as "heavy feedstock" and ethane, propane, and butane are natural gas liquids (NGLs) referred to as "light feedstock" which can originate either from petroleum refineries or gas processing plants, thus, the relative prices of these two categories are key drivers for feedstock choice.

In the Industrial Demand Module, first the shares of heavy versus light feedstocks were determined using proprietary data from Petral Consulting Company of historical feedstocks in the U.S. petrochemical industry. The next step determines the shares of propane and ethane based on heavy and light feedstock prices received from the Petroleum Market Module (PMM) using trends regressed from the same Petral data. Butane share was determined to be insignificant and assigned a fixed share near zero. To allocate the total petrochemical feedstocks to naphtha 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 2006, the glass and glass products industry produced approximately 20 million tons of glass products.

The glass and glass products industry consumed nearly 300 trillion Btu of energy in 2006.[14] This accounts for about a quarter 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 B 6 shows the unit energy consumption values for each process step.

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 22 percent of production in 2002, while the dry process accounted for about 78 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

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[14] Energy Information Administration (EIA), *2006 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/, June 2009. Note that the IDM’s energy consumption projection for 2006 may vary slightly from the *MECS2006* values due to the inclusion of data from the electricity data forms and model dynamics.

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 2006. 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 nearly 400 trillion Btu of energy in 2006.[15] Direct fuel, used in clinker-producing kilns, accounted for 89 percent of the total PA energy consumption.

The UEC values for each process in the cement industry are shown in Table B 7. 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 B 13.

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[15] Energy Information Administration (EIA), *2006 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/, June 2009. Note that the IDM's energy consumption projection for 2006 may vary slightly from the *MECS2006* values due to the inclusion of data from the electricity data forms and model dynamics.

Figure 8. Glass Industry Process Flow

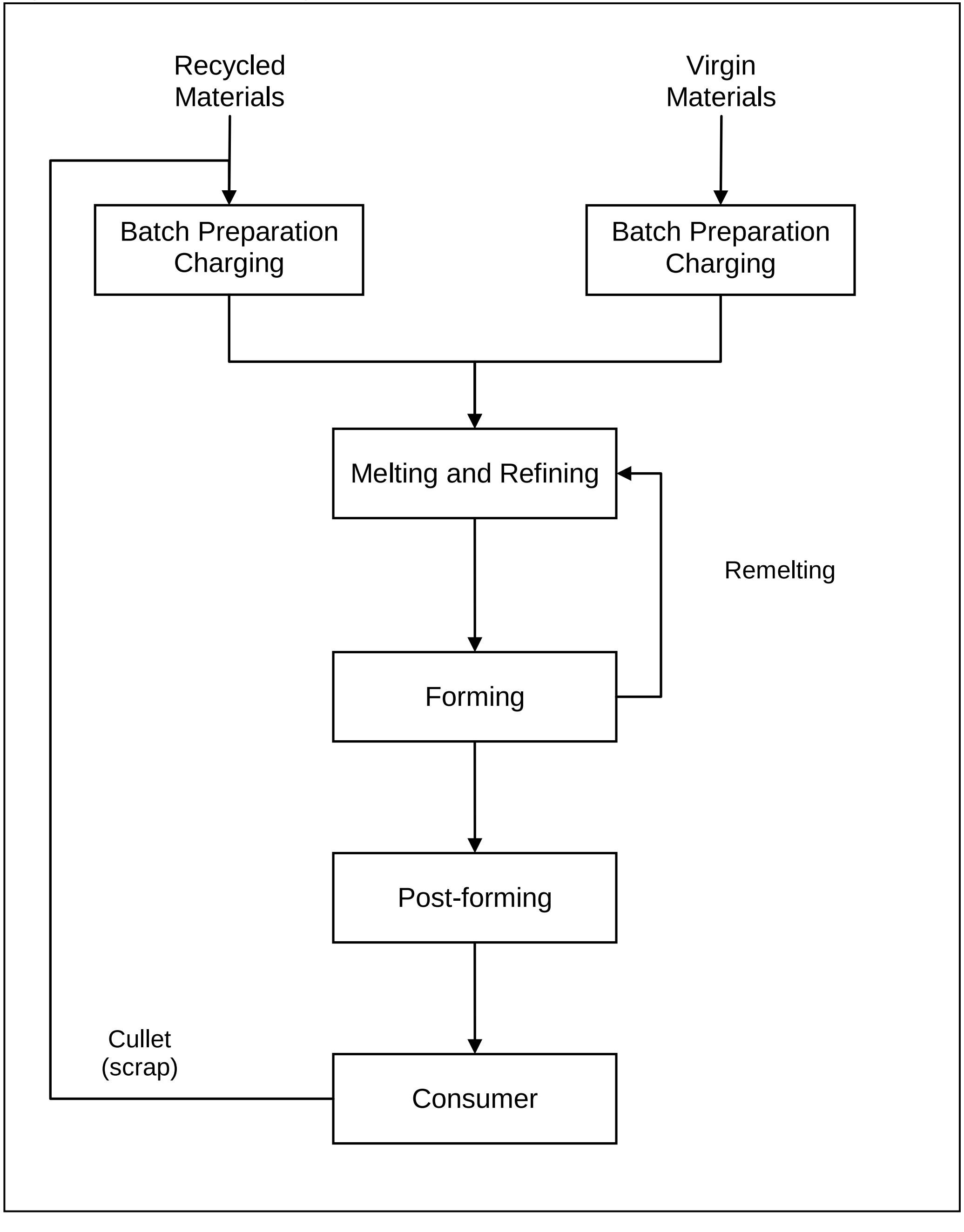
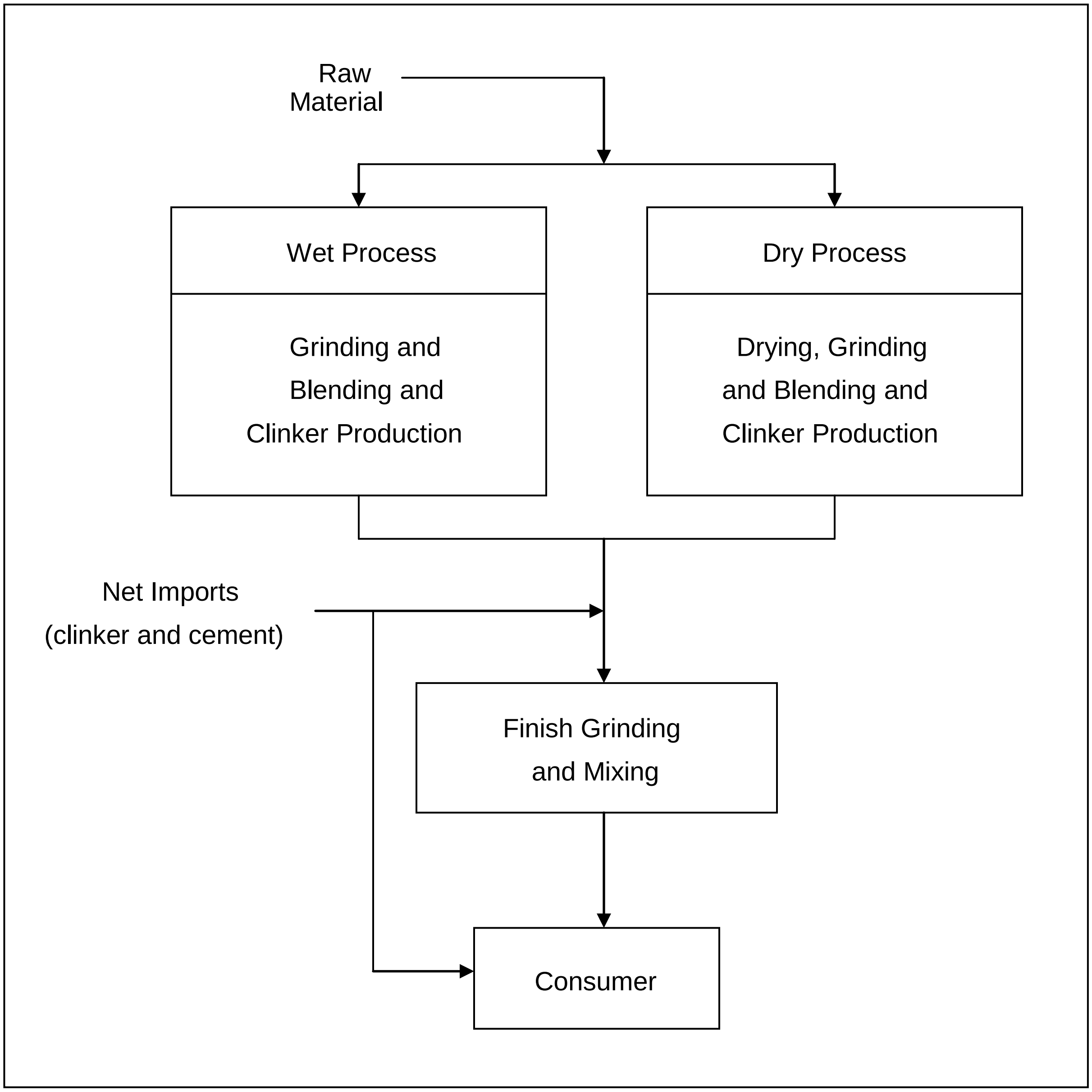


Figure 9. Cement Industry Process Flow



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 major process steps that are performed in the facility. Integrated plants perform all the process steps, whereas non-integrated plants, in general, perform only the last three steps.

For the Industrial Demand Module, a process flow was developed to classify the major process steps into 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.

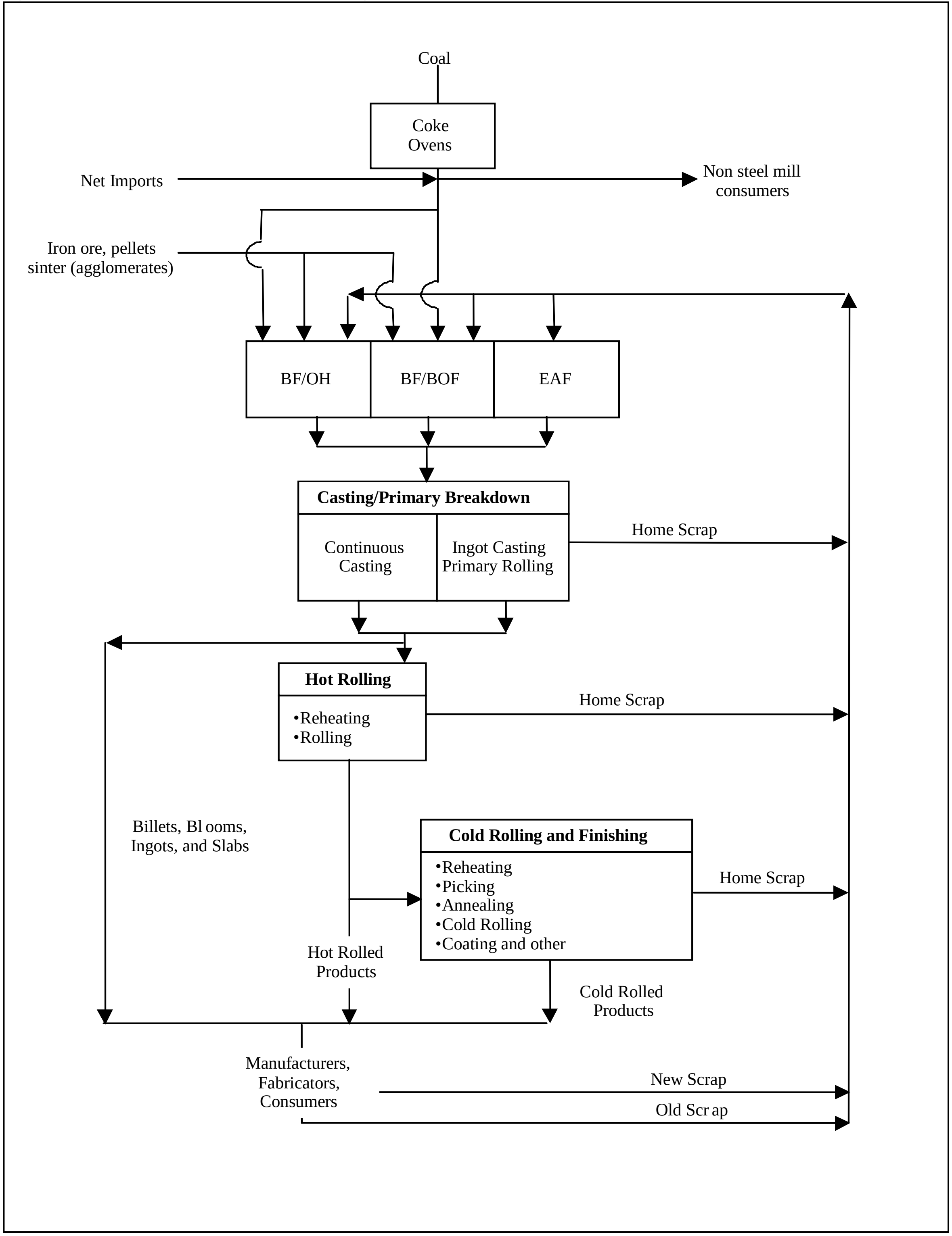
Iron is produced in the Blast Furnace (BF), which is then charged into a Basic Oxygen Furnace (BOF) or Open Hearth (OH) to produce raw steel. The OH is now obsolete in the United States and is not included in new facilities modeled in the IDM. The Electric Arc Furnace (EAF) is utilized to produce raw steel from an all scrap (recycled materials) charge, sometimes supplemented with direct reduced iron or hot briquetted iron.

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 2006, the U.S. steel industry produced 105 million tons of raw steel utilizing BF, BOF and EAF. Taking process yields into account, the total shipments were approximately 104 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 B 8 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 B 13.

Figure 10. Iron and Steel Industry Process Flow



Aluminum Industry (NAICS 3313)

The U.S. aluminum industry consists of two major sectors: the primary aluminum sector, which is dependent on alumina as raw material; 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. 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:

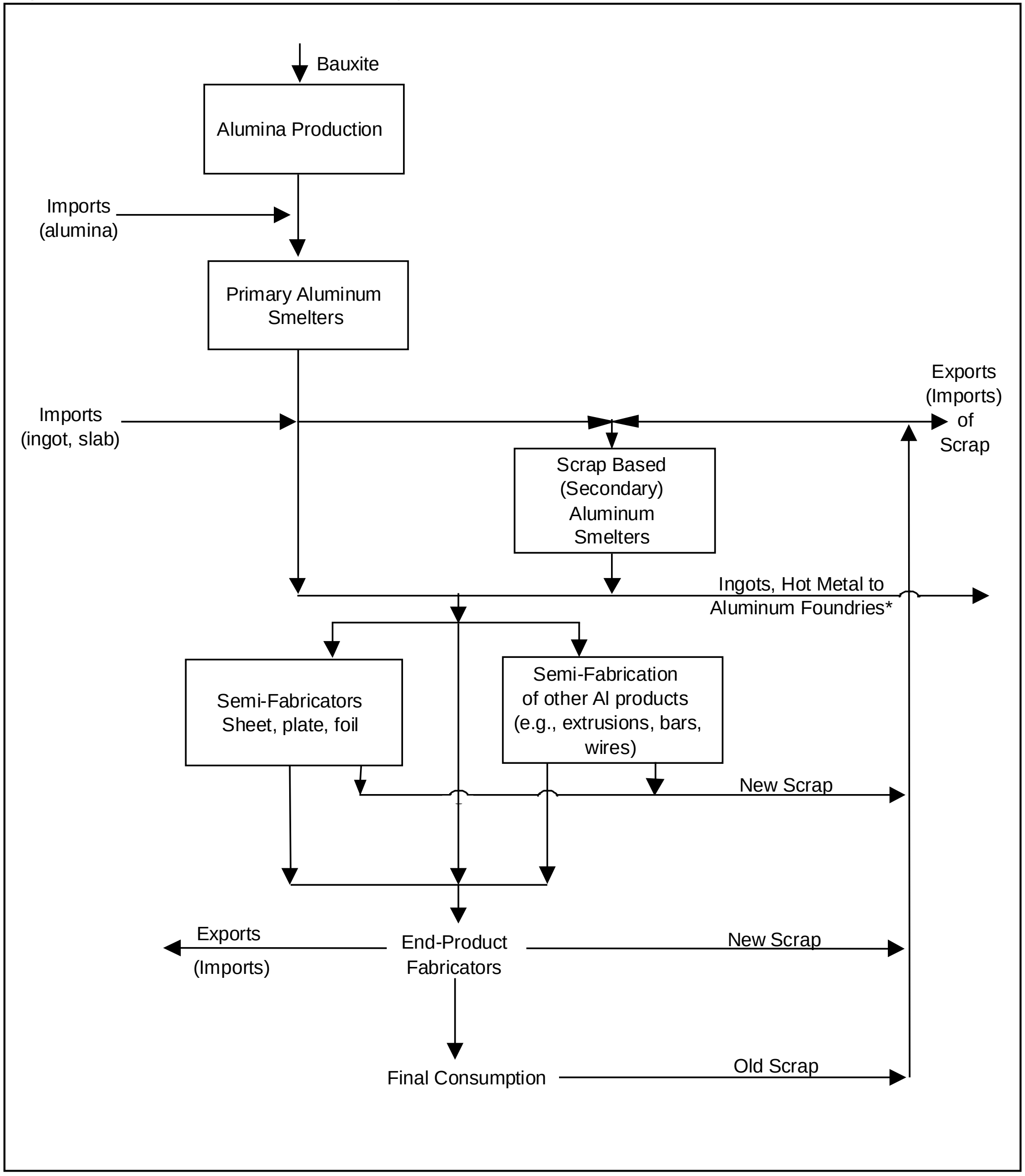
Alumina Refining (NAICS 331311)
Primary Aluminum Production (NAICS 331312)
Secondary Smelting and Alloying of Aluminum (NAICS 331314)
Aluminum Sheet, Plate, Foil Manufacturing (NAICS 331315) and
Aluminum Semi-fabrication of products such as extrusions, tube, cable, and wire (found in NAICS 3316 and NAICS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

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

The primary sector produced approximately 2.3 million tons of aluminum in 2006. The secondary (scrap-based) sector recovered 2.3 million tons, exceeding primary production by only 76 thousand tons. Domestic aluminum production plus aluminum semi-finished imports resulted in about 5.4 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 B 9. The principal form of energy used is electricity. The regional distribution of smelters in the aluminum industry is presented in Table B 13.

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, machinery, computer and electronic products, transportation equipment, and electrical equipment, appliances, and components. 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 2006* (*MECS2006).*[16] These end-use processes are shown in Figure 12.

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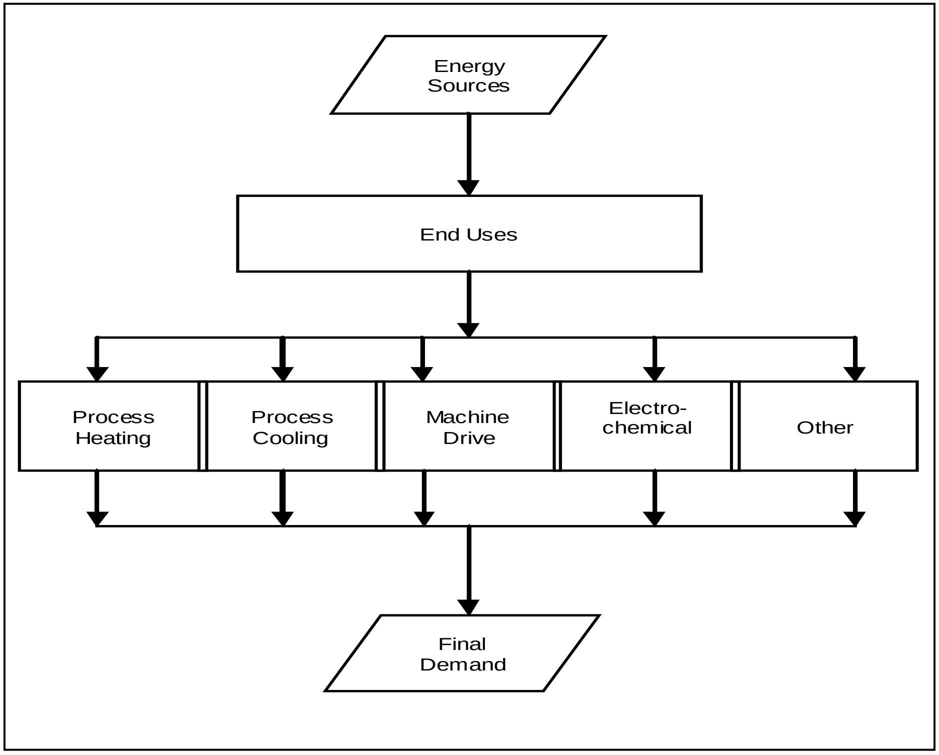
[16] Energy Information Administration (EIA), *2006 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/, June 2009. Note that the IDM's energy consumption projection for 2006 may

Figure 12. Metal-Based Durables Industry End Uses



The metal-based durables group has been disaggregated into five component sectors (Table 6). In 2006, the metal-based durables industry consumed 1.3 quadrillion Btu of energy.[17] 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.

