

## Industrial Demand Module

The NEMS Industrial Demand Module (IDM) estimates energy consumption by energy source (fuels and feedstocks) for 15 manufacturing and 6 nonmanufacturing industries. The manufacturing industries are subdivided further into the energy-intensive manufacturing industries and non-energy intensive manufacturing industries (Table 1). The manufacturing industries are modeled through a detailed process-flow or end-use accounting procedure. The nonmanufacturing industries are modeled with less detail because processes are simpler and fewer data are available. The petroleum refining industry is not included in the IDM because it is simulated separately in the Liquid Fuels Market Module (LFMM) of NEMS. The IDM calculates energy consumption for the four census regions (Table 2) and disaggregates regional energy consumption to the nine census divisions based on fixed shares from the U.S. Energy Information Administration's (EIA) *State Energy Data System* <sup>[1]</sup>.

**Table 1. Industry categories and NAICS codes**

Energy-intensive manufacturing		Non-energy-intensive manufacturing		Nonmanufacturing	
Food products	311	Metal-based durables industries		Agriculture: crop production	111
Paper and allied products	322	Fabricated metal products	332	Other agricultural production	112, 113, 115
<i>Bulk chemicals group<sup>1</sup></i>		Machinery	333	Coal mining	2121
Inorganic	325120-325180	Computer and electronic products	334	Oil and natural gas extraction	211
Organic	325110, 32519	Electrical equipment and appliances	335	Metal and other non-metallic mining	2122-2123
Resins	3252	Transportation equipment	336	Construction	23
Agricultural chemicals	3253	Wood products	321		
Glass and glass products	3272, 327993	Plastic and rubber products	326		

Energy-intensive manufacturing		Non-energy-intensive manufacturing	Nonmanufacturing
			312–316, 323, 3254–3256, 3259, 3271, 327320, 327330, 327390, 327420, 3279 (except 327993), 3314, 3315, 337, 339
Cement and lime	327310, 327410	Balance of manufacturing	
Iron and steel	331110, 3312, 324199 <sup>2</sup>		
Aluminum	3313		

NAICS = North American Industry Classification System (2012).

<sup>1</sup>Bulk chemicals energy consumption is reported as an aggregate in the *Annual Energy Outlook*.

<sup>2</sup>NAICS 324199 contains merchant coke ovens, which are considered part of the iron and steel industry in the *Annual Energy Outlook*.

Source: U.S. Department of Commerce, U.S. Census Bureau, North American Industry Classification system 2012 (NAICS)—United States (Washington, DC, August 2011), <https://www.census.gov/cgi-bin/sssd/naics/naicsrch?chart=2012>.

**Table 2. Census regions, census divisions, and states**

Census region	Census divisions	States
1 (East)	1,2	Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont
2 (Midwest)	3, 4	Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, North Dakota, Nebraska, Ohio, South Dakota, and Wisconsin
3 (South)	5, 6, 7	Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and West Virginia
4 (West)	8, 9	Arizona, Alaska, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming

Source: U.S. Energy Information Administration (Washington, DC, September 15, 2016), Appendix F, <http://www.eia.gov/outlooks/archive/aeo16/pdf/f1.pdf>.

Most industries are modeled as three separate, interrelated components:

- Process and Assembly (PA)

- Buildings (BLD)
- Boiler, Steam, and Cogeneration (BSC)

The PA component is calculated by end use for all but five manufacturing industries, which are calculated by production process (process flow):

- Paper
- Glass
- Cement and lime
- Iron and steel
- Aluminum

The BSC component satisfies the steam demand from the PA and BLD components. In some industries, the PA component produces byproducts that are consumed in the BSC component. The iron and steel, paper, and aluminum industries determine boiler and combined-heat-and-power (CHP) use within the PA step.

The IDM *base year* is currently 2014, which is the year of the latest available *Manufacturing Energy Consumption Survey* (MECS) <sup>[2]</sup>. EIA conducts the MECS every four years. No model results are available before the IDM base year. The IDM base year is periodically updated as new MECS become available.

Petroleum refining (NAICS 32411) is not modeled in the IDM. Refining energy consumption is modeled in detail in the LFMM module of NEMS, and the projected energy consumption is reported in the manufacturing total. In addition, projections of lease and plant fuel, energy used for liquefaction of natural gas, and fuels consumed in cogeneration in the oil and natural gas extraction industry (NAICS 211) are not calculated within the IDM. They are calculated in other modules.

### Key assumptions—manufacturing

The IDM primarily uses a bottom-up modeling approach. An energy accounting framework traces energy flows from fuels to an industry's output. The IDM depicts the manufacturing industries, except for petroleum refining, with either a detailed process-flow or end-use approach. Generally, industries with homogeneous products use a process-flow approach, and those with heterogeneous products use an end-use approach. Industries that use a process-flow approach are

- Paper
- Glass
- Cement and lime
- Iron and steel
- Aluminum

Industries that use an end-use approach are

- Food
- Bulk chemicals
- The five metal-based durables industries
- Wood
- Plastic and rubber products

- Balance of manufacturing

### *Process and assembly component for end-use models*

In end-use industries, energy consumption is measured by activity, such as heating, cooling, or machine drive, instead of a process. These activities could be thought of as services. End-use industries usually have many different products, which makes specifying a manageable number of process steps impossible. Most manufacturing are end-use industries. End-use process and assembly consumption is modeled at the census region level and aggregated to the national level.

For manufacturing industries modeled using an end-use approach, the process and assembly component models model the end use for each major production end use. The throughput production for each end use is computed, as is the energy required to produce it. The Unit Energy Consumption (UEC) is defined as the amount of energy required to produce a unit of output—the energy intensity.

For end-use industries, an important assumption in developing this system is the IDM base year (currently 2014). Initial UECs in the IDM base year are calculated by end use and region using the current MECS for that end use divided by shipments for that industry. Each UEC represents the energy required to produce one unit of the industry's output as measured by dollar value of shipments.

Each major process end use is characterized by a UEC estimate and a Technology Possibility Curve (TPC). A TPC represents the annual rate of change from the IDM base year to the end year of the projection period. For end-use industries, the TPC depicts the assumed average annual rate of change in energy intensity of an energy end use (e.g., natural gas-fired heating or electricity-powered cooling). Each TPC for new and existing capacity varies by industry, vintage, and process. These assumed rates were developed using professional engineering judgments about energy characteristics, year of availability, and market adoption rates for new process technologies.

The module distinguishes each UEC by three vintages of capital stock. The amount of energy consumption reflects the assumption that new vintage stock will consist of state-of-the-art technologies that have different efficiencies from the existing capital stock. Consequently, the amount of energy required to produce a unit of output using new capital stock is often less than that required by the existing capital stock. The old vintage consists of capital that exists in the IDM base year and continues to operate after adjusting for assumed retirements each year (Table 3). New production capacity is assumed to be added in a given projection year to ensure that sufficient surviving and new capacity is available to meet the level of an industry's output as determined in the NEMS Regional Macroeconomic Module. Middle vintage is capital added after 2014 through the year before the current projection year.

**Table 3. Annual retirement rates for end-use industries**

Industry	Retirement rate (x 100)	Industry	Retirement rate (x 100)
Food products	1.7	Wood products	1.3
Bulk chemicals	1.7	Plastics and rubber products	1.3
Metal-based durables	1.3	Balance of manufacturing	1.3

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

To simulate technological progress and adoption of more energy-efficient technologies, each UEC is adjusted every projection year based on the assumed TPC for each end-use step. A TPC is derived from assumptions about the relative energy intensity (REI) of productive capacity by vintage (new capacity relative to existing stock in a given year) or over time (new or surviving capacity in 2050 relative to the 2014 stock). Over time, each UEC for new capacity changes, and the TPC provides the rate of change. Every UEC of the surviving 2014 capital stock is also assumed to change over time but not as rapidly as for new capital stock because of retrofitting.