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vary slightly from the *MECS2006* values due to the inclusion of data from the electricity data forms and model dynamics.

[17] Energy Information Administration (EIA), *2006 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/, June 2009. Note that the IDM's energy consumption projection for 2006 may vary slightly from the *MECS2006* values due to the inclusion of data from the electricity data forms and model dynamics.

Table 6. Components of Metal-Based Durables Manufacturing

Sectors	NAICS	2006 Unit Energy Consumption (thousand Btu per dollar)	Shipments Growth Rate, Percent (2006-2035)
Fabricated metals	332	1.321	1.2
Machinery	333	0.623	1.5
Computers and electronics	334	0.635	2.7
Transportation equipment	336	0.683	1.6
Electrical equipment, appliances, and components	335	0.526	1.7
Total Metal-Based Durables		0.755	1.8

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 *MECS2006* 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 52 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). Approximately 55 percent of plastics manufacturing's energy consumption is electricity. Together, these two industries account for 788 trillion Btu of energy (4 percent of manufacturing) and 7 percent of manufacturing value of shipments[18]. The remaining industries are aggregated into "Balance of Manufacturing" as a catchall category.

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

Sectors	NAICS	2006 Unit Energy Consumption (thousand Btu per dollar)	Shipments Growth Rate, Percent (2006-2035)
Wood Products	321	3.630	-0.1
Plastics and Rubber Products	326	1.744	0.7
Balance of Manufacturing	NA	1.562	0.4
Total		1.761	0.4

In 2006, the other non-energy-intensive manufacturing industry consumed over 2 quadrillion Btu of energy.[18] 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

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[18] Energy Information Administration (EIA), *2006 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/, June 2009. Note that the IDM's energy consumption projection for 2006 may vary slightly from the *MECS2006* values due to the inclusion of data from the electricity data forms and model dynamics.

the other end uses in the PA component of the balance of manufacturing group are given in Table B 11.

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 Census of Agriculture conducted by the U.S. Department of Agriculture.[19] Expenditures for four energy sources were collected for crop farms and livestock farms. These data were converted from dollar expenditures to energy quantities using prices from the Department of Agriculture and the EIA.

The mining industry is divided into three sectors in the Industrial Demand 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 2007 Economic Census of Mining by the U.S. Census Bureau.[20] 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 2007 Economic Census were aggregated. Expenditure amounts for five energy sources were collected by the U.S. Census Bureau.[20] 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 2008*,[21] the *2006 Manufacturing Energy Consumption Survey*,[22] *Fuel Oil and Kerosene Sales 2007*,[23] and a special tabulation from the USDA-NASS.[24] 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 B 12 for the non-manufacturing industries.

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[19] U.S. Department of Agriculture, National Agricultural Statistical Service, *2007 Census of Agriculture*, Februray 2009 http://www.agcensus.usda.gov/Publications/2007/index.asp.

[20] U.S. Department of Commerce, Census Bureau, *Economic Census 2007: Mining and Construction Industry Series*, 2009, http://www.census.gov/econ/census07/.

[21] Energy Information Administration, *State Energy Data System 2008* (Washington, DC, June 2010).

[22] Energy Information Administration (EIA), *2006 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/, June 2009.

[23] Energy Information Administration, *Fuel Oil and Kerosene Sales 2007*, DOE/EIA-0535(07) (Washington, DC, December 2008).

[24] Jim Duffield, USDA-NASS, *2007 Census of Agriculture Special Tabulation*, April 2010 http://www.nass.usda.gov/Data_and_Statistics/Special_Tabulations/index.asp..

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 regarding 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 2006 unit energy consumption values to develop an index of relative energy intensity (REI). Relative energy intensity is defined as the ratio of energy use in a new or advanced process compared to 2006 average energy use (Table B 14).

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 Demand Module are based on 2006 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 a maximum of just under 1 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 (2006 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 B 14. 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 B 15. The list of SOA and advanced technologies considered in the analysis is presented in Table B 16.

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 2006. Otherwise, the default value for the intensity decline rate is used, $BCSC_{v,f,s}$.

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

where

$TPCPrat$ = Ratio of current year average industrial energy price to 2006 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*,[25] a report produced for the U.S. Department of Energy's Office of Industrial Technologies (Table B 17). 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,

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

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 B 18).

    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 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 B 19). 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 BSC component consumes fuels and renewable energy to produce the steam and, in appropriate situations, cogenerate electricity.

The use of fuels to produce both heat and electric power in a single unit, the cogeneration element of the BSC component, represents technology implemented in industry for efficiency, which also provides a financial benefit. Some industries have been operating cogeneration plant for more than 40 years; however, due to various incentives and barriers during periods of scarce capital, rising and falling interest rates, and variations in product demands the popularity of cogeneration has grown and declined historically. The modeling approach in the Industrial Demand Module captures both the benefits and risks in determining new capacity because a well-developed understanding of industrial steam generation is critical, especially under changing outlooks for natural gas and electricity supply and price to industrial end users. While many factors could contribute to the adoption of cogeneration systems, such as site-specific factors related to utility concerns, in-plant electric use, and financing alternatives in real projects, economics are the primary driver in decision making, as described further below and much in the same way that industry operators assess other capital expenditures based on receiving a payback of their capital expenditures in a minimum period of time.

The boiler component is estimated to consume 28 percent of manufacturing heat and power energy consumption, excluding byproduct fuels.[26] Within the BSC component, natural gas accounts for 73 percent and coal 19 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 B 20) 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 2006 prices; α_i are sensitivity parameters, assumed equal to -1.5 for all i; and the β_i are calibrated to reproduce the 2006 fuel shares using the relative prices that prevailed in 2006. The byproduct fuels are consumed before the quantity of purchased fuels is estimated. The boiler fuel shares are assumed to be those estimated using *MECS2006* and exclude waste and byproducts.

Cogeneration capacity, generation, fuel use, and thermal output are determined from exogenous data and new additions are simulated, as needed, using 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 are for 2008, with planned additions (units under construction) through 2012.[27]

The data are processed outside the model to separate industrial cogeneration from commercial sector cogeneration, cogeneration from refineries and enhanced oil recovery operations, and offsite cogeneration. Offsite cogeneration units are primarily merchant power plants selling to

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[26] Computed from Energy Information Administration (EIA), *2006 Manufacturing Energy Consumption Survey*, http://www.eia.doe.gov/emeu/mecs/, June 2009, Table 5.8. Note that byproduct and non-energy use of combustible fuels are excluded from the computation.

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

the grid and often supplying relatively small amounts of thermal energy. The remainder, or onsite industrial cogeneration portion, was approximately 41 percent of the total cogeneration capacity in 2006. The cogeneration data are available on a plant basis and include capacity, generation, useful thermal energy, energy use by fuel, and the shares of that energy for electricity and thermal. The data are 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 for two capacity types: 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.

Unplanned additions to fossil-fueled cogeneration are projected 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 based on a study performed for EIA[28].

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 cogeneration units.

   b. Classify non-cogenerated steam uses into six size ranges, or load segments, based on an exogenous data set[29] providing the boiler size distribution for each industry and assuming that steam loads are distributed in the same proportions as boiler capacity (Table B 21). 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 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).

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[28] SENTECH Inc., *Commercial and Industrial CHP Technology Cost and Performance Data for EIA*, report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, June 2010.

[29] Energy and Environmental Analysis, Inc, *Characterization of the U.S. Industrial Commercial Boiler Population*, submitted to Oak Ridge National Laboratory, May 2005.

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 B 22; the high technology case uses the characteristics in Table B 23):

      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 discounted using the 10-year Treasury bill rate plus a risk premium. 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. The model assumes that 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. Since a simplified representation is required for the broad modeling needs in the IDM, non-fuel operating costs are not included. The costs are small relative to fuel costs and can be difficult to quantify with aggregate, load segment methodology being used as well. The payback is determined by dividing the investment by the average annual cash flow.

3. Assess market penetration based on discounted 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 called the payback acceptance curve. Rather than using an actual curve, we use a table of assumed values that roughly describe the shape of the payback acceptance curve (Table B 24). For each integer payback period from 0 to 12 years, the table provides a 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 are estimated assuming linear market penetration 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 Census Bureau data and vintage information are often cursory). The Industrial Demand Module capital stock is grouped into three vintages: old, middle, and new. The old vintage consists of capital in production in 2006 and is assumed to retire at a fixed rate each year. Middle vintage capital is that which is added from 2006 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 stock added during the projection period is retired in subsequent years at the same rate as the pre-2007 capital stock. The retirement rates used in the IDM for the various industries are listed in Table B 14.

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 2006, 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 2006.

$$X = RetirePrat^{RetireBeta}$$

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

$$RetireRate_s = RetirePriceFactor * ProdRetr_s$$

where

$RetirePrat$ = Maximum (1, ratio of current year average industrial energy price to 2006 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 IDM. 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 issues related to the quality of recycled materials.

Legislative Requirements

The Energy Policy Act of 1992 (EPACT92) and the Clean Air Act Amendments of 1990 (CAAA) contain requirements that are represented in the Industrial Demand Module. These fall into three main categories: coke oven standards; efficiency standards for boilers, furnaces, and electric motors; and industrial process technologies. The IDM assumes the leakage standards for coke oven doors do not reduce the efficiency of producing coke, or increase unit energy consumption. The IDM 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 represented in the motor model are at least as efficient as the standards for a given projection year. The IDM incorporates the necessary reductions in unit energy consumption for the energy-intensive industries.

Section 108 of the Energy Policy Act of 2005 (EPACT05) 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, possible effects of this provision are not currently simulated in the model. When specific regulations are promulgated, their estimated impact may be modeled in NEMS. However, the current cement industry model does include the capability to increase the amount of blended component in the clinker mix.

Section 1321 of EPACT05 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. These assumptions are introduced into the model through a spreadsheet file. The cogeneration assumptions used for the *AEO* are presented in Table B 21, Table B 22, Table B 23, and Table B 24.

Benchmarking

The IDM energy demand projections are benchmarked to historical data values presented in *Annual Energy Review 2009*. The national-level values reported in *Annual Energy Review 2009* were allocated to the Census Divisions using the *State Energy Data Report 2008*. 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.[30] The specific impacts on reported industrial energy consumption are discussed in Energy Information Administration, *Annual Energy Outlook 2003*, pp. 32-34.[31] Additional calibration for the years 2010-2011 are performed to conform to the *Short-Term Energy Outlook*.

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[30] 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.

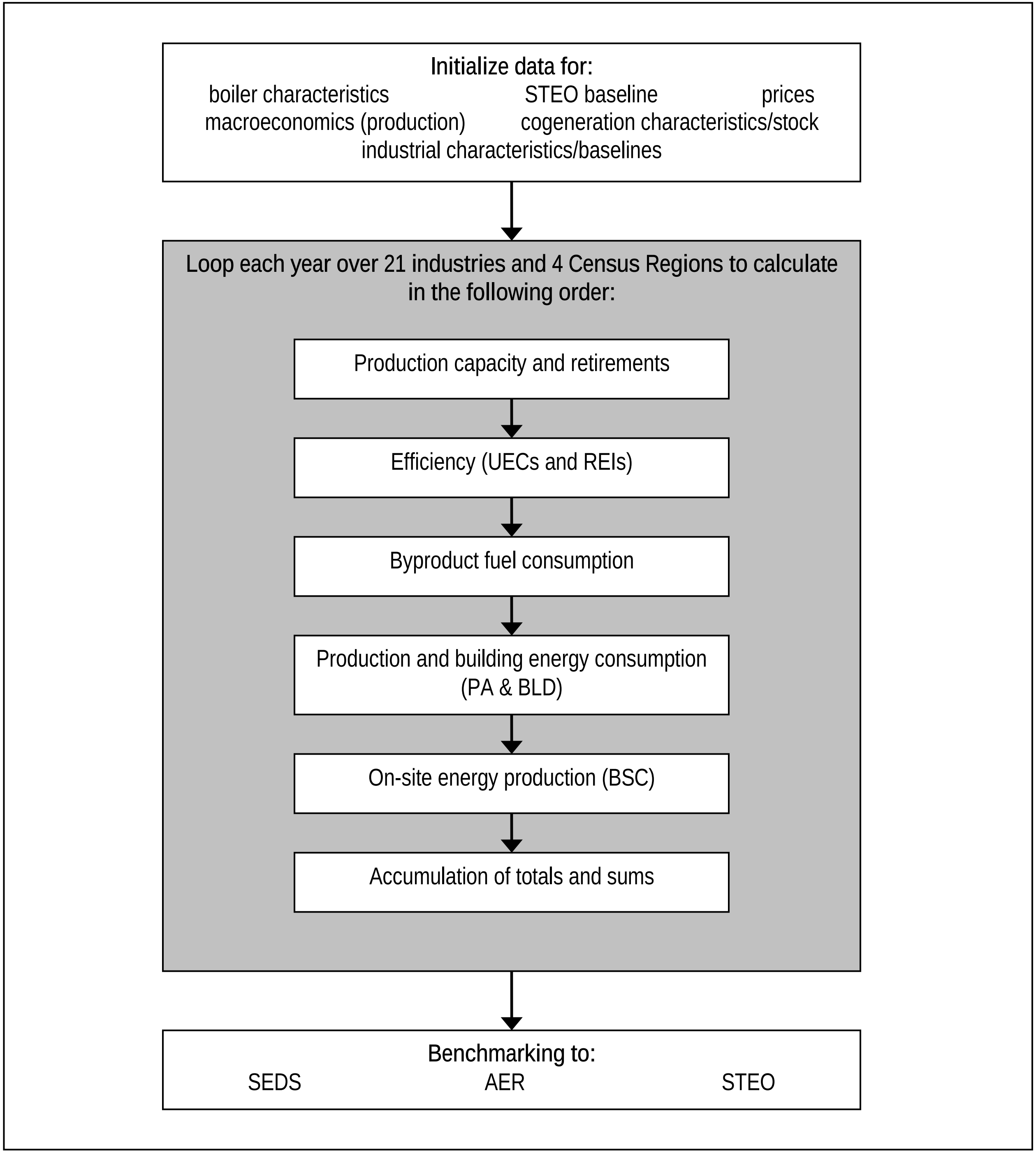
[31] Energy Information Administration, *Annual Energy Outlook 2003*, DOE/EIA-0383(2003) (January 2003), web site http://www.eia.doe.gov/oiaf/archive/aeo03/pdf/0383(2003).pdf.

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 2006 boiler fuel by subtracting Form 906 cogeneration fuel from 2006 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 MECS2006, respectively.
- MECS2006: Read PRODFLOW.TXT containing process/assembly step definitions and flow rates from most recent MECS data (2006)
- 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 (PA) 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 2008): calculate regional benchmark factors as the ratio of actual consumption to model consumption for each fuel in four Census Regions.
  - Post SEDS Years (2009-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 2010 to 2011, 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 Demand 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. Any calculation (all subroutines) is run for each year, industry, and Census Region unless otherwise indicated. For variables disaggregated to the Census Division level the subscript *d* will be used to differentiate it from standard regional detail.

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 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 IDM energy demand projections are benchmarked to values presented in *Annual Energy Review 2009* in subroutine WEXOG. The national-level values reported in the *Annual Energy Review 2009* are allocated to the Census Divisions using the *State Energy Data Report 2008*. Because detailed data for the IDM 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.

$$PRCX_{elec} = \frac{\sum_{d=1}^{Num_r} DPRCX_{elec,d} * QSELIN_{d,2008}}{\sum_{d=1}^{Num_r} QSELIN_{d,2008}} \qquad (5)$$

where

$PRCX_{elec}$ = Price for electricity,
NUM_r = Number of Census Divisions in Census Region r,
$DPRCX_{elec,d}$ = Price of electricity in Census Division d, and
$QSELIN_{d,2008}$ = SEDS consumption of electricity in Census Division d in 2008.

IND calls two subroutines: ISEAM, the subroutine that guides the IDM 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 IDM 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 IDM. 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 2006 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 Demand 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 IDM 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

The IRHEADER subroutine imports industry and region identifier numbers, base year values of output, physical to dollar output conversion factors, and base year steam demand.

It calculates the ratio of physical output to 2006 value of shipments for pulp and paper, glass, cement, steel and aluminum industries. This constant ratio is applied to value of shipments for subsequent years.

$$PHDRAT = \frac{PHYSICAL}{PRODVX} \tag{6}$$

where

$PHDRAT$ = Ratio of physical units to value of shipments,
$PHYSICAL$ = Physical units of output, and
$PRODVX$ = Value of shipments.

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

$$PRODX = PRODVX * PHDRAT \tag{7}$$

where

$PRODX$ = Output in physical units,
$PHDRAT$ = Ratio of physical units to value of shipments, and
$PRODVX$ = Value of shipments.

If the UEC is in dollar units, then the following direct substitution is used:

$$PRODX = PRODVX \tag{8}$$

where

$PRODX$ = Value of shipments, and
$PRODVX$ = Value of shipments.

MECS2006

The MECS2006 subroutine imports production throughput coefficients, process step retirement rates, and other process step flow information from the file PRODFLOW.TXT. Imported process step flow data for each process step include process step number, number of links, the process steps linked to the current step, physical throughput to each process step, retirement rate, and process step name.

A linkage is defined as a link between one or more process steps. The model simulates process steps for five energy-intensive industries: 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, so there is only one down-step throughput. As an example of process step linkage, the wood preparation process step in paper manufacturing 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.

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
$Y_2 = 0.502\ Y_1$
$Y_3 = 0.317\ (Y_1 + Y_2)$
$Y_4 = 0.041\ (Y_1 + Y_2)$
$Y_5 = 0.028\ (Y_1 + Y_2)$
$Y_6 = 0.377\ (Y_1 + Y_2)$
$Y_7 = 1.689\ (Y_4 + Y_5 + Y_6)$

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 $Y_7 = 109$.

For the above example, there are 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 passing through the wood preparation process, 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 Demand Module, these calculations are performed in an input-output formulation (see CALPROD below for more information).

Physical throughput is obtained for three vintages: old, middle, and new. Old vintage is defined as any capital installed in or before 2006. Middle vintage includes installations from 2007 to the year prior to the current projection year. New vintage includes any capital installed in the current projection year.

In summary, 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 2008. 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.

MECS2006

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

Read the industrial technology data file (ITECH.TXT) to update the initial ENPROD.TXT data file with 2006 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 Demand Module assumes that all byproduct fuels are consumed prior to the purchasing of any fuels. The CALBYPROD 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 2006, the ratio of the current year’s average industrial energy price to the average price in 2006 is computed. TPCPrat is the greater of this ratio and 1.0. As a result, TPC is an increasing function of TPCPrat:

$$
\begin{aligned}
&X = TPCPrat^{TPCBeta} \\
&TPCPriceFactor = \frac{X}{(1+X)} \qquad\qquad (9) \\
&TPCRate_v = 2{*}TPCPriceFactor{*}BYPCSC_{v,f,s}
\end{aligned}
$$

where

$TPCPrat$ = Maximum (1.0, Ratio of current year average industrial energy price to 2006 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.

$$BYPINT_{v,f,s} = (BYPINTLag_{v,f,s})^{TPCRate_{v}} \qquad (10)$$

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.

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

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.

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

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.

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

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.

$$ENPQTY_{v,f,s} = PRODCUR_{v,s} * ENPINT_{v,f,s} \tag{14}$$

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:[32]

Electricity,
Core and non-core natural gas,
Natural gas feedstocks,
Steam coal,
Coking coal (including net coke imports),
Residual oil,
Distillate oil,
Liquid petroleum gas for heat and power,
Liquid petroleum gas for feedstocks,
Motor gasoline,
Still gas,

---

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

Petroleum coke,
Asphalt and road oil,
Petrochemical feedstocks,
Other petroleum feedstocks, and
Other petroleum.

Intermediate fuels include the following:

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

Renewable fuels include the following although only the first 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 and the three vintage categories, as shown below for main fuels. The equations for intermediate and renewable fuels are similar.

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

where

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

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

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

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.

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 Demand 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.