The concepts of REI and TPC embody assumptions about new technology adoption in the manufacturing industry and the associated change in energy consumption without characterizing individual technologies in detail. This approach reflects the assumption that industrial plants will change energy consumption when owners

- Replace old equipment with new, more efficient equipment
- Add new capacity
- Add new products
- Upgrade their energy management practices

The increased efficiency cannot be directly attributed to technology choice decisions because of the complexity of these industries. Instead, the module uses the REI and TPC to characterize intensity trends for bundles of technologies available for end-use industries. The values for REI and TPC by end use, process, and census region are listed in the Appendix, which starts on page 23.

For EIA's *Annual Energy Outlook 2020* (AEO2020), new REIs were developed for some of the end-use industries, namely, food, metal-based durables, chemicals, and balance of manufacturing. These REIs are based on *state of the art* and *practical minimum* energy intensities (UECs) from recent [Advanced Manufacturing Office \(AMO\) Bandwidth Studies](#), as well as other studies on industry-specific technology improvements.<sup>1</sup> Note, the new *state of the art* and *practical minimum* UECs employed in AEO2020 for these industries represent very long-term (30-year) extensions of energy efficiency and therefore indicate short-term projections of energy intensity.

### *Electric motor stock model*

---

<sup>1</sup> [Bandwidth Study on Energy Use and Potential Energy Savings Opportunities in U.S. Food and Beverage Manufacturing](#), EERE (2017); [Energy Efficiency Improvement and Cost Saving Opportunities for the Corn Wet Milling Industry](#), LBNL (2003); [Energy Life-Cycle Assessment of Soybean Biodiesel](#), USDA (2009); [Energy Efficiency Improvement and Cost Saving Opportunities for the Dairy Processing Industry](#), LBNL (2011); [Energy Efficiency Improvement and Cost Saving Opportunities for the Fruit and Vegetable Processing Industry](#), LBNL (2008); [Energy Audits in Meat Processing Operations](#), American Meat Science Association (1979); [Updated Buildings Sector Appliance and Equipment Costs and Efficiencies](#), EIA (2018); ACEEE, [The Energy Savings Potential of Smart Manufacturing](#); [Measuring Plant Level Energy Efficiency and Technical Change in the U.S. Metal-Based Durable Manufacturing Sector Using Stochastic Frontier Analysis](#), CES (2016); [Energy Efficiency and Price Responsiveness in Energy Intensive Chemicals Manufacturing](#), EIA (2018); [Bandwidth Study on Energy Use and Potential energy Savings Opportunities in U.S. Plastics and Rubber Manufacturing](#), EERE (2017).

For calculating energy consumed in the machine-drive end use, an end-use electric motor stock technology model is used, instead of a UEC and TPC. For a number of industries, machine-drive electricity consumption is calculated using a motor stock model <sup>[3]</sup>:

- Bulk chemicals industry
- Food industry
- The five metal-based durables industries
- Wood
- Plastics
- Rubber products
- Balance of manufacturing

The beginning stock of motors is modified during the projection period. Motors are added to accommodate growth in shipments for each industry or industry group as motors are retired and replaced and as failed motors are rewound. When an old motor fails, an economic choice is made on whether to repair or replace the motor. When a new motor is added, either to accommodate growth or replace a retiring motor, it must meet the minimum efficiency standard. Table 4 provides the beginning stock efficiency for seven motor size groups in each of the three industry groups, as well as efficiencies for replacement motors. All replacement motors are assumed to be premium high-efficiency motors because of current efficiency regulations.