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

where

$ENPMQTY_{coke}$ = Quantity of coke imports in the PA component,
$ENPIQTY_{coke}$ = Consumption of coke in the PA 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 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 indexes that indicate the proportionate change in production between 2002 and the current projection year. They are used, along with the 2002 data, to project production of specific chemicals.

Organic Chemicals

In the model computer code, the organic chemicals are indicated by the numerical subscripts, as noted below.

Ethylene

Change in ethylene production (subscript 1) is assumed proportional to total bulk chemicals value of shipments.

$$OrganicPRodIdxUnc_1 = \frac{ChemShip_5}{ChemShip_{5,2002}} * 100.00 \tag{18}$$

where

$ChemShip_5$ = Total bulk chemicals value of shipments, and
$OrganicPRodIdxUnc_1$ = Ethylene production indexed to 2002.

Propylene

Propylene production (subscript 2) is a function of ethylene production.

$$\begin{aligned} OrganicPRodIdxUnc_2 = & \exp(PRIntercept) \\ & *(OrganicPRodIdxUnc_1)^{0.64307} \\ & *(y^{0.079787}) \end{aligned} \tag{19}$$

where

$PRIntercept$ = Calculated regression intercept based on 2002 data, and
$OrganicPRodIdxUnc_2$ = Propylene production indexed to 2002.

Butadiene

Butadiene production (subscript 3) is a function of ethylene production.

$$\begin{aligned} OrganicPRodIdxUnc_3 = & \exp(BUIntercept) \\ & *(OrganicPRodIdxUnc_1)^{1.302607} \\ & *(y^{0.047119}) \end{aligned} \tag{20}$$

where

$BUIntercept$ = Calculated regression intercept based on 2002 data, and
$OrganicPRodIdxUnc_3$ = Butadiene production indexed to 2002.

Acetic Acid

Acetic acid production (subscript 4) is assumed equal to vinyl acetate production.

$$OrganicPRodIdxUnc_4 = OrganicPRodIdxUnc_{31} \tag{21}$$

where

$OrganicPRodIdxUnc_4$ = Acetic acid production indexed to 2002, and
$OrganicPRodIdxUnc_{31}$ = Vinyl acetate production indexed to 2002.

Acrylonitrile

Acrylonitrile production (subscript 5) is a function of butadiene production.

$$\begin{aligned} OrganicPRodIdxUnc_5 = & \exp(ACIntercept) \\ & *(OrganicPRodIdxUnc_3)^{0.56996} \\ & *(y^{-0.062598}) \end{aligned} \tag{22}$$

where

$ACIntercept$ = Calculated regression intercept based on 2002 data, and
$OrganicPRodIdxUnc_5$ = Acrylonitrile production indexed to 2002.

Ethylbenzene

Ethylbenzene production (subscript 6) is a function of ethylene production.

$$\begin{aligned} OrganicPRodIdxUnc_6 &= \exp(EBIntercept) \\ &\quad * (OrganicPRodIdxUnc_1)^{1.1870531} \\ &\quad * (y^{-0.04729}) \end{aligned} \tag{23}$$

where

$EBIntercept$ = Calculated regression intercept based on 2002 data, and
$OrganicPRrodIdxUnc_6$ = Ethylbenzene production indexed to 2002.

Ethylene Dichloride

Ethylene dichloride production (subscript 7) is assumed equal to vinyl chloride production.

$$OrganicPRodIdxUnc_7 = RESINSPRodIdxUnc_5 \tag{24}$$

where

$OrganicPRrodIdxUnc_7$ = Ethylene dichloride production indexed to 2002, and
$RESINSPRodIdxUnc_5$ = Vinyl chloride production indexed to 2002.

Ethylene Oxide

Ethylene oxide production (subscript 9) is a function of ethylene production.

$$\begin{aligned} OrganicPRodIdxUnc_9 &= \exp(EOIntercept) \\ &\quad * (OrganicPRrodIdxUnc_1)^{0.951344} \\ &\quad * (y^{-0.06138}) \end{aligned} \tag{25}$$

where

$EOIntercept$ = Calculated regression intercept based on 2002 data, and
$OrganicPRodIdxUnc_9$ = Ethylene oxide production indexed to 2002.

Ethylene Glycol

Ethylene glycol production (subscript 8) is a function of ethylene oxide production.

$$\begin{aligned} OrganicPRodIdxUnc_8 &= \exp(EGIntercept) \\ &\quad * (OrganicPRodIdxUnc_9)^{1.000592} \\ &\quad * (y^{0.027261}) \end{aligned} \tag{26}$$

where

$EGIntercept$ = Calculated regression intercept based on 2002 data, and
$OrganicPRodIdxUnc_8$ = Ethylene glycol production indexed to 2002.

Formaldehyde

Formaldehyde production (subscript 10) is a function of wood and printing industry production (value of shipments).

$$
\begin{aligned}
OrganicPRodIdxUnc_{10} = \exp(FDIntercept) & \\
& *\left(\frac{chemwood}{chemwood\,2002}*100\right)^{0.488691} \\
& *\left(\frac{chempr\,\mathrm{int}}{chempr\,\mathrm{int}\,2002}*100\right)^{0.165717} \\
& *\left(y^{0.027899}\right)
\end{aligned} \tag{27}
$$

where

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

Methanol

Methanol Demand

Methanol demand follows formaldehyde production trends.

$$
\begin{aligned}
MethanolDemUnc = MethanolHistDem_{2002} & \\
& *\left(OrganicPRodIdxUnc_{10}\right)
\end{aligned} \tag{28}
$$

where

$MethanolHistDem_{2002}$ = Calculated factor based on 2002 data, and
MethanolDemUnc = Methanol demand indexed to 2002.

Methanol Imports

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

$$
\begin{aligned}
MethimpShareUnc = \exp(MEIntercept) & \\
& *\left(\frac{MethanolDemUnc}{MethanolHistDem_{2002}}*100\right)^{-0.498699} \\
& *\left(MEGasPR\right)^{0.303922} \\
& *\left(y^{0.329169}\right)
\end{aligned} \tag{29}
$$

where

MEIntercept = Calculated regression intercept based on 2002 data,
MEGasPR = Natural gas wellhead price adjusted to current year dollar, and
MethimpShareUnc = Methanol imports indexed to 2002.

Methanol Domestic Production

Methanol domestic production (subscript 11) is the difference between total methanol demand and total methanol imports.

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

where

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

Styrene

Styrene production (subscript 12) is a function of ethylbenzene production.

$$\begin{aligned} OrganicPRodIdxUnc_{12} = & \exp(STIntercept) \\ & * (OrganicPRodIdxUnc_{6})^{1.03554} \\ & * (y^{0.02}) \end{aligned} \quad (31)$$

where

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

Vinyl Acetate

Vinyl acetate production (subscript 13) is a function of ethylene production.

$$\begin{aligned} OrganicPRodIdxUnc_{13} = & \exp(VAIntercept) \\ & * (OrganicPRodIdxUnc_{1})^{1.112169} \\ & * (y^{-0.01494}) \end{aligned} \quad (32)$$

where

$VAIntercept$ = Calculated regression intercept based on 2002 data, and
$OrganicPRodIdxUnc_{13}$ = Vinyl acetate production indexed to 2002.

Ethanol

Ethanol production (subscript 14) is a function of total organic chemicals production (value of shipments).

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

where

$ChemShip_{2}$ = Organic chemicals value of shipments, and
$OrganicPRodIdxUnc_{14}$ = Ethanol production 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 does not apply to certain chemical operators. This production also results in byproduct ethylene production, which makes up 53 percent of 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
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

The change in other organic chemicals production (subscript 15) is assumed proportional to total organic chemicals production (value of shipments).

$$OrganicPRodIdxUnc_{15} = \frac{ChemShip_2}{ChemShip_{2,2002}} * 100.00 \qquad (34)$$

where

$OrganicPRodIdxUnc_{15}$ = Other organic chemicals production indexed to 2002.

Inorganic Chemicals

Acetylene

Acetylene production (subscript 1) is a function of vinyl acetate production.

$$InorganicPRodIdxUnc_1 = OrganicPRodIdxUnc_{13} \qquad (35)$$

where

$InorganicPRodIdxUnc_1$ = Acetylene production indexed to 2002.

Chlorine

Change in chlorine production (subscript 2) is assumed to be proportional to paper industry production (value of shipments).

$$InorganicPRodIdxUnc_2 = \frac{ChemPaper}{ChemPaper2002} * 100.00 \qquad (36)$$

where

$ChemPaper$ = Paper industry value of shipments for current year,
$ChemPaper2002$ = Paper industry value of shipments for 2002, and
$InorganicPRodIdxUnc_2$ = Chlorine production indexed to 2002.

Oxygen

Oxygen production (subscript 3) is a function of vinyl acetate production.

$$InorganicPRodIdxUnc_3 = OrganicPRodIdxUnc_{13} \qquad (37)$$

where

$InorganicPRodIdxUnc_3$ = Oxygen production indexed to 2002.

Sulfuric Acid

Sulfuric acid production (subscript 4) is a function of phosphoric acid production.

$$\begin{aligned} InorganicPRodIdxUnc_4 &= \exp(SAIntercept) \\ &* (AgrichemPRodIdxUnc_2)^{0.554257} \\ &* (y^{-0.04926}) \end{aligned} \qquad (38)$$

where

$SAIntercept$ = Calculated regression intercept based on 2002 data,

$AgrichemPRodIdxUnc_2$ = Phosphoric acid production indexed to 2002, and
$InorganicPRodIdxUnc_4$ = Sulfuric acid production indexed to 2002.

Hydrogen

Change in hydrogen production (subscript 5) is assumed proportional to change in total inorganic chemicals productions (value of shipments).

$$InorganicPRodIdxUnc_5 = \frac{ChemShip_1}{ChemShip_{1,2002}} * 100.00 \qquad (39)$$

where

$ChemShip_1$ = Inorganic chemicals value of shipments, and
$InorganicPRodIdxUnc_5$ = Hydrogen production indexed to 2002.

Other Inorganic Chemicals

Other inorganic chemicals production (subscript 6) is a function of total inorganic chemicals production (value of shipments).

$$InorganicPRodIdxUnc_6 = \frac{ChemShip_1}{ChemShip_{1,2002}} * 100.00 \qquad (40)$$

where

$InorganicPRodIdxUnc_6$ = Other inorganic chemicals production indexed to 2002.

Plastic Resins

Polyethylene

Polyethylene production (subscript 2) is a function of total plastic resins production (value of shipments).

$$RESINSPRodIdxUnc_2 = \frac{ChemShip_3}{ChemShip_{3,2002}} * 100.00 \qquad (41)$$

where

$ChemShip_3$ = Plastic resins value of shipments, and
$RESINSPRodIdxUnc_2$ = Polyethylene production indexed to 2002.

Polyvinyl Chloride (PVC)

PVC production (subscript 1) is a function of construction industry production (value of shipments) and polyethylene production.

$$RESINSPRodIdxUnc_1 = \exp(PVCIntercept) * \left(\frac{chemconst}{chemconst2002} * 100\right)^{0.470265} * \left(RESINSPRodIdxUnc_2\right)^{0.59181} * (y^{-0.08928}) \tag{42}$$

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
$RESINSPRodIdxUnc_1$ = PVC production indexed to 2002.

Polystyrene

Polystyrene production (subscript 3) is a function of styrene production and PVC production.

$$RESINSPRodIdxUnc_3 = \exp(PSIntercept) * (OrganicPRodIdxUnc_{12})^{0.323791} * (RESINSPRodIdxUnc_1)^{0.068003} * (y^{0.026836}) \tag{43}$$

where

$PSIntercept$ = Calculated regression intercept based on 2002 data, and
$RESINSPRodIdxUnc_3$ = Polystyrene production indexed to 2002.

Styrene-Butadiene-Rubber (SBR)

SBR production (subscript 4) is a function of butadiene production.

$$RESINSPRodIdxUnc_4 = OrganicPRodIdxUnc_3 \tag{44}$$

where

$RESINSPRodIdxUnc_4$ = SBR production indexed to 2002.

Vinyl Chloride

Vinyl chloride production (subscript 5) is a function of PVC production.

$$RESINSPRodIdxUnc_5 = RESINSPRodIdxUnc_1 \tag{45}$$

where

$RESINSPRodIdxUnc_5$ = Vinyl chloride production indexed to 2002.

Other Plastic Resins

Other plastic resins production (subscript 6) is a function of total plastic resins production (value of shipments).

$$RESINSPRodIdxUnc_6 = \frac{ChemShip_3}{ChemShip_{3,2002}} * 100.00 \qquad (46)$$

where

$RESINSPRodIdxUnc_6$ = Other plastic resins production indexed to 2002.

Agricultural Chemicals

Ammonia

Ammonia production (subscript 1) is a function of total agricultural chemicals production (value of shipments).

$$AgrichemPRodIdxUnc_1 = \frac{ChemShip_4}{ChemShip_{4,2002}} * 100.00 \qquad (47)$$

where

$ChemShip_4$ = Agricultural chemicals value of shipments, and
$AgrichemPRodIdxUnc_1$ = Polyethylene production indexed to 2002.

Phosphoric Acid

Phosphoric acid production (subscript 2) is a function of ammonia production.

$$\begin{aligned} AgrichemPRodIdxUnc_2 &= \exp(PAIntercept) \\ &* (AgrichemPRodIdxUnc_1)^{0.15298} \\ &* (y^{-0.06125}) \end{aligned} \qquad (48)$$

where

$PAIntercept$ = Calculated regression intercept based on 2002 data, and
$AgrichemPRodIdxUnc_2$ = Phosphoric acid production indexed to 2002.

Other Agricultural Chemicals

Other agricultural chemicals production (subscript 3) is a function of total agricultural chemicals production (value of shipments).

$$AgrichemPRrodIdxUnc_3 = \frac{ChemShip_4}{ChemShip_{4,2002}} * 100.00 \qquad (49)$$

where

$AgrichemPRodIdxUnc_3$ = Other agricultural chemicals production indexed to the value in 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):

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

where

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

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

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

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):

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

where

$OrganicPRodCal_{ic}$ = Final production in billion lbs of chemical *ic* for a given year,
$OrganicPRodCal2002_{ic}$ = Historical production in billion lbs of chemical *ic* for 2002, and
$OrganicPRodIdxCal_{ic}$ = Production of chemical *ic* for a given year indexed to 2002.

The relative “share” of processes used to produce a particular chemical are mostly exogenous to the model (see Table 5). The exceptions are those chemicals and their processes that use significant amounts of energy feedstocks, such as ethylene, propylene and butadiene. Because these chemicals are sensitive to energy prices, the model captures the 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):

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

where

$OrganicPRocPRod_{ic,ip}$ = Production in billion lbs of chemical *ic* using process *ip,*
$OrganicPRodCal_{ic}$ = Production in billion lbs of chemical *ic*, and
$OrganicPRocShr_{ip}$ = 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 relating the feedstock shares to oil and natural gas prices. Naphtha and gas oils are petrochemical feedstocks (called heavy feedstocks); and ethane, propane and butane are natural gas liquids (NGL) or liquefied petroleum gas (LPG) (called light feedstocks). Thus, the relative values of light and heavy feedstock combined prices, passed to the Industrial Demand Module from the PMM, are key drivers for the choice between using oil-based or gas-based feedstocks.

The model calculates consumption shares of ethane, propane, and petrochemical feedstocks based on light and heavy feedstock prices, as follows:

$$Q\_Ethane\_feedstock = 863{,}213{,}438 + 2{,}416{,}068 * P\_NAPHTHA\_87 + 1{,}843{,}346 * P\_PROPANE\_87 \tag{54}$$

$$Q\_Propane\_feedstock = 346{,}374{,}144 + 2{,}011{,}103 * P\_NAPHTHA\_87 + 1{,}560{,}694 * P\_PROPANE\_87 \tag{55}$$

$$Q\_Naptha\_feedstock = 153{,}658{,}769 + 7{,}488{,}622 * P\_NAPHTHA\_87 + 6{,}530{,}702 * P\_PROPANE\_87 \tag{56}$$

(57)

(58)

(59)

where

$P\_NAPHTHA\_87$ = Heavy feedstock combined price for whole country,
$P\_PROPANE\_87$ = Light feedstock combined price for whole country,
$Q\_Ethane\_feedstock$ = Regression implied quantity of ethane feedstock consumption,
$Q\_Propane\_feedstock$ = Regression implied quantity of propane feedstock consumption,
$Q\_Naphtha\_feedstock$ = Regression implied quantity of naphtha feedstock consumption,
$EthShr$ = Ethane share of feedstock consumption,
$ProShr$ = Propane share of feedstock consumption, and
$NapShr$ = Naphtha share of feedstock consumption.

Since ethylene, propylene, and butadiene are co-produced, careful accounting of energy and feedstock consumed to produce each chemical is necessary. The feedstock shares calculated using the equations above are first used to estimate the feedstock shares for ethylene.

There are six feedstocks for ethylene: ethane, propane, butane, naphtha, gas oil, and biomass. The shares calculated above reflect the dominance of only three of these feedstocks: naphtha, ethane, and propane. The results of these calculations are applied only to Census Region 3 since production of ethylene is limited to this region. Combining all the equations, let *OrganicPRocShr* represent the feedstock shares for ethylene as:

Ethylene Butane share

$$OrganicPRocShr_5 = 0.0001 \tag{60}$$

Ethylene Gas oil share

$$OrganicPRocShr_3 = 0.0001 \tag{61}$$

Ethylene Naphtha share

$$OrganicPRocShr_4 = NapShr \tag{62}$$

Ethylene Biomass share

$$OrganicPRocShr_6 = 0.0001 \tag{63}$$

Ethylene Ethane share

$$OrganicPRocShr_{1,r} = EthShr \tag{64}$$

Ethylene Propane share

$$OrganicPRocShr_2 = \Pr oShr \tag{65}$$

The process of feedstock shares used for propylene and butadiene are based on the shares for ethylene. Since each type of feedstock has different production rates for ethylene, propylene and butadiene, the shares are adjusted to account for these differences. The feedstock shares for propylene are calculated as follows:

$$\begin{aligned} sum = {} & (OrganicPRocShr_1 * 3.0) + (OrganicPRocShr_2 * 50.0) \\ & + (OrganicPRocShr_3 * 55.0) + (OrganicPRocShr_4 * 50.0) \\ & + (OrganicPRocShr_5 * 40.0) \end{aligned} \tag{66}$$

Propylene Ethane share

$$OrganicPRocShr_7 = (OrganicPRocShr_1 * 3.0) / sum \tag{67}$$

Propylene Propane share

$$OrganicPRocShr_8 = (OrganicPRocShr_2 * 50.0) / sum \tag{68}$$

Propylene Gas Oil share

$$OrganicPRocShr_9 = (OrganicPRocShr_3 * 55.0) / sum \tag{69}$$

Propylene Naphtha share

$$OrganicPRocShr_{10} = (OrganicPRocShr_4 * 50.0) / sum \tag{70}$$

Propylene Butane share

$$OrganicPRocShr_{11} = \min(0.08, (Organic\Pr ocShr_5 * 40.0 / sum)) \tag{71}$$

Note that butane share has an upper limit, which is similarly based on the upper limit for ethylene. If the limit is exceeded, then the difference between the estimated share and the limit is added to propane share.

$$
\begin{aligned}
OrganicPRocShr_8 = {} & OrganicPRocShr_8 + \\
& [(OrganicPRocShr_5 * 40.0) / sum) - \\
& OrganicPRocShr_{11}]
\end{aligned}
\tag{72}
$$

The shares for butadiene are calculated as follows:

Butadiene Catalytic dehydrogenation of butane share

$$OrganicPRocShr_{17} = OrganicHistPRocShr_{17} \tag{73}$$

where

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

Butadiene Catalytic dehydrogenation of n-butane share

$$OrganicPRocShr_{18} = OrganicHistPRocShr_{18} \tag{74}$$

where

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

Butadiene Ethane share

$$
\begin{aligned}
OrganicPRocShr_{12} = {} & (1 - OrganicPRocShr_{17} - OrganicPRocShr_{18}) \\
& * (OrganicPRocShr_1 * 2.0) / sum
\end{aligned}
\tag{75}
$$

where

$$
\begin{aligned}
sum = {} & (OrganicPRocShr_1 * 2.0) + (OrganicPRocShr_2 * 5.0) \\
& + (OrganicPRocShr_3 * 17.0) + (OrganicPRocShr_4 * 15.0) \\
& + OrganicPRocShr_5 * 9.0)
\end{aligned}
\tag{76}
$$

Butadiene Propane share

$$
\begin{aligned}
OrganicPRocShr_{13} = {} & (1 - OrganicPRocShr_{17} - OrganicPRocShr_{18}) \\
& * (OrganicPRocShr_2 * 5.0) / sum
\end{aligned}
\tag{77}
$$

Butadiene Gas Oil share

$$
\begin{aligned}
OrganicPRocShr_{14} = {} & (1 - OrganicPRocShr_{17} - OrganicPRocShr_{18}) \\
& * (OrganicPRocShr_3 * 17.0) / sum
\end{aligned}
\tag{78}
$$

Butadiene Naphtha share

$$
\begin{aligned}
OrganicPRocShr_{15} = {} & (1 - OrganicPRocShr_{17} - OrganicPRocShr_{18}) \\
& * (OrganicPRocShr_4 * 15.0) / sum
\end{aligned}
\tag{79}
$$

Butadiene Butane share

$$OrganicPRocShr_{16} = (1 - OrganicPRocShr_{17} - OrganicPRocShr_{18}) \\ * (OrganicPRocShr_{5} * 9.0) / sum \tag{80}$$

To avoid multiple-counting when the model calculates energy consumed in the production of 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 naphtha as feedstocks, and for butadiene, the calculations are based on butane.

The assignments described above are done only as a preliminary step to avoid double/triple counting of energy consumption. Energy consumption using ethane and biomass feedstocks does not solely determine total energy consumption to produce ethylene. Ethylene is produced using ethane and biomass, but also propane, gas oils, naphtha, and butane. To calculate total energy consumption to produce ethylene (or propylene or butadiene), the model sums the energy consumption across feedstocks.

The final step is the calculation of energy consumption for each chemical/chemical group in Table 2. 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.

The model performs the following steps for each chemical or chemical group:

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. For example, in the case of an organic chemical,

$$OrganicEnServ_{ic,ip,ie,if} = (OrganicPRodCal_{ic} * Organic\,\mathrm{Pr}\,ocShr_{ip} \\ * OrganicEn\,\mathrm{Re}\,q_{ip,ie,if}) / 1000 \tag{81}$$

where

$OrganicEnServ_{ic,ip,ie,if}$ = Energy consumption for energy service *ie* from fuel source *if* using process *ip* to manufacture chemical *ic*,
$OrganicProdCal_{ic}$ = Production in billion lbs of chemical *ic*,
$OrganicProcShr_{ip}$ = Share of process *ip*, and
$OrganicEnReq_{ip,ie,if}$ = Unit energy requirement of fuel source *if* for energy service *ie* using process *ip*.

where energy service categories are as follows:

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. For each chemical, process, and fuel source within a region calculate total energy consumption for process cooling, electrolysis, machine drive, process heat.

Process Cooling

$$OrganicPC_{ic,ip,if,r} = OrganicEnServ_{ic,ip,1,if,r} \tag{82}$$

Machine Drive

$$\begin{aligned} OrganicMD_{ic,ip,if,r} &= OrganicEnServ_{ic,ip,2,if,r} \\ &+ OrganicEnServ_{ic,ip,3,if,r} \\ &+ OrganicEnServ_{ic,ip,4,if,r} \end{aligned} \tag{83}$$

Electrolysis

$$OrganicEY_{ic,ip,if,r} = OrganicEnServ_{ic,ip,10,if,r} \tag{84}$$

Process Heat

$$\begin{aligned} OrganicHT_{ic,ip,if,r} &= OrganicEnServ_{ic,ip,5,if,r} \\ &+ OrganicEnServ_{ic,ip,6,if,r} \\ &+ OrganicEnServ_{ic,ip,7,if,r} \\ &+ OrganicEnServ_{ic,ip,8,if,r} \\ &+ OrganicEnServ_{ic,ip,9,if,r} \\ &+ OrganicEnServ_{ic,ip,12,if,r} \\ &+ OrganicEnServ_{ic,ip,13,if,r} \\ &+ OrganicEnServ_{ic,ip,14,if,r} \end{aligned} \tag{85}$$

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:

$$rat = price_{if,y} \,/\, price_{if,y-1} \tag{86}$$

where

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

The model estimates the savings rate based on the price change ratio, rat, as

$$SaveRt_{if} = SaveRt2002_{if} - (1 - (rat^{Elas_{if}})) \tag{87}$$

where

$SaveRt_{if}$ = Savings rate for fuel source *if*,
$SaveRt2002_{if}$ = Historical savings rate for fuel source *if*, 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

$$OrganicTotPC_{ic,if} = OrganicTotPC_{ic,if} * (1 + SaveRt_{if}) \qquad (88)$$

Machine Drive

$$OrganicTotMD_{ic,if} = OrganicTotMD_{ic,if} * (1 + SaveRt_{if}) \qquad (89)$$

Electrolysis

$$OrganicTotEY_{ic,if} = OrganicTotEY_{ic,if} * (1 + SaveRt_{if}) \qquad (90)$$

Process Heat

$$OrganicTotHT_{ic,if} = OrganicTotHT_{ic,if} * (1 + SaveRt_{if}) \qquad (91)$$

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

The model holds the fuel shares constant at 2002 values, which provide a reasonable approximation, because natural gas is the primary fuel for this application and substantial switching to fuel oils, coal, and electricity is unlikely, due to the increased costs and regulatory barriers.

Step 5. Calculate final feedstock consumption. The production of several chemicals in the model requires an energy product 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 feedstock consumption summed over the chemicals whose production consumes the feedstock (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 this and the fact that the EPACT92 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 (2006) values:

$MotorStock_{s,2006}$ = Motor stock for motor size group *s* in the base year (2006), number of motors,

$MotAvgEnergy_{s,2006}$ = Average energy consumption per motor for motor size group *s* in the base year (2006), kWh per motor per year,

$MotAvgEff_{s,2006}$ = Average motor energy efficiency rating for motor size group *s* in the base year (2006),

$FailurePct_s$ = Percentage of motors which fail each year for motor size group *s*,

$MotorRetPct_s$ = Percentage of motors retired upon failure for motor size group *s*,

$MotorRewDrop_s$ = Drop in efficiency for rewound motors in motor size group *s*,

$MotorSysLife_s$ = Motor system efficiency program life in motor size group *s*,

$PumpAppPct_s$ = Motor system efficiency applicability, percentage of pump systems in motor size group *s*,

$FanAppPct_s$ = Motor system efficiency applicability, percentage of fan systems in motor size group *s*,

$CompAppPct_s$ = Motor system efficiency applicability, percentage of compressor systems in motor size group *s*,

$PumpSavPct_s$ = Motor system efficiency savings fraction for pump systems in motor size group *s*,

$FanSavPct_s$ = Motor system efficiency savings fraction for fan systems in motor size group *s*, and

$CompSavPct_s$ = Motor system efficiency savings fraction for compressor systems in motor size group *s*.

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

$$TotalMotorEnergy_s = MotorStock_s * \left(MotorAvgEnergy_{s,2006} * \frac{3412}{10^{12}} \right) \qquad (92)$$

where

$TotalMotorEnergy_s$ = Motor energy consumption in trillion Btu for motor size group *s* in the base year (2006).

$MotorStock_s$ and $MotAvgEnergy_s$ 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:

$$ReplacePrPrem_s = PEListPrice_s * (1 - DealerDisc) - RewindCost_s \qquad (93)$$

where

$ReplacePrPrem_s$ = Premium for replacing a failed motor for 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
$RewindCost_s$ = The cost to rewind a failed motor for motor size group *s*.

The energy expenditure savings are calculated, with prices in 2002 year dollar for convenience, as follows:

$$ReplaceAnnSav_s = MotorHP_s * HPtoKW * MotorOpHr_s \\ * IndElecPrice * \left[\left(\frac{1}{RewoundEff_s} \right) - \left(\frac{1}{PEPctEff_s} \right) \right] \qquad (94)$$

where

$ReplaceAnnSav_s$ = The expected annual savings from the replacing a failed motor with a minimum efficiency motor for motor size group *s*, in 2002 dollars,
$MotorHP_s$ = The rated motor horsepower for motor size group *s*,
$HPtoKW_s$ = The conversion factor from horsepower to kilowatts,
$MotorOpHr_s$ = The annual operating hours for motors in motor size group *s*,
$IndElecPrice$ = The industrial electricity price in 2002 dollars per kWh,
$RewoundEff_s$ = The efficiency rating for a rewound motor for motor size group *s*, and
$PEPctEff_s$ = The efficiency rating for an EISA minimum efficiency motor for motor size group *s*.

The simple payback period in years is estimated as

$$ReplacePayback_s = \frac{ReplacePrPrem_s}{ReplaceAnnSav_s / (1 + disrate^{year})} \qquad (95)$$

where

$disrate$ = Real discount rate, which is the 10-year Treasury bill rate adjusted for risk, and
$ReplacePayback_s$ = Payback period, rounded to nearest year, for replacing a failed motor with a minimum efficiency motor purchased for motor size group *s*.

$ReplacePrPrem_s$ and $ReplaceAnnSav_s$ 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:

$$ReplaceAccept_s = Acceptance\left(PremAccept,5,ReplacePayback_s\right) \tag{96}$$

where

$ReplaceAccept_s$ = Fraction of premium efficiency motors purchased in motor size group *s* based on payback period acceptance assumptions, and

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

$ReplacePayBack_s$ is defined above.

The number of failed motors is given by

$$FailedMotors_{i,s,r,y} = MotorStock_{i,s,r,y-1} * FailurePct_{i,s} \tag{97}$$

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

$$RepMotorFlow_s = FailedMotors_s * ReplaceAccept_s \tag{98}$$

where

$RepMotorFlow_s$ = Number of new motors purchased to replace failed motors in motor size group *s* based on payback period acceptance assumptions.

$Failed\ Motors_s$ and $ReplaceAccept_s$ are defined above.

Motor stock changes are then summarized as

$$TotalMotorFlow_s = MotorStock_{s,y-1} * IndShipGr + RepMotorFlow_s \tag{99}$$

where

$TotalMotorFlow_s$ = New motors purchased for motor size group *s*, and

$IndShipGr$ = Growth from previous year in industrial value of shipments.

$MotorStock_{s,y-1}$ and $RepMotorFlow_s$ are defined above.

The new motor stock is then

$$\begin{aligned} MotorStock_s &= MotorStock_{s,y-1} - FailedMotors_s \\ &+ RewoundMotors_s + TotalMotorFlow_s \end{aligned} \tag{100}$$

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

$$RewoundMotors_s = FailedMotors_s * RepMotFlow_s \tag{101}$$

where

$RewoundMotors_s$ = Number of motors rewound for motor size group *s*.

$FailedMotors_{s,y-1}$ and $RepMotorFlow_s$ 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

$$RewoundEff_s = MotAvgEff_{s,y-1} - MotRewDrop_s \tag{102}$$

where

$RewoundEff_s$ = The efficiency of rewound motors for motor size group *s*, and

$MotRewDrop_s$ = The user-specified drop in efficiency for rewound motors in motor size group *s*.

$MotAvgEff_s$ is defined above.

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

$$NewMotorEff_s = \left(PEPctEff_s {*} PremMotorFlow_s\right)/RepMotFlow_s \tag{103}$$

where

$NewMotorEff_s$ = The average efficiency of new motors for motor size group *s*.

$PEPctEff_s$, $PremMotorFlow_s$, and $RepMotFlow_s$ are defined above.

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

$$NewMotorEnergy_s = MotAdjEnergy_{s,y-1} {*} \left(1 - \frac{\left(NewMotorEff_s - MotAvgEff_{s,y-1}\right)}{NewMotorEff_s}\right) \tag{104}$$

where

$NewMotorEnergy_s$ = The average energy consumed by new motors for motor size group *s* in kWh per motor per year, and

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

$NewMotorEff_s$ and $MotAvgEff_{s,y-1}$ are defined above.

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

$$RewMotorEnergy_s = MotAdjEnergy_{s,y-1} {*} \left(1 - \frac{\left(RewoundEff_s - MotAvgEff_{s,y-1}\right)}{RewoundEff_s}\right) \tag{105}$$

where

$RewMotorEnergy_s$ = The average energy consumed by rewound motors for motor size group *s* in kWh per motor per year, and

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

$RewoundEff_s$ and $MotAvgEff_{s,y-1}$ are defined above.

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

$$MotAvgEnergy_s = \frac{\begin{pmatrix} MotAdjEnergy_{s,y-1}* \\ \left(MotorStock_{s,y-1} - FailedMotors_s\right) \\ + \left(TotalMotorFlow_s * NewMotorEnergy_s\right) \\ + \left(RewoundMotors_s * RewMotorEnergy_s\right) \end{pmatrix}}{MotorStock_s} \tag{106}$$

where

$MotAvgEnergy_s$ = The average energy consumed by all motors for motor size group *s* in kWh per motor per year, and

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

$MotorStock_{s,y-1}$, $FailedMotors_s$, $TotalMotorFlow_s$, $NewMotorEnergy_s$, $RewoundMotors_s$, $RewMotorEnergy_s$, and $MotAdjEnergy_{s,y-1}$ are defined above.

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

$$RewoundEff_s = MotAvgEff_{s,y-1} - MotRewDrop_s \tag{107}$$

where

$MotAvgEff_s$ = The average energy efficiency of motors for motor size group *s*.

$RewoundEff_s$ and $MotRewDrop_s$ 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 consumption savings rate:

$$SystemSavingsR_s = \frac{\begin{pmatrix} \left(PumpAppPct_s * PumpSavPct_s\right) \\ + \left(FanAppPct_s * FanSavPct_s\right) \\ + \left(CompAppPct_s * CompSavPct_s\right) \end{pmatrix}}{MotSysLife_s} \tag{108}$$

where

$SystemSavingsR_s$ = The overall savings rate from pump, fan, and compressor system efficiency improvements for motor size group *s*,

$PumpAppPct_s$ = Motor system efficiency applicability, percentage of pump systems in motor size group *s*,

$PumpSavPct_s$ = Motor system efficiency savings fraction for pump systems in motor size group *s*

$FanAppPct_s$ = Motor system efficiency applicability, percentage of fan systems in motor size group *s*,

$FanSavPct_s$ = Motor system efficiency savings fraction for fan systems in motor size group *s*,

$CompAppPct_s$ = Motor system efficiency applicability, percentage of compressor systems in motor size group *s*,

$CompSavPct_s$ = Motor system efficiency savings fraction for compressor systems in motor size group *s*, and

$MotorSysLife_s$ = Motor system efficiency improvement life in years for motors in 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:

$$MotAdjEnergy_s = MotAvgEnergy_s * (1 - SystemSavingsR_s) \tag{109}$$

where

$MotAdjEnergy_s$ = The adjusted average energy consumption of the motor stock for motor size group *s* in kWh per motor per year.

$MotorAvgEnergy_{s,\,y-1}$, and $SystemSavingsR_s$ are defined above.

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

$$TotalMotorEnergy_s = (MotorStock_s * MotorAveEnergy_s) * \frac{3412}{10^{12}} \tag{110}$$

where

$TotalMotorEnergy_s$ = The total motor energy consumption of the motor stock for motor size group *s* in trillion Btu per year.

$MotorStock_s$ and $MotorAvgEnergy_s$ are defined above.

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

$$TotalAdjMotorEnergy_s = (MotorStock_s * MotorAdjEnergy_s) * \frac{3412}{10^{12}} \tag{111}$$

where

$TotalAdjMotorEnergy_s$ = The total adjusted motor energy consumption of the motor stock for motor size group *s* in trillion Btu per year.

$MotorStock_s$ and $MotorAdjEnergy_s$ 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.

$$ENBQTY_{e,f} = \begin{pmatrix} EWeight*[EMPLX*ENBINT_{e,f}] \\ + PWeight*[ProdVX*ONBINT_{e,f}] \end{pmatrix} *BldPFac \tag{112}$$

where:

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

$EMPLX$ = Employment,
$ProdVX$ = Output,
$ENBINT_{e,f}$ = Employment unit energy consumption (Btu per employee) 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
$BldPfac$ = Effect of energy price increases on buildings energy consumption.

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

$$BldPFac = BldPRat^{BldElas} \tag{113}$$

where

$BldPRat$ = Ratio of current year's average industrial energy price to 2006 price, and
$BldElas$ = Assumed elasticity, currently -0.5.

CALGEN

Subroutine CALGEN accounts for electricity generation from cogeneration. It combines estimated existing and planned cogeneration with new projected cogeneration based on an endogenous economic and engineering evaluation. The subroutine estimates market penetration of new (not currently planned) 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 based on total generation and the shares of sales to the grid reported on Form EIA-860B data.[33]

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.[34]

$$STEMCUR = ENBQTY_{hvac,steam} + ENPIQTY_{steam} \tag{114}$$

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:

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[33] 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.

[34] 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.

$$NonCogSteam = STEMCUR - CogSteam \tag{115}$$

where

$NonCogSteam$ = Non-cogenerated steam based on existing cogeneration capacity,
$STEMCUR$ = Total steam demand, and
$CogSteam$ = Steam met by existing cogeneration units as of the last data year.

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

$$AggSteamLoad_{loadsegment} = NonCogSteam * SteamSeg_{loadsegment} \tag{116}$$

where

$AggSteamLoad_{loadsegment}$ = Steam demand for a given load segment,
$NonCogSteam$ = Non-cogenerated steam based on existing cogeneration capacity, and
$SteamSeg_{loadsegment}$ = 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, 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 8,760 operating hours per year and converting from trillions to millions of Btu per hour:

$$AveHourlyLoad_{loadsegment} = \frac{AggSteamLoad_{loadsegment}}{0.008760} \tag{117}$$

The maximum technical potential for cogeneration is calculated assuming all non-cogeneration steam demand 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:

$$TechPot_{loadsegment} = AvgHourlyLoad_{loadsegement} * PowerSteam_{isys} \tag{118}$$

where

$TechPot_{loadsegment}$ = Technical potential for cogeneration, in megawatts, for a load segment, 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 for cogeneration is estimated from the technical potential by applying the estimated fraction of that potential that will be realized over an extended time period, based on market acceptance criteria (as applied in subroutine EvalCogen):

$$EconPot_{loadsegement} = TechPot_{loadsegment} * EconFrac_{loadsegment} \tag{119}$$

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:

$$CapAddMW_{loadsegment} = EconPot_{loadsegment} * PenetrationRate \tag{120}$$

where

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

$EconPot_{loadsegment}$ = 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.

Based on the results of a study performed for EIA[35], which includes cogeneration system cost and performance characteristics, 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 as follows:

$$COGGEN_{d,ngas} = COGGEN_{d,ngas} + CAPADDGWH * DSHR \tag{121}$$

$$COGCAP_{d,ngas} = COGCAP_{d,ngas} + CAPADDGWH * DSHR \tag{122}$$

$$COGTHR_{d,ngas} = COGTHR_{d,ngas} + STMADDTRIL * DSHR \tag{123}$$

$$\begin{aligned} COGELF_{d,ngas} &= COGELF_{d,ngas} \\ &\quad + \left(\left(CAPADDGWH*AVEHTRT \middle/ 10^6 \right) - \left(STMADDTRIL \middle/ 0.8 \right) \right) *DSHR \end{aligned} \tag{124}$$

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

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[35] SENTECH Inc., *Commercial and Industrial CHP Technology Cost and Performance Data for EIA*, report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, June 2010.

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:

$$BIO = Max\left(0, \frac{BioAvail - BioAvail_{y-1}}{HeatRate}\right) \tag{125}$$

where

$BioAvail$ = Biomass available for generation,

$BioAvail_{y-1}$ = Biomass available 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):

$$COGGEN_{d,biomass} = COGGEN_{d,biomass} + BIO * DSHR \tag{126}$$

where

$COGGEN_{d,biomass}$ = Total biomass cogeneration by Census Division *d*, 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 IDM. 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 cogenerated electricity 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 $COGGRD_{d,f}$. 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-sales 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:

$$NEWGEN_{d,f} = CapAddGWH_{f} * DSHR \tag{127}$$

$$OLDGRD_{d,f} = COGGEN_{d,f} + COGGRD_{d,f} \tag{128}$$

$$NEWGRD_{d,f} = NEWGEN_{d,f} * COGGRDNEW_i \tag{129}$$

$$COGGRD_{d,f} = \frac{(OLDGRD_{d,f} + NEWGRD_{d,f})}{(COGGEN_{d,f} + NEWGEN_{d,f})} \tag{130}$$

where

$NEWGEN_{d,f}$ = Generation from the capacity additions in the current year and fuel loop (*CapAddGWH*) equally shared (*DSHR*) to Census Divisions in a region,

$OLDGRD_{d,f}$ = Generation sold to the grid, prior to adjusting the sales and generation to reflect the new additions,

$NEWGRD_{d,f}$ = Portion of new capacity generation estimated for the current year and fuel loop (*NEWGEN*) sold to the grid, and

$COGGRDNEW_i$ = Assumed grid share by industry only.