**Table 4. Cost and performance parameters for industrial motor choice model**

Industry/horsepower (hp) range	Average efficiency	Replacement motor efficiency	Rewind cost (2002\$)	Replacement cost (2002\$)
<b>Food</b>				
1–5 hp	81.3	89.5	230	442
6–20 hp	87.1	93.0	427	1,047
21–50 hp	90.1	94.5	665	1,889
51–100 hp	92.7	95.4	1,258	5,398
101–200 hp	93.5	96.2	2,231	10,400
201–500 hp	93.8	96.2	4,363	20,942
> 500 hp	93.0	96.2	5,726	28,115
<b>Bulk chemicals</b>				
1–5 hp	82.0	89.5	230	442
6–20 hp	87.4	93.0	427	1,047
21–50 hp	90.4	94.5	665	1,889
51–100 hp	92.4	95.4	1,258	5,398
101–200 hp	93.5	96.2	2,231	10,400
201–500 hp	93.3	96.2	4,363	20,942
> 500 hp	93.2	96.2	57,26	28,115
<b>Metal-based durables<sup>a</sup></b>				
1–5 hp	82.2	89.5	230	442
6–20 hp	87.3	93.0	427	1,047
21–50 hp	90.1	94.5	665	1,889
51–100 hp	92.4	95.4	1,258	5,398
101–200 hp	93.5	96.2	2,231	10,400
201–500 hp	94.5	96.2	4,363	20,942

Industry/horsepower (hp) range	Average efficiency	Replacement motor efficiency	Rewind cost (2002\$)	Replacement cost (2002\$)
>500 hp	94.4	96.2	5,726	28,115
<b>Wood, plastic, and balance of manufacturing</b>				
1–5 hp	81.8	89.5	230	442
6–20 hp	86.6	93.0	427	1,047
21–50 hp	89.9	94.5	665	1,889
51–100 hp	92.1	95.4	1,258	5,398
101–200 hp	93.2	96.2	2,231	10,400
201–500 hp	93.1	96.2	4,363	20,942
>500 hp	93.1	96.2	5,726	28,115

<sup>a</sup>The metal-based durables group includes five industries that are modeled separately: fabricated metals, machinery, computers and electronics, electrical equipment, and transportation equipment.

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.

Source: U.S. Energy Information Administration, *Model Documentation Report*, Industrial Sector Demand Module of the National Energy Modeling System (Washington, DC, September 2013).

### *Petrochemical feedstock requirement*

The IDM estimates feedstock requirements for the major petrochemical olefin products such as ethylene, propylene, and butadiene, as well as natural gas used for producing methanol, ammonia, and hydrogen. The primary feedstocks used to produce the olefins are hydrocarbon gas liquids (HGL) (e.g., ethane, propane, and butane) and heavier petrochemical feedstocks (e.g., gas oil and naphtha) <sup>[4]</sup>. Biomass is a potential raw material source, but biomass-based capacity is assumed to be unavailable during the projection period because of economic barriers. The type of feedstock determines the energy requirements for heat and power to produce the chemicals, as well as the product yield.

To determine the relative amounts of feedstock (HGL or heavy petrochemical) baseline intensities, feedstock consumption intensities for 2014 are derived from the 2014 MECS. Feedstock consumption of both types grows or declines with the organic chemicals shipment value. The feedstock intensity does not change over time: every feedstock TPC is assumed to be zero. Unlike most other processes represented in manufacturing PA components, chemical yields are governed by basic chemical stoichiometry that allows for specific yields under set conditions of pressure and temperature.

For years 2018–21, an exogenous natural gas feedstock forecast was used based on project-level methanol and ammonia/urea capacity data. Ethylene cracker project-level data were similarly employed for both the HGL (light) and naphtha (heavy) feedstock forecast for 2018–21. In addition, for the AEO2020 projections, HGL feedstock was broken down into its components (ethane, propane, butanes, and natural gasoline). Propylene demand for the IDM in AEO2020 was held constant throughout the projection period at a level equal with current U.S. refinery propylene production.

### *Process/assembly component for process-flow models*

Five energy-intensive manufacturing industries are modeled using a process-flow approach instead of an end-use approach:

- Paper
- Glass
- Cement and lime

- Iron and steel
- Aluminum

These modules, completed in AEO2016, use a suite of detailed technology choices for each process flow. Instead of the energy intensity for each process and end use evolving according to a TPC, the process-flow models use technology choice for each process flow. Energy requirements for each technology are obtained from technology estimates (e.g., expenditures, energy coefficients, and utility needs) from the Consolidated Impacts Modeling System (CIMS) database, which is prepared by the Pacific Northwest National Laboratory <sup>[5]</sup>. Depending on the industry, these data are calibrated using inputs from the U.S. Geological Survey (USGS) of the U.S. Department of the Interior, the Portland Cement Association, and our latest MECS <sup>[6, 7, 8]</sup>.

The process-flow models calculate surviving capacity based on retirement and needed capacity based on shipments and surviving capacity. The baseline capacity (as of 2014) is assumed to retire at a linear rate over a fixed period (20 years). Incremental, or added, capacity is assumed to retire according to a logistic survival function and have a potential maximum life of 30 years. The exact shape of the logistic S-curve can be obtained through parameters adjusted by the analyst. New capital equipment information (capital and operating costs, energy use, and emissions) was obtained from the CIMS database. Each step of the process flow allows for several technology choices whose fuel type and efficiency are known at the national level because regional fuel breakouts are fixed using available EIA data.

### *Pulp and paper industry*

The pulp and paper industry converts wood fiber to pulp, and then it manufactures paper, paperboard, and consumer products that are generally sold in the domestic marketplace. The industry produces a full line of paper and board products, as well as dried pulp, which is sold as a commodity product to domestic and international paper and board manufacturers. This industry includes several manufacturing steps and technologies:

- Wood preparation removes bark and chips logs into small pieces.
- Pulping is the process to remove fibrous cellulose in the wood from the surrounding lignin. Pulping can occur with a chemical or a mechanical process.
- Pulp washing means washing the pulp with water to remove the cooking chemicals and lignin from the fiber.
- Drying, liquor evaporation, effluent treatment, and other miscellaneous steps are part of the pulping process. Pulp is sent to a pressing section to squeeze out as much water as possible by mechanical means. The pulp is compressed between two rotating rolls, and the amount of water removed depends on the design and speed of the machine. When the pressed pulp leaves the pressing section, it has about a 65% moisture content. It is then heat-dried. Various techniques for drying are available, and each has different energy consumption characteristics.
- Bleaching is required to produce white paper stock.

Paperboard, newsprint, coated paper, uncoated paper, and tissue paper are final products. Producing final products requires drying, finishing, and stock preparation.

### *Glass industry*

For the glass industry model, each step of the three glass product processes modeled in the IDM (flat

glass, pressed and blown glass, and glass containers) allows for several technology choices whose fuel type and efficiency are known, as well as other operating characteristics.

For flat glass (NAICS 327211) the process steps include batch preparation, furnace, form and finish, and tempering. For pressed and blown glass (NAICS 327212), the process steps include preparation, furnace, form and finish, and fire polish. For glass containers (NAICS 327213), the process steps include preparation, furnaces, and form and finish. For fiberglass (*mineral wool*—NAICS 327993), the process steps include preparation, furnaces, and form and finish. The final category (glass from glass products—NAICS 327215) was not modeled as a process flow with technology choice but instead uses a UEC and TPC for each fuel to capture energy intensity changes over time.

Several technologies are used in the glass submodule. Not all of the technologies below are available to all processes:

- The preparation step (collection, grinding, and mixing of raw materials including recycled glass, which is known as cullet) uses either a standard set of grinders/motors or an advanced set that is computer-controlled.
- The furnaces, which melt the glass, are air-fueled or oxy-fueled burners that use natural gas. Electric-boosting furnace technology is also available. Direct-electric (or Joule) heating is available for fiberglass production.
- The form and finish process is used for all glass products, and the technologies can be selected from high-pressure natural gas-fired computer-controlled technology or basic technology.
- No technology choice exists for the tempering step (flat glass) or the polish step (blown glass). Placeholders for more efficient future technology choices were implemented, but their introduction into these processes was rather limited.

As with the other submodules, the technology slate in each of these process steps evolves over time and depends on the relative cost of equipment, cost of fuel, and fuel efficiency. Oxy-fueled burners were added as a retrofit to the burner technologies, and their additive impact is determined by the relative price of natural gas and electricity.

### *Combined cement and lime industry*

For the cement process flow, each step (raw material grinding, kiln, and finish grinding) can be achieved by several technology choices, and each step's fuel types and efficiency levels are known at the national level because regional fuel breakouts are fixed using EIA data.