$CapAddGWH_f$, *DSHR*, $COGGEN_{d,f}$, and $COGGRD_{d,f}$ are defined above.

Electricity generation for own use is then calculated as follows:

$$ELOWN = \sum_d \sum_f (COGGEN_{d,f} * COGGRD_{d,f}) \tag{131}$$

where

ELOWN = Electricity generation for own use.

$COGGEN_{d,f}$, and $COGGRD_{d,f}$ 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 as follows:

$$SteamLoad_{loadsegment} = AveBoilSize_{loadsegment} * EboilEff_{loadsegment} \tag{132}$$

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.

For each load segment, the model preselects a candidate cogeneration system with thermal output that roughly matches the steam output of the average-sized boiler in the load segment. The number of system/segment options is *nsys*, currently 8, with each system indicated by the subscript *isys*. The model relies on the following user-supplied set of characteristics for each cogeneration systems:

$CogSizeKW_{isys}$ = Net electric generation capacity in kilowatts,
$CogCapCostKW_{isys}$ = Total installed cost, in 2005 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.
≈ $CogSizeKW_{isys} * 0.003412 / PowerSteam_{isys}$
$disrate$ = Real discount rate, which is the 10-year Treasury bill rate adjusted for risk

For consistency the system number for each steam load segment is the same as 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):

$$SteamOutput_{isys} \leq SteamLoad_{loadsegment} < SteamOutput_{isys+1} \tag{133}$$

where

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

Next, the model estimates investment payback period ($Cpayback_{loadsegment}$) required to recover the prototypical cogeneration investment for each load segment. 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 performed in each annual model loop are as follows:

Determine annual fuel cost of the prototype cogeneration system in each load segment:

$$FuelCost_{loadsegment} = FuelUse_{isys} * CogFuelPrice \tag{134}$$

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

$$ExistFuelUse_{loadsegment} = \frac{SteamOutput_{isys} * 8.76 * CapFac_{isys}}{EboilEff_{loadsegment}} \quad (135)$$

$$ExistFuelCost_{loadsegment} = ExistFuelUse_{loadsegment} * CogFuelPrice \quad (136)$$

Determine incremental fuel cost and the value of cogenerated electricity:

$$IncrFuelCost_{loadsegment} = FuelCost_{loadsegment} - ExistFuelCost_{loadsegment} \quad (137)$$

$$ElecValue_{loadsegment} = ElecSizeMWh_{isys} * CogElecPrice * 0.003412 \quad (138)$$

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

$$OperProfit_{loadsegemnt} = ElecValue_{loadsegment} - IncrFuelCost_{loadsegment} \quad (139)$$

Determine the investment capital cost and the investment payback period:

$$Investment_{loadsegment} = CogSizeKW_{isys} * CogCapCostKW_{isys} \quad (140)$$

$$CPayBack_{loadsegment} = \frac{Investment_{loadsegment}}{OperProfit_{loadsegment} / (1 + disrate^{year})} \quad (141)$$

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

$$EconFrac_{loadsegment} = Acceptance\left(AcceptFrac, 13, CPayBack_{loadsegment}\right) \quad (142)$$

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 within an industry (*STEMCUR*). Steam demand and fuel consumption (in BTU) 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 estimated consumption of fuel for cogeneration is stored in two variables: fuel used to generate electricity (*COGELF*) and fuel 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:

$$FuelSys_f = \sum_d COGELF_{d,f} + (COGOTHR_{d,f} / 0.8) \qquad (143)$$

Conventional boiler fuel use is split between biomass-derived fuels and fossil fuels. The total available biomass is calculated as byproduct fuels ($BYPBSCR_{biofuel}$). Some of it is 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 estimated based on an assumed biomass boiler efficiency (0.65).

The steam demand 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. Allocating this total to specific 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. The model calibrates the fuel volumes to ensure that the sum of the cogeneration fuel and conventional boiler fuel (from Form 860b) equals the MECS indirect fuel estimate 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 (*BSCbsyr*) and the cogeneration (or CHP) fuel use from form 860B (*CHPbsyr*), and stores it in array *BOILBSYR*. A separate calibration is performed for biomass- and fossil-fueled boilers. The calibration factor for fossil-fuels is computed as follows in model year 2006:

$$\begin{aligned} Estimated &= NonCogFosSteam / 0.8 \\ Implied &= \sum_f BOILBSYR_f \\ CALIB2002\_FOS &= Implied / Estimated \end{aligned}$$

where

Estimated = Preliminary estimate of fossil fuel use from conventional boilers,
Implied = Conventional boiler fuel use,
$BOILBSYR_f$ = Ratio of MECS and form 860b for each boiler fuel *f*, and
CALIBBSYR_FOS = Calibration factor for conventional boiler fuel use.

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

$$NonCogFosFuel = \left(\frac{NonCogFosSteam}{0.8} \right) * \left(CALIBBSYR\_FOS \right) \qquad (144)$$

where

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

$NonCogFosSteam$ and $CALIBBSYR\_FOS$ are defined above.

Conventional boiler fuel use ($FuelFos_{steam}$) is allocated to fuels based on fuel shares adjusted for price changes since 2006. The fuel shares ($BSSHR$) are estimated in subroutine CALBSC:

$$FuelFos_{steam} = NonCogFosFuel * BSSSHR_{f} \tag{145}$$

The fossil fuels consumption for non-cogeneration boilers is added to cogeneration fuel consumption to yield total fuel consumption in the BSC component:

$$ENSQTY_{f} = CogBoilFuel_{f} + FosFuelSteam_{f} \tag{146}$$

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 estimate 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:

$$\begin{aligned} QTYMAIN_{f} = {} & ENPMQTY_{f} + ENBQTY_{total,f} \\ & + ENSQTY_{f} + BYPBSCM_{f} \end{aligned} \tag{147}$$

where

$QTYMAIN_f$ = Consumption of fuel f,
$ENPMQTY_f$ = 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.

For modeling purposes, consumption of electricity is defined as purchased electricity only; therefore, electricity generation for own use is removed from the consumption estimate as follows:

$$QTYMAIN_{elec} = ENPMQTY_{elec} + ENBQTY_{total,elec} - ELOWN \tag{148}$$

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 calculating all four Census Regions for an industry, NATTOTAL computes a national industry estimate of energy consumption. This subroutine also computes the consumption total over all fuel categories (main, intermediate, and renewable). Total consumption for the entire industrial sector for each main, intermediate, and renewable fuel is computed by accumulating across all industries:

$$TQMAIN_f = \sum_{i=1}^{INDMAX} QTYMAIN_f \tag{149}$$

where

$TQMAIN_f$ = Total consumption for fuel f,
$INDMAX$ = Number of industries, and
$QTYMAIN_f$ = Consumption of fuel f within the current industry calculation loop.

CONTAB

CONTAB reports 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.[36] Similar equations are used for the other industries.

$$FOODCON_f = \sum_{r=1}^{4} QTYMAIN_{r,f} \tag{150}$$

where

$FOODCON_f$ = Total national consumption of fuel in the food products industry,
NUM_f = Number of fuels in fuel category, and
$QTYMAIN_{r,f}$ = Consumption of fuel f for Census Region r in the food products industry.

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 vary over industry or 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*).

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

$$\begin{aligned}
CGINDCAP_{d,f,grid} &= \sum_{i}^{ind\max}\left(COGCAP_{d,i,f} * COGGRD_{d,i,f}\right)\\
CGINDCAP_{d,f,ownuse} &= \sum_{i}^{ind\max}\left(COGCAP_{d,i,f} * \left(1 - COGGRD_{d,i,f}\right)\right)\\
CGINDGEN_{d,f,grid} &= \sum_{i}^{ind\max}\left(COGGEN_{d,i,f} * COGGRD_{d,i,f}\right)\\
CGINDGEN_{d,f,ownuse} &= \sum_{i}^{ind\max}\left(COGGEN_{d,i,f} * \left(1 - COGGRD_{d,i,f}\right)\right)\\
CGINDQ_{d,f,grid} &= \sum_{i}^{ind\max}\left(COGELF_{d,i,f} * COGGRD_{d,i,f}\right)\\
CGINDQ_{d,f,ownuse} &= \sum_{i}^{ind\max}\left(COGELF_{d,i,f} * \left(1 - COGGRD_{d,i,f}\right)\right)
\end{aligned} \tag{151}$$

where

$CGINDCAP_{d,f,u}$ = Cogeneration capacity by Census Division *d*, fuel *f*, and use ,

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

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

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

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

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

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

WEXOG

WEXOG writes calculated industrial quantities to the NEMS exogenous variable array. Prior to assigning values to the NEMS variables, the model computes total industrial fuel consumption quantities. 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 that have consumption values greater than zero and are additive otherwise.

The equation for total industrial electricity consumption is below. Similar equations are used for all other fuels. Where appropriate, the summands include refinery consumption and oil and gas consumption included only where appropriate.[37]

$$BMAIN_{f} = TQMAIN_{f} + QELRF \tag{152}$$

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[37] 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.

where

$BMAIN_f$ = Total (industrial and refinery) consumption of fuel *f* (electricity),
$TQMAIN_f$ = IDM consumption of fuel *f* (electricity), and
$QELRF$ = Refinery consumption of fuel *f* (electricity).

The equation for total industrial natural gas consumption is:

$$BMAIN_f = TQMAIN_f + QNGRF + CGOGQ_s + CGOGQ_o \tag{153}$$

where

$BMAIN_f$ = Consumption of fuel *f* (natural gas),
$TQMAIN_f$ = Consumption of fuel *f* (natural gas),
$QNGRF$ = Consumption of natural gas from Refining,
$CGOGQ_s$ = Consumption of natural gas from cogeneration of electricity for sales to the grid in enhanced oil recovery *s*, input from Oil and Gas Module, and
$CGOGQ_o$ = Consumption of natural gas from cogeneration of electricity for own use in enhanced oil recovery *o*, input from Oil and Gas Module.

Total industrial consumption for other fuels is calculated similarly.

SEDS benchmark factors are calculated as follows:

$$SEDSBF_f = \frac{SEDS4_{f,d}}{BMAIN_f} \tag{154}$$

where

$SEDSBF_f$ = Current SEDS data year benchmark factors by fuel *f* and,
$SEDS4_{f,d}$ = Current SEDS data year consumption aggregated from the Census Division level *d* to the Census Region level by fuel *f*, and
$BMAIN_f$ = Total industrial consumption of fuel *f*.

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

$$BENCH_f = SEDSBF_f * BMAIN_f \tag{155}$$

where

$BENCH_f$ = Benchmarked total industrial consumption of fuel *f*.

$SEDSBF_f$ and $BMAIN_f$ are defined above.

STEO benchmark factors are calculated as follows:

$$STEOBF_f = \frac{STEO_f}{\sum_f \sum_r BENCH_f} \tag{156}$$

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),
$STEO_f$ = STEO projected industrial consumption by fuel *f* for each STEO projection year, and
$BENCH_f$ = Benchmarked total industrial consumption by fuel *f*.

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

$$FinalBENCH_f = STEOBF_f * BENCH_f \qquad (157)$$

To avoid a break in the series after the last STEO projection year, the STEO benchmark factors are incrementally decreased to one (zero impact) beginning in the first year after the STEO projection year through 2015.

Because most renewable fuel consumption occurs in the paper and lumber industries, the consumption shares for renewable fuels depend on the the paper and lumber industries:

$$DSRENW_{f,d} = \frac{OUTIND_{13,d} + OUTIND_{11,d}}{\sum_{d=1}^{NUM_r}\left(OUTIND_{13,d} + OUTIND_{11,d}\right)} \qquad (158)$$

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:

$$BENCHFAC_{bm,d} = \frac{BIOFUELS_d}{\sum_{f=2}^{3} DQRENW_{f,d}} \qquad (159)$$

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*.

The renewable fuel consumption estimated above is calculated as

$$DQRENW_{f,d} = TQRENW_{f,r} * DSRENW_{f,d} \qquad (160)$$

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* *within region r*.

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.

$$QELIN_d = BENCH_{elec} * SEDSHR_{elec,d} \tag{161}$$

where

$QELIN_d$ = Industrial consumption of electricity in Census Division *d*,
$BENCH_{elec}$ = Consumption of electricity, and
$SEDSHR_{elec,d}$ = SEDS share of electricity in Census Division *d*.

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

$$QGFIN_d = BENCH_{ngas} * SEDSHR_{ngas,d} * \left[\frac{TQMAIN_{cng} + TQMAIN_{fds}}{BMAIN_{ngas}} \right] \tag{162}$$

where

$QGFIN_d$ = Industrial consumption of core natural gas in Census Division *d*,
$BENCH_{ngas}$ = Benchmarked consumption of total natural gas,
$SEDSHR_{ngas,d}$ = SEDS share of natural gas in Census Division *d*,
$TQMAIN_{cng}$ = Consumption of core natural gas, from Subroutine NATTOTAL,
$TQMAIN_{fds}$ = Consumption of feedstock natural gas, from Subroutine NATTOTAL, and
$BMAIN_{ngas}$ = Total un-benchmarked (calculated) consumption of natural gas.

$$QGIIN_d = QNGIN_{ngas,d} - QGFIN_d \tag{163}$$

where

$QGIIN_d$ = Industrial consumption of non-core natural gas in Census Division *d*,
$QNGIN_{ngas,d}$ = Consumption of natural gas in Census Division *d*, and
$QGFIN_d$ = Industrial consumption of core natural gas in Census Division *d*.

Industrial consumption of biomass is calculated as follows:

$$QBMIN_d = \left[\sum_{f=2}^{3} DQRENW_{f,d} \right] + \left[\sum_{u=1}^{2} CGOGO_{d,bm,u} \right] + QBMRF_d \tag{164}$$

where

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

Division d.

Consumption of total renewable fuels is calculated by summing the consumption totals for the individual renewable fuel sources.

$$\begin{aligned} QTRIN_d &= QHOIN_d + QBMIN_d + QGEIN_d + QSTIN_d \\ &\quad + QPVIN_d + QWIIN_d + QMSIN_d \end{aligned} \tag{165}$$

where

$QTRIN_d$ = Total industrial consumption of renewable fuels in Census Division d,
$QHOIN_d$ = Industrial consumption of hydropower in Census Division d,
$QBMIN_d$ = Industrial consumption of biomass in Census Division d,
$QGEIN_d$ = Industrial consumption of geothermal in Census Division d,
$QSTIN_d$ = Industrial consumption of solar thermal in Census Division d,
$QPVIN_d$ = Industrial consumption of photovoltaic in Census Division d,
$QWIIN_d$ = Industrial consumption of wind in Census Division d, and
$QMSIN_d$ = Industrial consumption of municipal solid waste in Census Division d.

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 B 14). The retirement rate is posited to be a positive function of energy prices. For years after 2006, *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 2006.

$$X = RetirePrat^{RetireBeta}$$

$$RetirePriceFactor = \frac{X}{(1+X)} \qquad (166)$$

$$RetireRate_s = 2*RetirePriceFactor*ProdRetr_s$$

where

$RetirePrat$ = Maximum (1, Ratio of current year average industrial energy price to 2006 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*.

$$PRODCUR_{old,s} = (PRODCUR_{old,s} + IDLCAP_{old,s})*(1 - RetireRate_s) \qquad (167)$$

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*.

$$PRODCUR_{mid,s} = PRODCUR_{mid,s} + PRODCUR_{new,s} \qquad (168)$$

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.

$$PRODX = PHDRAT * PRODVX \qquad (169)$$

where

$PRODX$ = Value of output in physical units,
$PHDRAT$ = Ratio of physical units to value of output (by industry but not region), and
$PRODVX$ = Output in dollars.

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:

$$(\mathbf{I}-\mathbf{A}) * \mathbf{X} = \mathbf{D} \tag{170}$$

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

$$\mathbf{X} = (\mathbf{I}-\mathbf{A})^{-1} * \mathbf{D} \tag{171}$$

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 ($\mathbf{I}$-$\mathbf{A_{old}}$) and ($\mathbf{I}$-$\mathbf{A_{new}}$) 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:

$$\begin{gathered}\mathbf{X_{tot}} = \mathbf{X_{surv}} + \mathbf{X_{new}} \\ \textit{or} \\ \mathbf{X_{tot}} = \mathbf{X_{old}} - \mathbf{X_{ret}} + \mathbf{X_{new}}\end{gathered} \tag{172}$$

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

$$\begin{gathered}\mathbf{IA_{old}} * \mathbf{X_{old}} = \mathbf{D}_{2006} \\ \textit{or} \\ \mathbf{X_{old}} = \mathbf{IA_{old}}^{-1} * \mathbf{D}\end{gathered} \tag{173}$$

$\mathbf{X_{new}}$ 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:

$$\mathbf{X}_{\mathbf{ret}} = \mathbf{X}_{\mathbf{old}} * (1 - R)^{(Year-2006)} \tag{174}$$

$$\mathbf{X}_{\mathbf{surv}} = \mathbf{X}_{\mathbf{old}} - \mathbf{X}_{\mathbf{ret}} \tag{175}$$

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

$$\mathbf{D}_{\mathbf{old}} = \mathbf{IA}_{\mathbf{old}} * \mathbf{X}_{\mathbf{surv}} \tag{176}$$

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

$$\mathbf{IA}_{\mathbf{old}} * \mathbf{X}_{\mathbf{surv},\text{ year}} + \mathbf{IA}_{\mathbf{new}} * \mathbf{X}_{\mathbf{new},\text{ year}} = \mathbf{D}_{\text{year}} \tag{177}$$

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

$$\mathbf{IA}_{\mathbf{new}} * \mathbf{X}_{\mathbf{new,year}} = \mathbf{D}_{\mathbf{year}} - \mathbf{IA}_{\mathbf{old}} * \mathbf{X}_{\mathbf{surv,year}} \tag{178}$$

Therefore,

$$\mathbf{X}_{\mathbf{new,year}} = \mathbf{IA}_{\mathbf{new}}^{\mathbf{-1}} * (\mathbf{D}_{\mathbf{year}} - \mathbf{IA}_{\mathbf{old}} * \mathbf{X}_{\mathbf{surv,year}}) \tag{179}$$

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 $\mathbf{IA}_{\mathbf{new}}^{\mathbf{-1}}$, followed by calls to intrinsic matrix multiplication functions to solve for $\mathbf{X}_{\mathbf{new}}$. 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.

$$ENPINT_{v,f,s} = ENPINTLAG_{v,f,s} * (1 + TPCRate_v) \tag{180}$$

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, $BCSC_{v,f,s}$.

$$\begin{aligned} X &= TPCPrat^{TPCBeta} \\ TPCPriceFactor &= \frac{X}{(1+X)} \\ TPCRate_v &= 2*TPCPriceFactor*BCSC_{v,f,s} \end{aligned} \tag{181}$$

where

TPCPrat = Ratio of current year average industrial energy price to 2006 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 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:

$$ENPINT_{mid,f,s} = \frac{SUMPINT_{f,s}}{CUMPROD_{new,s}} \qquad (182)$$

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 fuel 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 calculation because they are assumed to be consumed first. The boiler fuel sharing equation for each manufacturing industry is as follows:

$$ShareFuel_f = \frac{\left(P_f^{\alpha_i} \beta_f\right)}{\sum_{f=1}^{3} P_f^{\alpha_i} \beta_f} \qquad (183)$$

where

$ShareFuel_f$ = Boiler fuel share for fuel *f*,

P_f = Fuel price relative to the 2006 price for fuel *f*,

α_f = Sensitivity parameter for fuel *f*, default value is -2.0, and

$BCSC_{v,f,s}$ = Fuel chares calibrated to 2006 using relative prices that prevailed in that year.