Cement has both dry and wet mill processes. Some technologies are available for both processes, but others are available for only one process. The technology choices within each group are

- Raw materials grinding
  - Ball mill or roller mill
- Kilns (rotators)
  - Dry process only
    - Rotary long with preheat, precalcining, and computer control
    - Rotary preheat with high-efficiency cooler

- Rotary preheat and precalcine with efficient cooler
  - Wet process only: rotary wet standard with waste heat recovery boiler and cogeneration
- Kilns (burners)
  - Coal-fired, standard or efficient
  - Natural gas-fired, standard or efficient
  - Petroleum coke-fired, standard
  - Alternative fuel such as Municipal Solid Waste (MSW), standard
- Finish grinding
  - Ball mill, standard or with high efficiency separator
  - Roller mill, standard or with high efficiency separator

The technology slate in each process step evolves over time and depends on the relative cost of equipment, cost of fuel, and fuel efficiency. Retirement of existing wet process kiln technology is assumed to be permanent; only dry process kilns can be added to replace retired wet kilns or to satisfy needed additional capacity.

The IDM base year technology slate is determined from the latest CIMS database and calibrated for the year 2008 with dry and wet mill capacity cement fuel data from the Portland Cement Association, the USGS, and the 2014 MECS. All new cement capacity, both for replacement and increased production, is assumed to be dry cement capacity. Existing wet capacity is assumed to retire at a linear rate over 20 years with no replacement. Imported clinker, additives, and fly ash are assumed to make constant percentage contributions to the finished product and to displace a certain amount of domestic clinker production, which affects energy use.

Lime energy consumption is estimated separately from cement but presented together as the consolidated cement and lime energy consumption. Energy consumption and technology evolution in the lime industry are driven by the same methods implemented for cement with different, industry-specific equipment choices.

### *Iron and steel industry*

The iron and steel industry includes several major process steps:

- Coke making
- Iron making
- Steel making
- Steel casting
- Steel forming

Steel manufacturing plants are either integrated or non-integrated. The classification depends on the number of major process steps performed in the facility. Integrated plants perform all of the process steps, whereas non-integrated plants, in general, perform only the last three steps.

For the IDM, a process flow was developed in five steps from which unit energy consumption values were estimated. These steps and technologies are for steel made primarily from raw materials (i.e., primary steel):

- Coke ovens convert metallurgical coal into coke.
- Iron is produced in the blast furnace (BF), which is then charged into a basic oxygen furnace (BOF) to produce raw steel.
- The electric arc furnace (EAF) produces 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 blooms, billets, or slabs using continuous casting, or more rarely, ingots. Some ingot or cast steel is sold directly (e.g., forging-grade billets).
- Steel is then hot-rolled into various mill products. Some of these are sold as hot-rolled mill products, while others are further cold rolled to impart surface finish or other desirable properties.

The technology slate in each of these process steps evolves over time and depends on the relative cost of equipment, cost of fuel, and fuel efficiency. The IDM base year technology slate is determined from the latest CIMS database and calibrated for the IDM base year 2014 MECS and USGS physical output for 2014 through 2016.

### *Aluminum industry*

For the aluminum industry model, each step—alumina production, anode production, electrolysis for primary aluminum production, and melting for secondary production—has several technology choices for new capacity with known fuel types and efficiencies, as well as other operating characteristics. Technology shares are known at the national level, and regional fuel breakouts are based on fixed allocations using available EIA data.

The aluminum industry has both primary and secondary production processes, which vary widely in their energy demands. Recently, the share of secondary aluminum has increased significantly higher than its historical share. A number of primary smelters have closed during the past few years and are not expected to reopen. Therefore, based on expert judgment, the share of secondary aluminum is expected to constitute at least 75% of total aluminum output through 2050. Consistent with assumptions in previous years, no new primary aluminum plants are assumed to be built in the United States before 2050, although very limited capacity expansion of existing primary smelters may occur.

Some technologies are available to both processes and others are available to only one process:

- Primary smelting (Hall-Heroult electrolysis cell) is represented as smelting in four pre-bake anode technologies that denote standard and retrofitted choices and one inert anode-wetted cathode choice.
- Anode production, used in primary production only, is represented by three natural gas-fired furnaces under various configurations in forming and baking pre-bake anodes and the formation of Söderberg anodes. Anodes are a requirement for the Hall-Heroult process.
- Alumina production (Bayer Process) is used in primary production only and selects between existing natural gas facilities and those with retrofits.

- Secondary production selects between two natural gas-fired melters: standard and high efficiency.

The technology slate in each of these process steps evolves over time and depends on the relative cost of equipment, cost of fuel, and fuel efficiency, subject to the constraint that the secondary production share is at least 75% of all aluminum production. The IDM base year technology slate is determined from the latest CIMS database and is calibrated to the 2014 MECS energy consumption data (2014 is also the IDM model base year) and the USGS physical production of primary and secondary aluminum. All new capacities for aluminum production, both for replacement and increased production needs, are now assumed to be either pre-existing primary production or new secondary production, based on historical trend data and projected energy prices. Similar to the energy-intensive technology of the cement industry, the lifespan of existing and new production capacity is assumed to be 20 and 30 years, respectively. In addition, idle production is allowed to reenter production before new equipment is built.

### *Buildings component*

The total buildings energy demand by industry for each region is a function of regional industrial employment and output. Building energy consumption was estimated for building lighting, HVAC (heating, ventilation, and air conditioning), facility support, and onsite transportation. Space heating was further divided to estimate the amount provided by direct combustion of fossil fuels and by steam (Table 5). Energy consumption in the BLD component for an industry is estimated based on regional employment and output growth for that industry using the 2014 MECS as a basis.

**Table 5. Buildings component energy consumption inputs**

trillion British thermal units

Industry	Census region	Lighting - electricity	HVAC - electricity	HVAC - natural gas	HVAC - steam	Facilities support total	Onsite transportation total
<b>Food products</b>							
	1	2	2	3	2	2	1
	2	9	10	15	5	9	2
	3	6	7	9	5	6	3
	4	3	4	9	5	5	3
<b>Paper products</b>							
	1	1	2	2	0	1	0
	2	3	4	3	0	1	1
	3	7	8	9	0	3	2
	4	2	3	2	0	1	1
<b>Bulk chemicals</b>							
	1	1	1	1	0	1	1
	2	5	5	8	0	3	2
	3	10	11	23	0	7	4
	4	1	2	1	0	1	1

Industry	Census region	Lighting - electricity	HVAC - electricity	HVAC - natural gas	HVAC - steam	Facilities support total	Onsite transportation total
<b>Glass</b>							
	1	0	1	2	0	0	0
	2	1	1	2	0	0	0
	3	1	1	3	0	0	0
	4	0	0	1	0	0	0
<b>Cement and lime</b>							
	1	0	0	0	0	0	0
	2	0	0	0	0	0	1
	3	0	0	0	0	0	1
	4	0	0	0	0	0	1
<b>Iron and steel</b>							
	1	1	1	2	0	1	0
	2	3	2	9	0	4	2
	3	3	2	3	0	2	1
	4	1	0	0	0	0	0
<b>Aluminum</b>							
	1	1	1	1	0	0	0
	2	2	5	2	0	1	1
	3	3	6	4	0	2	1
	4	1	3	0	0	0	0
<b>Metal-based durables: fabricated metals</b>							
	1	2	2	5	1	1	1
	2	7	11	29	7	4	3
	3	4	7	8	2	2	1
	4	2	3	4	1	1	1
<b>Metal-based durables: machinery</b>							
	1	1	2	4	1	1	0
	2	5	7	20	8	2	1
	3	4	5	7	3	1	1
	4	1	1	1	0	0	0
<b>Metal-based durables: computers</b>							
	1	2	5	3	2	1	0
	2	1	4	4	3	1	0
	3	2	6	3	2	2	0
	4	5	13	6	5	3	1