The fuels (*f*) 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 B 1. Building Component Energy Consumption, Part 1 (trillion Btu)

		Lighting	Heating, Ventilation, and Air Conditioning		
	Region	Electricity	Electricity	Natural Gas	Steam
Food	NE	1.496	1.654	1.744	1.201
	MW	8.269	9.140	14.949	5.293
	SO	6.458	7.138	8.702	5.996
	WE	3.544	3.917	6.980	4.809
Paper	NE	1.577	1.774	2.599	0.000
	MW	3.655	4.112	2.878	0.000
	SO	8.671	9.755	9.500	0.000
	WE	3.870	4.354	2.924	0.000
Bulk Chem.	NE	0.999	1.307	1.621	0.000
	MW	2.919	3.820	4.201	0.000
	SO	11.074	14.487	11.470	0.000
	WE	1.123	1.469	1.694	0.000
Glass	NE	0.366	0.312	3.415	0.000
	MW	1.207	1.028	5.837	0.000
	SO	1.099	0.936	6.071	0.000
	WE	0.320	0.273	3.140	0.000
Cement	NE	0.243	0.364	0.748	0.000
	MW	0.534	0.801	0.707	0.000
	SO	0.728	1.092	0.823	0.000
	WE	0.486	0.728	0.635	0.000
Steel	NE	1.049	0.750	2.605	0.000
	MW	2.825	2.018	8.763	0.000
	SO	2.744	1.960	3.568	0.000
	WE	0.444	0.317	1.273	0.000
Aluminum	NE	0.354	0.236	0.585	0.000
	MW	0.492	0.328	1.076	0.000
	SO	1.870	1.247	2.776	0.000
	WE	0.276	0.184	0.410	0.000
Fab. Metal	NE	1.780	1.780	4.688	3.971
	MW	5.934	5.934	18.723	15.859
	SO	4.747	4.747	11.861	10.046
	WE	1.780	1.780	2.535	2.147
Machinery	NE	2.516	3.931	5.113	3.010
	MW	9.472	14.801	18.976	11.169
	SO	3.700	5.781	9.058	5.331
	WE	0.740	1.156	0.957	0.563
Computer	NE	2.030	4.798	4.418	3.855
	MW	1.672	3.951	4.581	3.997
	SO	3.105	7.338	4.178	3.646
	WE	4.299	10.160	7.402	6.459
Trans. Equip.	NE	3.458	4.531	11.564	0.863
	MW	15.185	19.898	56.199	4.193
	SO	7.968	10.441	14.106	1.052
	WE	2.706	3.546	5.977	0.446
Electrical	NE	0.575	0.690	0.657	0.509
	MW	1.725	2.070	2.413	1.870
	SO	2.530	3.036	4.754	3.684
	WE	0.230	0.276	0.462	0.358

Wood Prod.	NE	0.480	0.343	0.480	0.935
	MW	2.079	1.485	2.972	5.790
	SO	3.278	2.342	1.885	3.672
	WE	1.439	1.028	1.694	3.300
Plastic	NE	2.029	2.536	4.346	0.000
	MW	6.968	8.710	9.645	0.000
	SO	5.909	7.387	11.210	0.000
	WE	1.147	1.433	0.806	0.000
BOM/Other	NE	5.715	8.822	14.900	0.000
	MW	16.729	25.821	23.108	0.000
	SO	21.370	32.985	43.672	0.000
	WE	3.984	6.149	11.065	0.000

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010

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

		Facility Support				On-site Transportation			
	Region	Elec.	Nat. Gas	Distillate	LPG	Elec.	Nat. Gas	Distillate	LPG
Food	NE	0.473	0.475	0.046	0.021	0.079	0.013	0.381	0.086
	MW	2.611	4.276	0.030	0.086	0.435	0.114	0.254	0.360
	SO	2.039	2.447	0.061	0.086	0.340	0.065	0.508	0.360
	WE	1.119	1.944	0.107	0.086	0.187	0.052	0.888	0.360
Paper	NE	0.394	0.148	0.021	0.115	0.099	0.035	0.266	1.440
	MW	0.914	0.173	0.021	0.058	0.228	0.041	0.266	0.720
	SO	2.168	0.569	0.170	0.115	0.542	0.136	2.130	1.440
	WE	0.967	0.191	0.064	0.058	0.242	0.046	0.799	0.720
Bulk Chem.	NE	0.544	0.067	0.278	0.237	0.171	0.009	0.666	1.026
	MW	1.588	0.490	0.397	0.607	0.499	0.065	0.952	2.632
	SO	6.024	3.050	1.183	0.383	1.893	0.402	2.840	1.658
	WE	0.611	0.103	0.278	0.260	0.192	0.014	0.666	1.128
Glass	NE	0.109	0.130	0.480	1.440	0.109	0.000	0.960	1.440
	MW	0.358	0.439	0.480	1.440	0.358	0.000	0.960	1.440
	SO	0.326	0.469	0.480	1.440	0.326	0.000	0.960	1.440
	WE	0.095	0.095	0.480	1.440	0.095	0.000	0.960	1.440
Cement	NE	0.121	0.003	0.026	0.480	0.029	0.000	0.213	0.480
	MW	0.267	0.120	0.107	0.480	0.064	0.000	0.889	0.480
	SO	0.364	0.072	0.213	0.480	0.087	0.000	1.778	0.480
	WE	0.243	0.048	0.107	0.480	0.058	0.000	0.889	0.480
Steel	NE	0.150	0.150	0.000	0.480	0.036	0.000	0.160	0.480
	MW	0.404	0.580	0.000	0.480	0.097	0.000	1.333	0.480
	SO	0.392	0.215	0.000	0.480	0.094	0.000	0.667	0.480
	WE	0.063	0.055	0.000	0.480	0.015	0.000	0.160	0.480
Aluminum	NE	0.118	0.114	0.058	0.071	0.028	0.027	0.058	0.071
	MW	0.164	0.237	0.058	0.071	0.039	0.057	0.058	0.071
	SO	0.623	0.605	0.058	0.298	0.150	0.145	0.058	0.298
	WE	0.092	0.070	0.058	0.071	0.022	0.017	0.058	0.071
Fabricated Metals	NE	0.381	0.249	0.032	0.015	0.031	0.030	0.134	0.191
	MW	1.272	1.038	0.032	0.127	0.102	0.125	0.134	1.590
	SO	1.017	0.626	0.134	0.127	0.081	0.075	0.560	1.590

	WE	0.381	0.137	0.070	0.015	0.031	0.016	0.291	0.191
Machinery	NE	0.472	0.158	0.029	0.021	0.157	0.038	0.029	0.086
	MW	1.776	0.585	0.120	0.086	0.592	0.140	0.120	0.360
	SO	0.694	0.256	0.029	0.131	0.231	0.061	0.029	0.547
	WE	0.139	0.024	0.029	0.021	0.046	0.006	0.029	0.086
Computers	NE	1.107	0.051	0.071	0.480	0.044	0.000	0.071	0.480
	MW	0.912	0.057	0.071	0.480	0.036	0.000	0.071	0.480
	SO	1.693	0.051	0.071	0.480	0.068	0.000	0.071	0.480
	WE	2.345	0.097	0.071	0.480	0.094	0.000	0.071	0.480
Electrical Equipment	NE	0.835	0.392	0.021	0.015	0.119	0.031	0.086	0.127
	MW	3.665	1.971	0.086	0.127	0.524	0.158	0.360	1.060
	SO	1.923	0.477	0.086	0.064	0.275	0.038	0.360	0.530
	WE	0.653	0.208	0.066	0.015	0.093	0.017	0.274	0.127
Transportation Equipment	NE	0.230	0.018	0.000	0.000	0.028	0.018	0.000	0.298
	MW	0.690	0.070	0.000	0.000	0.083	0.070	0.000	0.298
	SO	1.012	0.140	0.000	0.000	0.121	0.140	0.000	0.298
	WE	0.092	0.012	0.000	0.000	0.011	0.012	0.000	0.298
Wood Products	NE	0.069	0.017	0.016	0.014	0.016	0.017	0.677	0.173
	MW	0.297	0.111	0.065	0.101	0.071	0.111	2.709	1.267
	SO	0.468	0.066	0.081	0.115	0.112	0.066	3.387	1.440
	WE	0.206	0.051	0.081	0.058	0.049	0.051	3.387	0.720
Plastic & Rubber Products	NE	0.634	0.344	0.111	0.125	0.127	0.041	0.111	1.040
	MW	2.177	0.802	0.021	0.050	0.435	0.096	0.021	0.419
	SO	1.847	0.851	0.107	0.050	0.369	0.102	0.107	0.419
	WE	0.358	0.065	0.021	0.026	0.072	0.008	0.021	0.218
BOM	NE	1.768	0.575	0.000	0.000	0.000	0.000	1.857	0.000
	MW	5.176	0.892	0.000	0.000	0.000	0.000	1.289	0.000
	SO	6.611	1.686	0.000	0.000	0.000	0.000	2.089	0.000
	WE	1.232	0.427	0.000	0.000	0.000	0.000	0.861	0.000

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010

Table B 3. Food Industry National UECs, 2006

(Thousand Btu/2005$ of Shipments, Unless Otherwise Indicated)

End Use	Shipments (Billion 2005$)	Electricity	Natural Gas	Residual	Distillate	LPG	Coal	Steam
Direct Heat	541.2	0.031	0.392	0.000	0.004	0.001	0.021	0.877
Refrigeration	541.2	0.133	0.006	0.000	0.000	0.000	0.000	0.000
Machine Drive	541.2	0.247	0.021	0.000	0.006	0.001	0.000	0.000
Other	541.2	0.004	0.019	0.000	0.002	0.000	0.000	0.000

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010.

Table B 4. Pulp and Paper Industry National UECs, 2006

(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Resid	Distillate	LPG	Coal	Steam	Byproduct Produced
Wood Preparation	102.0	0.249	0.000	0.000	0.000	0.000	0.000	0.000	3.266
Pulping									
Waste	47.2	1.246	0.000	0.000	0.000	0.000	0.000	1.138	0.000
Mech.	4.8	4.965	0.000	0.000	0.000	0.000	0.000	0.407	0.000
Semi-chem.	3.8	1.338	0.000	0.000	0.000	0.000	0.000	4.377	0.000
Kraft	51.2	1.338	1.374	0.252	0.039	0.015	0.080	9.401	16.466
Bleaching	52.4	0.277	0.000	0.000	0.000	0.000	0.000	4.617	0.000
Paper making	96.6	1.532	0.830	0.144	0.021	0.010	0.050	5.515	0.000

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010.

Table B 5. Bulk Chemical Industry Total and Sub-total National UECs, 2006

(Thousand Btu/2005$ of Shipments, Unless Otherwise Indicated)

	Shipments (Billion 2005$)	**Electricity**	**Natural Gas**	**Residual**	**Distillate**	**LPG**	**Coal**	**Steam**	**Petrochemical Feedstocks**
Bulk Chemicals Total									
End Use									
Direct Heat	320.7	0.576	2.112	0.042	0.012	0.169	0.021	4.272	0.000
Refrigeration	320.7	0.002	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	320.7	1.152	0.034	0.000	0.003	0.001	0.000	0.000	0.000
Electrolytic	320.7	0.162	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	320.7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Feedstocks	320.7	0.000	1.731	0.000	0.000	6.075	0.000	0.000	4.426
Inorganic									
End Use									
Direct Heat	37.3	0.097	1.695	0.045	0.093	0.002	0.088	1.826	0.000
Refrigeration	37.3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	37.3	6.553	0.000	0.000	0.013	0.002	0.000	0.000	0.000
Electrolytic	37.3	1.397	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	37.3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Feedstocks	37.3	0.000	8.561	0.000	0.000	0.000	0.000	0.000	0.000
Organic									
End Use									
Direct Heat	154.6	1.010	3.151	0.070	0.001	0.351	0.011	6.320	0.000
Refrigeration	154.6	0.004	0.006	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	154.6	0.140	0.009	0.000	0.000	0.000	0.000	0.000	0.000
Electrolytic	154.6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	154.6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Feedstocks	154.6	0.000	0.139	0.000	0.000	12.602	0.000	0.000	9.181
Resins									
End Use									
Direct Heat	102.3	0.056	0.432	0.004	0.001	0.000	0.009	1.058	0.000
Refrigeration	102.3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	102.3	0.823	0.023	0.001	0.001	0.001	0.000	0.000	0.000
Electrolytic	102.3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	102.3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Feedstocks	102.3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Agricultural Chemicals									
End Use									
Direct Heat	26.5	0.730	3.125	0.023	0.003	0.000	0.023	8.172	0.000
Refrigeration	26.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	26.5	0.730	0.273	0.000	0.008	0.000	0.000	0.000	0.000
Electrolytic	26.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	26.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Feedstocks	26.5	0.000	8.095	0.000	0.000	0.000	0.000	0.000	0.000

Source: Calculated based on values reported in Table B26

Table B 6. Glass Products Industry National UECs, 2006

(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Residual	Distillate	LPG	Steam
Virgin							
Batch Prep	16.3	0.240	0.000	0.000	0.000	0.000	0.000
Melting/Refining	16.3	0.567	5.309	0.032	0.398	0.460	0.643
Scrap							
Batch Prep	2.3	0.207	0.000	0.000	0.000	0.000	0.000
Melting/Refining	2.3	0.458	4.248	0.026	0.319	0.368	0.611
Forming	19.0	1.058	1.636	0.010	0.123	0.142	0.193
Post-Forming	19.0	0.458	1.924	0.012	0.144	0.167	0.225

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010.

Table B 7. Cement Industry National UECs, 2006

(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Residual	Distillate	LPG	Coal	Coke	Steam
Dry Process	70.0	0.216	0.195	0.009	0.029	0.000	2.349	0.051	0.000
Wet Process	20.3	0.197	0.237	0.030	0.036	0.000	3.263	0.065	0.290
Finish Grinding	99.3	0.207	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010.

Table B 8. Iron and Steel Industry National UECs, 2006

(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Resid	Distillate	Coal	Coke	Steam	Byproduct Consumed
Coke Ovens	17.5	0.104	0.010	0.000	0.000	38.700	0.000	0.570	2.083
Iron & Steel making									
BOF	52.2	0.217	1.650	0.035	0.000	0.690	8.710	0.835	1.360
EAF	52.8	1.565	0.591	0.000	0.000	0.000	0.000	0.000	0.000
Casting									
Ingot	2.9	0.320	1.436	0.000	0.000	0.000	0.090	0.024	0.000
Continuous	102.3	0.094	0.253	0.000	0.000	0.000	0.000	0.008	0.000
Hot Rolling	110.1	0.377	1.300	0.000	0.000	0.000	0.000	0.016	0.040
Cold Rolling	41.0	0.849	1.436	0.000	0.004	0.000	0.000	1.051	0.000

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010.

Table B 9. Aluminum Industry National UECs, 2006

(Million Btu/Ton of Flow, Unless Otherwise Indicated)

Process Step	Flow (MMtons)	Electricity	Natural Gas	Distillate	LPG	Steam	Petroleum Coke
Alumina Refining	3.6	0.352	1.674	0.005	0.056	3.729	0.000
Primary Smelting	2.3	47.030	3.774	0.049	0.163	0.315	13.702
Secondary/Scrap	2.3	0.792	7.228	0.077	0.253	0.000	0.000
Semi-Fabrication							
Sheet, Plate, Foil	3.7	2.818	9.877	0.076	0.332	0.000	0.000
Other	1.7	2.994	5.367	0.054	0.188	0.000	0.000

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010.

Table B 10. Metal-Based Durables PA Component National UECs, 2006

(Thousand Btu/2005$ of Shipments, Unless Otherwise Indicated)

Industry	Ship-ments (Billion 2005$)	Elec-tricity	Natural Gas	Resid.	Distillate	LPG	Coal	Petroleum Coke	Steam
Fabricated Metals									
Heating	304.9	0.093	0.521	0.000	0.000	0.004	0.017	0.000	0.000
Refrigeration	304.9	0.017	0.003	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	304.9	0.251	0.003	0.000	0.001	0.000	0.000	0.000	0.000
Electrochemical	304.9	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	304.9	0.013	0.003	0.000	0.001	0.000	0.000	0.000	0.000
Machinery									
Heating	317.2	0.026	0.081	0.000	0.001	0.001	0.000	0.000	0.000
Refrigeration	317.2	0.010	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	317.2	0.135	0.001	0.000	0.001	0.001	0.000	0.000	0.000
Electrochemical	317.2	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	317.2	0.006	0.013	0.000	0.001	0.000	0.000	0.000	0.000
Computers and Electronics									
Heating	461.3	0.093	0.028	0.000	0.002	0.017	0.000	0.000	0.000
Refrigeration	461.3	0.093	0.005	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	461.3	0.068	0.002	0.000	0.002	0.017	0.000	0.000	0.000
Electrochemical	461.3	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	461.3	0.065	0.009	0.000	0.002	0.000	0.000	0.000	0.000
Electrical Equipment									
Heating	115.6	0.020	0.042	0.000	0.000	0.001	0.000	0.000	0.000
Refrigeration	115.6	0.004	0.002	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	115.6	0.157	0.000	0.000	0.000	0.001	0.000	0.000	0.000
Electrochemical	115.6	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	115.6	0.002	0.002	0.000	0.000	0.000	0.000	0.030	0.000
Transportation Equipment									
Heating	688.4	0.040	0.111	0.000	0.000	0.000	0.000	0.000	0.071
Refrigeration	688.4	0.018	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	688.4	0.112	0.004	0.000	0.002	0.000	0.000	0.000	0.000
Electrochemical	688.4	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	688.4	0.007	0.050	0.000	0.000	0.000	0.000	0.000	0.000

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010 and Office of Integrated Analysis and Forecasting estimates.

Table B 11. Other Manufacturing Sectors PA Component National UECs, 2006

(Thousand Btu/2005$ of Shipments, Unless Otherwise Indicated)

Industry	Ship-ments (Billion 2005$)	Elec-tricity	Natural Gas	Resid	Distillate	LPG	Coal	Petroleum Coke	Steam
Wood Products									
Heating	114.1	0.064	0.422	0.003	0.002	0.010	0.133	0.000	1.652
Refrigeration	114.1	0.009	0.004	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	114.1	0.499	0.018	0.003	0.018	0.002	0.000	0.000	0.000
Electrochemical	114.1	0.009	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	114.1	0.002	0.027	0.003	0.002	0.000	0.000	0.000	0.000
Plastic Products									
Heating	196.4	0.143	0.163	0.010	0.001	0.011	0.000	0.000	0.320
Refrigeration	196.4	0.082	0.001	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	196.4	0.501	0.016	0.000	0.001	0.001	0.000	0.000	0.000
Electrochemical	196.4	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	196.4	0.015	0.016	0.000	0.000	0.000	0.000	0.000	0.000
Balance of Manufacturing									
Heating	1056.2	0.064	0.367	0.009	0.004	0.000	0.057	0.000	1.000
Refrigeration	1056.2	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Machine Drive	1056.2	0.287	0.000	0.000	0.005	0.000	0.000	0.000	0.000
Electrochemical	1056.2	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Other	1056.2	0.006	0.015	0.001	0.001	0.000	0.010	0.000	0.000

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010 and Office of Integrated Analysis and Forecasting estimates.

Table B 12. Non-Manufacturing Sector PA Component National UECs, 2006

(Thousand Btu/2005$ of Shipments, Unless Otherwise Indicated)

Industry	Shipments (Billion 2005$)	Electricity	Natural Gas	Distillate	LPG	Motor Gasoline	Coal	Asphalt
Agri-Crops	112.6	0.528	0.861	1.553	0.336	0.612	0.000	0.000
Agri-Other	182.6	0.442	0.313	0.668	0.207	0.746	0.000	0.000
Coal Mining	26.8	1.154	0.226	1.280	0.000	0.189	0.131	0.000
Oil & Gas	464.7	0.147	0.000	0.085	0.000	0.057	0.000	0.000
Other Mining	37.8	2.512	4.220	1.072	0.000	0.265	0.177	0.000
Construction	1339.5	0.114	0.375	0.476	0.000	0.088	0.000	0.932

Notes: Natural gas excludes lease and plant fuel.
Sources: Calculated from data provided in U.S. Census Bureau, *Economic Census 2007: Mining Industry Series*; U.S. Census Bureau, *Economic Census 2007: Construction Industry Series*; and U.S. Department of Agriculture, *2007 Census of Agriculture*.

Table B 13. Regional Technology Shares (percent)

Industry	Technology	Census Region			
		Northeast	Midwest	South	West
Pulp and Paper	Kraft (incl. Sulfite)	9	7	72	12
	Semi-Chemical	2	40	52	6
	Mechanical	16	18	46	20
	Waste Fiber	18	28	39	15
	Bleaching	13	18	56	13
	Paper making	13	18	56	13
Cement	Wet Process	23	29	40	8
	Dry Process	8	28	36	28
	Clinker	11	28	37	24
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	41	31	18
	Semi-Fab: Sheet	19	22	55	4
	Semi-Fab: Other	15	33	38	14

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010.

Table B 14. 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 (%)	
Food Products						
Process Heating	0.883	-0.426	0.900	0.784	-0.477	1.7
Process Heating-Steam	0.780	-0.853	0.900	0.682	-0.953	1.7
Process Cooling-Electricity	0.855	-0.540	0.850	0.734	-0.506	1.7
Process Cooling-Natural Gas	0.883	-0.426	0.900	0.784	-0.477	1.7
Other-Electricity	0.900	-0.364	0.915	0.793	-0.493	1.7
Other-Natural Gas	0.883	-0.426	0.900	0.784	-0.477	1.7
Paper & Allied Products						
Wood Preparation	0.792	-0.802	0.882	0.701	-0.790	2.3
Waste Pulping-Electricity	0.936	-0.228	0.936	0.936	0.000	2.3
Waste Pulping-Steam	0.876	-0.456	0.936	0.936	0.000	2.3
Mechanical Pulping-Electricity	0.800	-0.767	0.931	0.622	-1.380	2.3
Mechanical Pulping-Steam	0.639	-1.533	0.931	0.413	-2.760	2.3
Semi-Chemical-Electricity	0.951	-0.173	0.971	0.930	-0.149	2.3
Semi-Chemical-Steam	0.904	-0.346	0.971	0.891	-0.297	2.3
Kraft, Sulfite, Misc. Chemicals	0.860	-0.519	0.914	0.810	-0.415	2.3
Kraft, Sulfite, Misc. Chemicals-	0.739	-1.037	0.914	0.718	-0.830	2.3

Bleaching-Electricity	0.780	-0.853	0.878	0.680	-0.878	2.3
Bleaching-Steam	0.607	-1.706	0.878	0.525	-1.756	2.3
Paper Making	0.869	-0.485	0.885	0.852	-0.132	2.3
Paper Making-Steam	0.976	-0.969	0.885	0.820	-0.264	2.3
Glass & Glass Products						
Batch Preparation-Electricity	0.941	-0.209	0.882	0.882	0.000	1.3
Melting/Refining	0.934	-0.235	0.900	0.868	-0.125	1.3
Melting/Refining-Steam	0.872	-0.470	0.900	0.837	-0.250	1.3
Forming	0.984	-0.056	0.982	0.968	-0.048	1.3
Forming-Steam	0.968	-0.111	0.982	0.955	-0.096	1.3
Post-Forming	0.978	-0.078	0.968	0.955	-0.045	1.3
Post-Forming-Steam	0.955	-0.157	0.968	0.943	-0.090	1.3
Cement						
Dry Process	0.885	-0.420	0.885	0.770	-0.479	1.2
Wet Process	0.944	-0.197	NA	NA	NA	1.2
Wet Process-Steam	0.892	-0.395	NA	NA	NA	1.2
Finish Grinding-Electricity	0.975	-0.087	0.950	0.950	0.000	1.2
Iron and Steel						
Coke Oven	0.935	-0.233	0.902	0.869	-0.128	2.5
Coke Oven-Steam	0.873	-0.467	0.902	0.837	-0.257	2.5
BF/BOF	0.994	-0.022	0.987	0.987	0.000	1.5
BF/BOF-Steam	0.987	-0.045	0.987	0.987	0.000	1.5
EAF	0.915	-0.308	0.990	0.830	-0.606	1.5
Ingot Casting/Primary Rolling	1.000	0.000	NA	NA	NA	2.9
Continuous Casting	1.000	0.000	1.000	1.000	0.000	2.9
Hot Rolling	0.816	-0.699	0.800	0.633	-0.804	2.9
Hot Rolling-Steam	0.665	-1.397	0.800	0.500	-1.608	2.9
Cold Rolling	0.717	-1.141	0.924	0.433	-2.580	2.9
Cold Rolling-Steam	0.512	-2.281	0.924	0.199	-5.160	2.9
Aluminum						
Alumina Refining	0.927	-0.262	0.900	0.854	-0.182	1.0
Alumina Refining-Steam	0.859	-0.524	0.900	0.809	-0.365	1.0
Primary Smelting	0.890	-0.401	0.950	0.780	-0.678	1.0
Primary Smelting-Steam	0.792	-0.802	0.950	0.640	-1.355	1.0
Secondary	0.868	-0.487	0.850	0.736	-0.495	1.0
Semi-Fabrication, Sheet	0.893	-0.389	0.900	0.786	-0.466	1.0
Semi-Fabrication, Other	0.918	-0.295	0.950	0.836	-0.440	1.0
Metal-Based Durables						
Fabricated Metals						
Process Heating	0.659	-1.427	0.675	0.400	-1.784	1.3
Process Cooling-Electricity	0.720	-1.127	0.638	0.365	-1.903	1.3
Process Cooling-Natural Gas	0.720	-1.127	0.675	0.413	-1.679	1.3
Other	0.720	-1.127	0.675	0.413	-1.679	1.3
Other-Electricity	0.720	-1.127	0.686	0.401	-1.834	1.3
Machinery						
Process Heating	0.659	-1.427	0.675	0.307	-2.676	1.3
Process Cooling-Electricity	0.720	-1.127	0.638	0.275	-2.855	1.3
Process Cooling-Natural Gas	0.720	-1.127	0.675	0.322	-2.519	1.3
Other	0.720	-1.127	0.675	0.322	-2.519	1.3

Other-Electricity	0.720	-1.127	0.686	0.306	-2.751	1.3
Computers and Electronics						
Process Heating	0.758	-0.952	0.720	0.555	-0.892	1.3
Process Cooling-Electricity	0.804	-0.751	0.680	0.515	-0.952	1.3
Process Cooling-Natural Gas	0.804	-0.751	0.720	0.564	-0.840	1.3
Other	0.804	-0.751	0.720	0.564	-0.840	1.3
Other-Electricity	0.804	-0.751	0.732	0.560	-0.917	1.3
Electrical Equipment						
Process Heating	0.758	-0.952	0.720	0.555	-0.892	1.3
Process Heating-Steam	NA	-1.502	NA	NA	-1.679	1.3
Process Cooling-Electricity	0.804	-0.751	0.680	0.515	-0.952	1.3
Process Cooling-Natural Gas	0.804	-0.751	0.720	0.564	-0.840	1.3
Other	0.804	-0.751	0.720	0.564	-0.840	1.3
Other-Electricity	0.804	-0.751	0.732	0.560	-0.917	1.3
Transportation Equipment						
Process Heating	0.824	-0.666	0.765	0.622	-0.714	1.3
Process Heating-Steam	0.736	-1.052	0.765	0.517	-1.343	1.3
Process Cooling-Electricity	0.858	-0.526	0.723	0.579	-0.761	1.3
Process Cooling-Natural Gas	0.858	-0.526	0.765	0.629	-0.672	1.3
Other	0.858	-0.526	0.765	0.629	-0.672	1.3
Other-Electricity	0.858	-0.526	0.778	0.628	-0.734	1.3
Other Non-Intensive Manufacturing						
Wood Products						
Process Heating	0.659	-1.427	0.630	0.374	-1.784	1.3
Process Heating-Steam	0.516	-2.253	0.630	0.234	-3.358	1.3
Process Cooling-Electricity	0.720	-1.127	0.595	0.341	-1.903	1.3
Process Cooling-Natural Gas	0.720	-1.127	0.630	0.386	-1.679	1.3
Other	0.720	-1.127	0.630	0.386	-1.679	1.3
Other-Electricity	0.722	-1.115	0.641	0.373	-1.845	1.3
Plastic Products						
Process Heating	0.758	-0.952	0.675	0.521	-0.892	1.3
Process Heating-Steam	0.645	-1.502	0.675	0.413	-1.679	1.3
Process Cooling-Electricity	0.804	-0.751	0.638	0.483	-0.952	1.3
Process Cooling-Natural Gas	0.804	-0.751	0.675	0.529	-0.840	1.3
Other	0.804	-0.751	0.675	0.529	-0.840	1.3
Other-Electricity	0.805	-0.743	0.686	0.525	-0.922	1.3
Balance of Manufacturing						
Process Heating	0.812	-0.714	0.675	0.548	-0.714	1.3
Process Heating-Steam	0.917	-0.300	0.900	0.781	-0.490	1.3
Process Cooling-Electricity	0.849	-0.563	0.638	0.511	-0.761	1.3
Process Cooling-Natural Gas	NA	-0.563	NA	NA	-0.672	1.3
Other-Natural Gas	0.849	-0.563	0.675	0.555	-0.672	1.3

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010.

Table B 15. 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	0.987	-0.045	0.876	-0.094
Process Heating-Steam	0.974	-0.091	0.852	-0.188
Process Cooling-Electricity	0.983	-0.057	0.826	-0.100
Process Cooling-Natural Gas	0.987	-0.045	0.876	-0.094
Other-Electricity	0.989	-0.039	0.890	-0.097
Other-Natural Gas	0.987	-0.045	0.876	-0.094
Paper & Allied Products				
Wood Preparation	0.990	-0.033	0.987	0.386
Waste Pulping-Electricity	0.954	-0.161	0.876	-0.228
Waste Pulping-Steam	0.954	-0.161	0.876	-0.228
Mechanical Pulping-Electricity	1.006	0.021	1.205	0.893
Mechanical Pulping-Steam	1.006	0.021	1.205	0.893
Semi-Chemical-Electricity	0.993	-0.025	0.956	-0.052
Semi-Chemical-Steam	0.993	-0.025	0.956	-0.052
Kraft, Sulfite, Misc. Chemicals	0.930	-0.249	0.790	-0.502
Kraft, Sulfite, Misc. Chemicals-Steam	0.930	-0.249	0.790	-0.502
Bleaching-Electricity	0.929	-0.252	0.912	0.129
Bleaching-Steam	0.929	-0.252	0.912	0.129
Paper Making	0.835	-0.621	0.592	-1.376
Paper Making-Steam	0.835	-0.621	0.592	-1.376
Glass & Glass Products				
Batch Preparation-Electricity	1.000	0.000	0.882	0.000
Melting/Refining	0.846	-0.576	0.601	-1.381
Melting/Refining-Steam	0.846	-0.576	0.601	-1.381
Forming	0.976	-0.085	0.933	-0.175
Forming-Steam	0.976	-0.085	0.933	-0.175
Post-Forming	0.990	-0.034	0.948	-0.069
Post-Forming-Steam	0.990	-0.034	0.948	-0.069
Cement				
Dry Process	0.870	-0.479	0.621	-1.216
Wet Process	0.931	-0.245	NA	NA
Wet Process-Steam	0.851	-0.554	NA	NA
Finish Grinding-Electricity	0.851	-0.554	0.660	-1.248
Iron and Steel				
Coke Oven	0.883	-0.429	0.659	-1.076
Coke Oven-Steam	0.883	-0.429	0.659	-1.076
BF/BOF	0.951	-0.172	0.885	-0.375
BF/BOF-Steam	0.951	-0.172	0.885	-0.375
EAF	0.904	-0.346	0.781	-0.813
Ingot Casting/Primary Rolling	1.000	0.000	NA	NA
Continuous Casting	1.000	0.000	1.000	0.000
Hot Rolling	0.905	-0.344	0.602	-0.978
Hot Rolling-Steam	0.905	-0.344	0.602	-0.978
Cold Rolling	0.948	-0.183	0.854	-0.273
Cold Rolling-Steam	0.948	-0.183	0.854	-0.273
Aluminum				
Alumina Refining	0.982	-0.063	0.865	-0.138
Alumina Refining-Steam	0.871	-0.476	0.635	-1.198

Primary Smelting	0.871	-0.476	0.670	-1.198
Primary Smelting-Steam	0.871	-0.476	0.670	-1.198
Secondary	0.933	-0.238	0.716	-0.590
Semi-Fabrication, Sheet	0.807	-0.735	0.512	-1.927
Semi-Fabrication, Other	0.874	-0.465	0.688	-1.109
Metal-Based Durables				
Fabricated Metals				
Process Heating	0.651	-1.468	0.337	-2.370
Process Cooling-Electricity	0.587	-1.820	0.307	-2.493
Process Cooling-Natural Gas	0.651	-1.468	0.337	-2.370
Other	0.651	-1.468	0.337	-2.370
Other-Electricity	0.689	-1.274	0.335	-2.439
Machinery				
Process Heating	0.651	-1.468	0.236	-3.555
Process Cooling-Electricity	0.587	-1.820	0.211	-3.740
Process Cooling-Natural Gas	0.651	-1.468	0.236	-3.555
Other	0.651	-1.468	0.236	-3.555
Other-Electricity	0.689	-1.274	0.233	-3.658
Computers and Electronics				
Process Heating	0.752	-0.979	0.510	-1.185
Process Cooling-Electricity	0.702	-1.213	0.473	-1.247
Process Cooling-Natural Gas	0.752	-0.979	0.510	-1.185
Other	0.752	-0.979	0.510	-1.185
Other-Electricity	0.781	-0.850	0.513	-1.219
Electrical Equipment				
Process Heating	0.752	-0.979	0.510	-1.185
Process Heating-Steam	NA	-1.957	NA	-2.370
Process Cooling-Electricity	0.702	-1.213	0.473	-1.247
Process Cooling-Natural Gas	0.752	-0.979	0.510	-1.185
Other	0.752	-0.979	0.510	-1.185
Other-Electricity	0.781	-0.850	0.513	-1.219
Transportation Equipment				
Process Heating	0.819	-0.685	0.580	-0.948
Process Heating-Steam	0.670	-1.370	0.439	-1.896
Process Cooling-Electricity	0.781	-0.849	0.540	-0.997
Process Cooling-Natural Gas	0.819	-0.685	0.580	-0.948
Other	0.819	-0.685	0.580	-0.948
Other-Electricity	0.841	-0.595	0.585	-0.975
Other Non-Intensive Manufacturing				
Wood Products				
Process Heating	0.654	-1.452	0.315	-2.358
Process Heating-Steam	0.426	-2.903	0.155	-4.716
Process Cooling-Electricity	0.590	-1.804	0.287	-2.481
Process Cooling-Natural Gas	0.654	-1.452	0.315	-2.358
Other	0.690	-1.272	0.330	-2.209
Other-Electricity	0.879	-0.443	0.318	-2.388
Plastic Products				
Process Heating	0.754	-0.968	0.479	-1.179
Process Heating-Steam	0.567	-1.936	0.338	-2.358
Process Cooling-Electricity	0.704	-1.203	0.444	-1.241
Process Cooling-Natural Gas	0.754	-0.968	0.479	-1.179
Other	0.781	-0.848	0.489	-1.104
Other-Electricity	0.918	-0.295	0.484	-1.194

Balance of Manufacturing				
Process Heating	0.810	-0.726	0.513	-0.943
Process Heating-Steam	0.894	-0.387	0.737	-0.688
Process Cooling-Electricity	0.769	-0.902	0.477	-0.992
Process Cooling-Natural Gas	NA	-0.726	NA	-0.943
Other-Natural Gas	0.831	-0.636	0.522	-0.883

Source: SAIC, *IDM Base Year Update with MECS 2006 Data*, unpublished data prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, August 2010.

Table B 16. 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		

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 section		1	

Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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		
		Chemical Boosting	1		
		Chimney Block Regenerator Refractories	1		

Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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 Techniques*	1		
		Improved Protective Coatings*	1		
		Mold Cooling Systems	1		

Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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		
		Blended Cements*	1		
		Catalyzed, Low-Temperature Calcination		1	
		Cone Crushers*	1		
		Differential Grinding	1		

Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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		
		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		

Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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		
		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		

Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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
		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	

Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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				
		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

Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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		
	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

Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		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
		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	1		1

Sector	Major Process Step	Technology	Improvement in Sub-process	Alternative Process	EERE
		Combustion			
		Ultra-Low Nox Burners with Flue Gas Recirculation and Partial Reformer	1		1
	Boilers				
		Forced Internal Recirculation Burner	1		1
		Super Boiler - including recovery of latent heat in flue gases		1	1
	Metals-based Durables				
		Lost Form Casting Technology		1	1

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

Table B 17. Industrial Motor Characteristics

Industrial Sector Horsepower Range	2006 Stock	2005 Average Energy Use (kWh/motor)	2005 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); USDOE, MotorMaster+ 4.0 software database, 2007; Energy Information Administration, *Manufacturing Consumption of Energy 2006*.

Table B 18. Cost and Performance Parameters for Industrial Motor Choice Model

Industrial Sector Horsepower Range	2006 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).

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 B 19. Payback Acceptance Rate Assumptions for Motor Decisions

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

Source: Energy Information Administration, Office Energy Analysis.

Table B 20. Energy Consumption in Boilers (trillion Btu)

Industry	Region	Alpha	Natural Gas	Coal	Oil	Renewables
Food Products	Northeast	-2.0	19	0	4	1
	Midwest	-2.0	168	109	12	22
	South	-2.0	96	11	12	52
	West	-2.0	76	14	4	4
Paper & Allied Products	Northeast	-2.0	41	40	16	80
	Midwest	-2.0	48	60	12	90
	South	-2.0	159	91	64	998
	West	-2.0	53	13	4	97
Bulk Chemicals	Northeast	-2.0	13	0	56	0
	Midwest	-2.0	97	37	18	0
	South	-2.0	605	31	384	0
	West	-2.0	20	21	6	0
Glass & Glass Products	Northeast	-2.0	2	0	3	10
	Midwest	-2.0	6	0	3	1
	South	-2.0	6	0	3	2
	West	-2.0	1	0	3	1
Cement	Northeast	-2.0	0	0	1	1
	Midwest	-2.0	1	0	1	5
	South	-2.0	0	0	1	3
	West	-2.0	0	0	1	3
Iron & Steel	Northeast	-2.0	4	6	20	0
	Midwest	-2.0	16	1	66	0
	South	-2.0	6	0	7	0
	West	-2.0	1	0	1	0
Aluminum	Northeast	-2.0	2	0	0	0
	Midwest	-2.0	4	0	0	0
	South	-2.0	11	0	0	0
	West	-2.0	1	0	0	0
Metal-Based Durables						
Fabricated Metal	Northeast	-2.0	5	0	0	0

Products						
	Midwest	-2.0	19	0	0	2
	South	-2.0	12	0	1	0
	West	-2.0	3	0	0	0
Machinery	Northeast	-2.0	3	0	1	0
	Midwest	-2.0	12	1	0	1
	South	-2.0	5	0	0	0
	West	-2.0	1	0	0	0
Computers & Electronic Products	Northeast	-2.0	4	0	1	0
	Midwest	-2.0	5	0	1	0
	South	-2.0	4	0	1	0
	West	-2.0	8	0	1	1
Electrical Equipment	Northeast	-2.0	5	8	3	7
	Midwest	-2.0	27	-3	1	5
	South	-2.0	7	1	3	4
	West	-2.0	3	0	0	0
Transportation Equipment	Northeast	-2.0	1	0	0	0
	Midwest	-2.0	2	0	0	0
	South	-2.0	4	0	0	0
	West	-2.0	0	0	0	0
Other Non-Intensive Manufacturing						
Wood Products	Northeast	-2.0	2	0	0	11
	Midwest	-2.0	12	1	1	40
	South	-2.0	7	0	1	123
	West	-2.0	5	0	2	48
Plastic Products	Northeast	-2.0	10	0	2	0
	Midwest	-2.0	23	0	0	0
	South	-2.0	25	10	6	0
	West	-2.0	2	0	0	0
Balance of Manufacturing	Northeast	-2.0	41	-11	18	1
	Midwest	-2.0	64	51	28	2
	South	-2.0	121	58	31	22
	West	-2.0	31	8	15	0

Note: Alpha is the parameter of the logistic switching function.
Source: Energy Information Administration, Office of Integrated Analysis and Forecasting estimates based on *Manufacturing Consumption of Energy 2006*.

Table B 21. 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 B 22. 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)**	**2010**	**2035**	**2010**	**2035**	**2010**	**2035**
1 Engine	1,000	1,440	576	9,097	9,097	0.806	0.893
2 Engine	2,000	1,260	396	9,394	9,394	0.832	0.918
3 Gas Turbine	3,510	1,719	1,496	13,893	13,893	0.760	0.780
4 Gas Turbine	5,670	1,152	1,023	12,254	12,254	0.772	0.785
5 Gas Turbine	14,990	982	869	10,945	10,945	0.769	0.777
6 Gas Turbine	25,000	987	860	9,945	9,948	0.707	0.729
7 Gas Turbine	40,000	875	830	9,220	9,222	0.721	0.741
8 Combined Cycle	100,000	723	684	6,736	6,337	0.704	0.730

Note: Cost given in constant 2005 dollars.

Source: SENTECH Inc., *Commercial and Industrial CHP Technology Cost and Performance Data for EIA*, report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, June 2010.

Table B 23. Characteristics of Candidate Combined Heat and Power Systems, High Technology Case

		Total Installed Cost per Kilowatt		Total Heat Rate (Btu per kWh)		Overall Efficiency	
System	**Size (kilowatts)**	**2010**	**2035**	**2010**	**2035**	**2010**	**2035**
1 Engine	1,000	1,398	535	8,586	9,097	0.844	0.931
2 Engine	2,000	1,218	354	9,145	9,394	0.843	0.930
3 Gas Turbine	3,510	1,673	1,450	13,751	13,893	0.761	0.781
4 Gas Turbine	5,670	1,135	1,006	11,996	12,254	0.774	0.787
5 Gas Turbine	14,990	982	869	10,833	10,945	0.772	0.780
6 Gas Turbine	25,000	987	860	9,842	9,948	0.709	0.731
7 Gas Turbine	40,000	875	830	9,125	9,222	0.727	0.747
8 Combined Cycle	100,000	716	668	6,667	6,143	0.709	0.744

Note: Cost given in constant 2005 dollars.

Source: SENTECH Inc., *Commercial and Industrial CHP Technology Cost and Performance Data for EIA*, report prepared for the Office of Integrated Analysis and Forecasting, Energy Information Administration, Washington, DC, June 2010.

Table B 24. Payback Acceptance Rate Assumptions for Cogeneration Market Penetration

Payback Period in Years	Acceptance Rate
0	100.00%
1	97.00%
2	86.00%
3	68.50%
4	51.50%
5	37.25%
6	25.00%
7	15.50%
8	8.50%
9	4.00%
10	1.50%
11	0.25%
12	0.00%

Source: Energy Information Administration, Office of Energy Analysis; Johnson Controls Inc., 2009 Energy Efficiency Indicator IFMA Summary Report (2009).

Table B 25. 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: 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 B 26. 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:

IDM

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 IDM 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 IDM generates long-term projections of industrial sector energy consumption. The IDM 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 2010.

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 2011.

Archive Media and Installation Manual(s):

The model is archived as part of the National Energy Modeling System production runs used to generate the *AEO2011*.

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, 2006 through 2035.

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 2006, June 2009

State Energy Data System 2008, June 2010

Annual Energy Review 2009, August 2010

Computing Environment:

Hardware Used: Intel Xeon CPU

Operating System: Microsoft Windows XP

Language/Software Used: Intel Visual FORTRAN 11.1

Estimated Run Time: 53 seconds for a 2006-2035 run in non-iterating, stand-alone mode.

Special Features: None

Appendix D. Descriptions of Major Industrial Groups and Selected Industries

This appendix contains descriptions of industrial groups and selected industries taken from the North American Industry Classification System (NAICS). This appendix includes general descriptions of the 15 manufacturing and 6 nonmanufacturing groups that comprise the industries modeled in the Industrial Demand Module. NAICS is the standard used by Federal statistical agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to the U.S. business economy.

NAICS 11 - The **Agriculture, Forestry, Fishing and Hunting** sector comprises establishments primarily engaged in growing crops, raising animals, harvesting timber, and harvesting fish and other animals from a farm, ranch, or their natural habitats.

The establishments in this sector are often described as farms, ranches, dairies, greenhouses, nurseries, orchards, or hatcheries. A farm may consist of a single tract of land or a number of separate tracts which may be held under different tenures. For example, one tract may be owned by the farm operator and another rented. It may be operated by the operator alone or with the assistance of members of the household or hired employees, or it may be operated by a partnership, corporation, or other type of organization. When a landowner has one or more tenants, renters, croppers, or managers, the land operated by each is considered a farm.

The sector distinguishes two basic activities: agricultural production and agricultural support activities. Agricultural production includes establishments performing the complete farm or ranch operation, such as farm owner-operators, tenant farm operators, and sharecroppers. Agricultural support activities include establishments that perform one or more activities associated with farm operation, such as soil preparation, planting, harvesting, and management, on a contract or fee basis.

NAICS 21 - The **Mining, Quarrying, and Oil and Gas Extraction** sector comprises establishments that extract naturally occurring mineral solids, such as coal and ores; liquid minerals, such as crude petroleum; and gases, such as natural gas. The term mining is used in the broad sense to include quarrying, well operations, beneficiating (e.g., crushing, screening, washing, and flotation), and other preparation customarily performed at the mine site, or as a part of mining activity.

The Mining, Quarrying, and Oil and Gas Extraction sector distinguishes two basic activities: mine operation and mining support activities. Mine operation includes establishments operating mines, quarries, or oil and gas wells on their own account or for others on a contract or fee basis. Mining support activities include establishments that perform exploration (except geophysical surveying) and/or other mining services on a contract or fee basis (except mine site preparation and construction of oil/gas pipelines).

Establishments in the Mining, Quarrying, and Oil and Gas Extraction sector are grouped and classified according to the natural resource mined or to be mined. Industries include establishments that develop the mine site, extract the natural resources, and/or those that beneficiate (i.e., prepare) the mineral mined. Beneficiation is the process whereby the extracted material is reduced to particles that can be separated into mineral and waste, the former suitable for further processing or direct use. The operations that take place in beneficiation are primarily mechanical, such as grinding, washing, magnetic separation, and centrifugal separation. In contrast, manufacturing operations primarily use chemical and electrochemical processes, such as electrolysis and distillation. However, some treatments, such as heat treatments, take place in both the beneficiation and the manufacturing (i.e., smelting/refining) stages. The range of preparation activities varies by mineral and the purity of any given ore deposit. While some minerals, such as petroleum and natural gas, require little or no preparation, others are washed and screened, while yet others, such as gold and silver, can be transformed into bullion before leaving the mine site.

NAICS 23 - The **Construction** sector comprises establishments primarily engaged in the construction of buildings or engineering projects (e.g., highways and utility systems). Establishments primarily engaged in the preparation of sites for new construction and establishments primarily engaged in subdividing land for sale as building sites also are included in this sector.

Construction work done may include new work, additions, alterations, or maintenance and repairs. Activities of these establishments generally are managed at a fixed place of business, but they usually perform construction activities at multiple project sites. Production responsibilities for establishments in this sector are usually specified in (1) contracts with the owners of construction projects (prime contracts) or (2) contracts with other construction establishments (subcontracts).

NAICS 311 - Industries in the **Food Manufacturing** subsector transform livestock and agricultural products into products for intermediate or final consumption. The industry groups are distinguished by the raw materials (generally of animal or vegetable origin) processed into food products.

The food products manufactured in these establishments are typically sold to wholesalers or retailers for distribution to consumers, but establishments primarily engaged in retailing bakery and candy products made on the premises not for immediate consumption are included.

NAICS 312 - Industries in the **Beverage and Tobacco Product Manufacturing** subsector manufacture beverages and tobacco products. The industry group, Beverage Manufacturing, includes three types of establishments: (1) those that manufacture nonalcoholic beverages; (2) those that manufacture alcoholic beverages through the fermentation process; and (3) those that produce distilled alcoholic beverages. Ice manufacturing, while not a beverage, is included with nonalcoholic beverage manufacturing because it uses the same production process as water purification.

In the case of activities related to the manufacture of beverages, the structure follows the defined production processes. Brandy, a distilled beverage, was not placed under distillery product manufacturing, but rather under the NAICS class for winery product manufacturing since the production process used in the manufacturing of alcoholic grape-based beverages produces both wines (fermented beverage) and brandies (distilled beverage).

The industry group, Tobacco Manufacturing, includes two types of establishments: (1) those engaged in redrying and stemming tobacco and, (2) those that manufacture tobacco products, such as cigarettes and cigars.

NAICS 313 - Industries in the **Textile Mills** subsector group establishments that transform a basic fiber (natural or synthetic) into a product, such as yarn or fabric that is further manufactured into usable items, such as apparel, sheets, towels, and textile bags for individual or industrial consumption. The further manufacturing may be performed in the same establishment and classified in this subsector, or it may be performed at a separate establishment and be classified elsewhere in manufacturing.

The main processes in this subsector include preparation and spinning of fiber, knitting or weaving of fabric, and the finishing of the textile. The NAICS structure follows and captures this process flow. Major industries in this flow, such as preparation of fibers, weaving of fabric, knitting of fabric, and fiber and fabric finishing, are uniquely identified. Texturizing, throwing, twisting, and winding of yarn contains aspects of both fiber preparation and fiber finishing and is classified with preparation of fibers rather than with finishing of fiber.

NAICS 314 - Industries in the **Textile Product Mills** subsector group establishments that make textile products (except apparel). With a few exceptions, processes used in these industries are generally cut and sew (i.e., purchasing fabric and cutting and sewing to make nonapparel textile products, such as sheets and towels).

NAICS 315 - Industries in the **Apparel Manufacturing** subsector group establishments with two distinct manufacturing processes: (1) cut and sew (i.e., purchasing fabric and cutting and sewing to make a garment), and (2) the manufacture of garments in establishments that first knit fabric and then cut and sew the fabric into a garment. The Apparel Manufacturing subsector includes a diverse range of establishments manufacturing full lines of ready-to-wear apparel and custom apparel: apparel contractors, performing cutting or sewing operations on materials owned by others; jobbers performing entrepreneurial functions involved in apparel manufacture; and tailors, manufacturing custom garments for individual clients are all included. Knitting, when done alone, is classified in the Textile Mills subsector, but when knitting is combined with the production of complete garments, the activity is classified in Apparel Manufacturing.

NAICS 316 - Establishments in the **Leather and Allied Product Manufacturing** subsector transform hides into leather by tanning or curing and fabricating the leather into products for final consumption. It also includes the manufacture of similar products from other materials, including products (except apparel) made from "leather substitutes," such as rubber, plastics, or textiles. Rubber footwear, textile luggage, and plastics purses or wallets are examples of "leather substitute" products included in this group. The products made from leather substitutes are included in this subsector because they are made in similar ways leather products are made (e.g., luggage). They are made in the same establishments, so it is not practical to separate them.

The inclusion of leather making in this subsector is partly because leather tanning is a relatively small industry that has few close neighbors as a production process, partly because leather is an input to some of the other products classified in this subsector and partly for historical reasons.
NAICS 321 - Industries in the **Wood Product Manufacturing** subsector manufacture wood products, such as lumber, plywood, veneers, wood containers, wood flooring, wood trusses, manufactured homes (i.e., mobile homes), and prefabricated wood buildings. The production processes of the Wood Product Manufacturing subsector include sawing, planing, shaping, laminating, and assembling of wood products starting from logs that are cut into bolts, or lumber that then may be further cut, or shaped by lathes or other shaping tools. The lumber or other transformed wood shapes may also be subsequently planed or smoothed, and assembled into finished products, such as wood containers. The Wood Product Manufacturing subsector includes establishments that make wood products from logs and bolts that are sawed and shaped, and establishments that purchase sawed lumber and make wood products. With the exception of sawmills and wood preservation establishments, the establishments are grouped into industries mainly based on the specific products manufactured.

NAICS 322 - Industries in the **Paper Manufacturing** subsector make pulp, paper, or converted paper products. The manufacturing of these products is grouped together because they constitute a series of vertically connected processes. More than one is often carried out in a single establishment. There are essentially three activities. The manufacturing of pulp involves separating the cellulose fibers from other impurities in wood or used paper. The manufacturing of paper involves matting these fibers into a sheet. Converted paper products are made from paper and other materials by various cutting and shaping techniques and include coating and laminating activities.

The Paper Manufacturing subsector is subdivided into two industry groups, the first for the manufacturing of pulp and paper and the second for the manufacturing of converted paper products. Paper making is treated as the core activity of the subsector. Therefore, any establishment that makes paper (including paperboard), either alone or in combination with pulp manufacturing or paper converting, is classified as a paper or paperboard mill. Establishments that make pulp without making paper are classified as pulp mills. Pulp mills, paper mills and paperboard mills comprise the first industry group.

Establishments that make products from purchased paper and other materials make up the second industry group, Converted Paper Product Manufacturing. This general activity is then subdivided based, for the most part, on process distinctions. Paperboard container manufacturing uses corrugating, cutting, and shaping machinery to form paperboard into containers. Paper bag and coated and treated paper manufacturing establishments cut and coat paper and foil. Stationery product manufacturing establishments make a variety of paper products used for writing, filing, and similar applications. 0ther converted paper product manufacturing includes, in particular, the conversion of sanitary paper stock into such things as tissue paper and disposable diapers.

NAICS 323 - Industries in the **Printing and Related Support Activities** subsector print products, such as newspapers, books, labels, business cards, stationery, business forms, and other materials, and perform support activities, such as data imaging, platemaking services, and bookbinding. The support activities included here are an integral part of the printing industry, and a product (a printing plate, a bound book, or a computer disk or file) that is an integral part of the printing industry is almost always provided by these operations.

Processes used in printing include a variety of methods used to transfer an image from a plate, screen, film, or computer file to some medium, such as paper, plastics, metal, textile articles, or wood. The most prominent of these methods is to transfer the image from a plate or screen to the medium (lithographic, gravure, screen, and flexographic printing). A rapidly growing new technology uses a computer file to directly "drive" the printing mechanism to create the image and new electrostatic and other types of equipment (digital or nonimpact printing).

NAICS 324 **-** The **Petroleum and Coal Products Manufacturing** subsector is based on the transformation of crude petroleum and coal into usable products. The dominant process is petroleum refining that involves the separation of crude petroleum into component products through such techniques as cracking and distillation.

NAICS 325 - The **Chemical Manufacturing** subsector is based on the transformation of organic and inorganic raw materials by a chemical process and the formulation of products. This subsector distinguishes the production of basic chemicals that comprise the first industry group from the production of intermediate and end products produced by further processing of basic chemicals that make up the remaining industry groups.

NAICS 326 - Industries in the **Plastics and Rubber Products Manufacturing** subsector make goods by processing plastics materials and raw rubber. The core technology employed by establishments in this subsector is that of plastics or rubber product production. Plastics and rubber are combined in the same subsector because plastics are increasingly being used as a substitute for rubber; however the subsector is generally restricted to the production of products made of just one material, either solely plastics or rubber.

Many manufacturing activities use plastics or rubber, for example the manufacture of footwear, or furniture. Typically, the production process of these products involves more than one material. In these cases, technologies that allow disparate materials to be formed and combined are of central importance in describing the manufacturing activity. In NAICS, such activities (the footwear and furniture manufacturing) are not classified in the Plastics and Rubber Products Manufacturing subsector because the core technologies for these activities are diverse and involve multiple materials.

NAICS 327 - The **Nonmetallic Mineral Product Manufacturing** subsector transforms mined or quarried nonmetallic minerals, such as sand, gravel, stone, clay, and refractory materials, into products for intermediate or final consumption. Processes used include grinding, mixing, cutting, shaping, and honing. Heat often is used in the process and chemicals are frequently mixed to change the composition, purity, and chemical properties for the intended product. For example, glass is produced by heating silica sand to the melting point (sometimes combined with cullet or recycled glass) and then drawn, floated, or blow molded to the desired shape or thickness. Refractory materials are heated and then formed into bricks or other shapes for use in industrial applications.

The Nonmetallic Mineral Product Manufacturing subsector includes establishments that manufacture products, such as bricks, refractories, ceramic products, and glass and glass products, such as plate glass and containers. Also included are cement and concrete products, lime, gypsum and other nonmetallic mineral products including abrasive products, ceramic plumbing fixtures, statuary, cut stone products, and mineral wool. The products are used in a wide range of activities from construction and heavy and light manufacturing to articles for personal use.

NAICS 331 - Industries in the **Primary Metal Manufacturing** subsector smelt and/or refine ferrous and nonferrous metals from ore, pig or scrap, using electrometallurgical and other process metallurgical techniques. Establishments in this subsector also manufacture metal alloys and superalloys by introducing other chemical elements to pure metals. The output of smelting and refining, usually in ingot form, is used in rolling, drawing, and extruding operations to make sheet, strip, bar, rod, or wire, and in molten form to make castings and other basic metal products.

Primary manufacturing of ferrous and nonferrous metals begins with ore or concentrate as the primary input. Establishments manufacturing primary metals from ore and/or concentrate remain classified in the primary smelting, primary refining, or iron and steel mill industries regardless of the form of their output. Establishments primarily engaged in secondary smelting and/or secondary refining recover ferrous and nonferrous metals from scrap and/or dross. The output of the secondary smelting and/or secondary refining industries is limited to shapes, such as ingot or billet, that will be further processed. Recovery of metals from scrap often occurs in establishments that are primarily engaged in activities, such as rolling, drawing, extruding, or similar processes.

NAICS 332 - Industries in the **Fabricated Metal Product Manufacturing** subsector transform metal into intermediate or end products, other than machinery, computers and electronics, and metal furniture, or treat metals and metal formed products fabricated elsewhere. Important fabricated metal processes are forging, stamping, bending, forming, and machining, used to shape individual pieces of metal; and other processes, such as welding and assembling, used to join separate parts together. Establishments in this subsector may use one of these processes or a combination of these processes.

NAICS 333 - Industries in the **Machinery Manufacturing** subsector create end products that apply mechanical force, for example, the application of gears and levers, to perform work. Some important processes for the manufacture of machinery are forging, stamping, bending, forming, and machining that are used to shape individual pieces of metal. Processes, such as welding and assembling are used to join separate parts together. Although these processes are similar to those used in metal fabricating establishments, machinery manufacturing is different because it typically employs multiple metal forming processes in manufacturing the various parts of the machine. Moreover, complex assembly operations are an inherent part of the production process.

NAICS 334 - Industries in the **Computer and Electronic Product Manufacturing** subsector group establishments that manufacture computers, computer peripherals, communications equipment, and similar electronic products, and establishments that manufacture components for such products. The Computer and Electronic Product Manufacturing industries have been combined in the hierarchy of NAICS because of the economic significance they have attained. Their rapid growth suggests that they will become even more important to the economies of all three North American countries in the future, and in addition their manufacturing processes are fundamentally different from the manufacturing processes of other machinery and equipment. The design and use of integrated circuits and the application of highly specialized miniaturization technologies are common elements in the production technologies of the computer and electronic subsector. Convergence of technology motivates this NAICS subsector. Digitalization of sound recording, for example, causes both the medium (the compact disc) and the equipment to resemble the technologies for recording, storing, transmitting, and manipulating data. Communications technology and equipment have been converging with computer technology. When technologically-related components are in the same sector, it makes it easier to adjust the classification for future changes, without needing to redefine its basic structure. The creation of the Computer and Electronic Product Manufacturing subsector assists in delineating new and emerging industries because the activities that will serve as the probable sources of new industries, such as computer manufacturing and communications equipment manufacturing, or computers and audio equipment, are brought together. As new activities emerge, they are less likely therefore, to cross the subsector boundaries of the classification.

NAICS 335 - Industries in the **Electrical Equipment, Appliance, and Component Manufacturing** subsector manufacture products that generate, distribute and use electrical power. Electric Lighting Equipment Manufacturing establishments produce electric lamp bulbs, lighting fixtures, and parts. Household Appliance Manufacturing establishments make both small and major electrical appliances and parts. Electrical Equipment Manufacturing establishments make goods, such as electric motors, generators, transformers, and switchgear apparatus. 0ther Electrical Equipment and Component Manufacturing establishments make devices for storing electrical power (e.g., batteries), for transmitting electricity (e.g., insulated wire), and wiring devices (e.g., electrical outlets, fuse boxes, and light switches).

NAICS 336 - Industries in the **Transportation Equipment Manufacturing** subsector produce equipment for transporting people and goods. Transportation equipment is a type of machinery. An entire subsector is devoted to this activity because of the significance of its economic size in all three North American countries.

Establishments in this subsector utilize production processes similar to those of other machinery manufacturing establishments - bending, forming, welding, machining, and assembling metal or plastic parts into components and finished products. However, the assembly of components and subassemblies and their further assembly into finished vehicles tends to be a more common production process in this subsector than in the Machinery Manufacturing subsector.

NAICS 337 - Industries in the **Furniture and Related Product Manufacturing** subsector make furniture and related articles, such as mattresses, window blinds, cabinets, and fixtures. The processes used in the manufacture of furniture include the cutting, bending, molding, laminating, and assembly of such materials as wood, metal, glass, plastics, and rattan. However, the production process for furniture is not solely bending metal, cutting and shaping wood, or extruding and molding plastics. Design and fashion trends play an important part in the production of furniture. The integrated design of the article for both esthetic and functional qualities is also a major part of the process of manufacturing furniture. Design services may be performed by the furniture establishments’ work force or may be purchased from industrial designers.

NAICS 339 - Industries in the **Miscellaneous Manufacturing** subsector make a wide range of products that cannot readily be classified in specific NAICS subsectors in manufacturing. Processes used by these establishments vary significantly, both among and within industries. For example, a variety of manufacturing processes are used in manufacturing sporting and athletic goods that include products such as tennis racquets and golf balls. The processes for these products differ from each other, and the processes differ significantly from the fabrication processes used in making dolls or toys, the melting and shaping of precious metals to make jewelry, and the bending, forming, and assembly used in making medical products.