Industry	Census region	Lighting - electricity	HVAC - electricity	HVAC - natural gas	HVAC - steam	Facilities support total	Onsite transportation total
<b>Metal-based durables: transportation equipment</b>							
	1	1	2	4	0	1	0
	2	9	13	25	2	4	3
	3	7	11	15	1	3	3
	4	2	3	6	0	1	1
<b>Metal-based durables: electrical equipment</b>							
	1	1	1	1	1	0	0
	2	1	2	1	1	1	0
	3	2	3	3	2	1	0
	4	0	1	1	1	0	0
<b>Wood products</b>							
	1	0	1	1	1	0	2
	2	1	1	1	3	0	2
	3	2	4	3	6	1	5
	4	1	1	1	3	0	2
<b>Plastic products</b>							
	1	2	2	3	0	0	1
	2	5	6	9	0	2	1
	3	7	8	9	0	2	2
	4	3	3	1	0	1	0
<b>Balance of manufacturing</b>							
	1	5	9	14	0	2	1
	2	12	19	29	0	5	1
	3	18	30	41	0	8	8
	4	5	8	11	0	2	1

HVAC = heating, ventilation, and air conditioning

Source: Leidos, IDM Base Year Update with MECS 2014 Data, unpublished data prepared for the Industrial Team, Office of Energy Consumption and Efficiency Analysis, U.S. Energy Information Administration (Washington, DC, September 2017).

### *Boiler, steam, and cogeneration component*

Except for the iron and steel industry and the pulp and paper industry, the steam demand and byproducts from the PA and BLD components are passed to the BSC component, which applies a heat rate and a fuel share equation (Table 6) to the boiler steam requirements to compute the required energy consumption. The iron and steel and pulp and paper industries have independent BSC and cogeneration-related modeling that is calculated as part of the PA step.

The boiler fuel shares apply only to the fuels that are used in boilers for steam-only applications. Fuel use for the share of the steam demand associated with combined heat and power (CHP) is described in the next section. Some fuel switching for the remainder of the boiler fuel use is assumed and is calculated with a logit-sharing equation where fuel shares are a function of fuel prices; the logit parameter is assumed to be -2 for all regions and industries. The equation is calibrated to 2014 so that the 2014 fuel shares are produced for the relative prices in 2014.

The byproduct fuels, production of which is estimated in the PA component, are assumed to be consumed without regard to price, independent of purchased fuels. The boiler fuel share equations and calculations are based on the 2014 MECS and information from the Council of Industrial Boiler Owners [8].

**Table 6. Boiler steam cogeneration component energy inputs, 2014**

trillion British thermal units

Industry	Census region	Natural gas	Coal	Renewables	Petroleum
<b>Food products</b>					
	1	25	0	0	2
	2	145	69	21	2
	3	87	5	95	3
	4	79	15	8	3
<b>Bulk chemicals</b>					
	1	19	0	0	8
	2	227	91	0	53
	3	689	61	0	382
	4	24	38	0	11
<b>Glass</b>					
	1	1	0	10	0
	2	1	0	1	0
	3	2	0	1	1
	4	1	0	1	0
<b>Cement and lime</b>					
	1	0	0	1	0
	2	0	0	2	0
	3	0	0	4	0
	4	0	0	3	0

Industry	Census region	Natural gas	Coal	Renewables	Petroleum
<b>Metal-based durables: fabricated metals</b>					
	1	2	0	0	0
	2	13	0	0	0
	3	3	0	0	0
	4	2	0	0	0
<b>Metal-based durables: machinery</b>					
	1	2	0	0	0
	2	9	1	1	0
	3	3	0	0	0
	4	0	0	0	0
<b>Metal-based durables: computers</b>					
	1	3	0	0	0
	2	4	0	0	0
	3	3	0	0	0
	4	7	0	0	0
<b>Metal-based durables: transportation equipment</b>					
	1	2	0	1	0
	2	13	1	4	1
	3	8	0	3	1
	4	3	0	2	0
<b>Metal-based durables: electrical equipment</b>					
	1	1	0	0	0
	2	1	0	0	0
	3	1	0	0	0
	4	0	0	0	0
<b>Wood products</b>					
	1	1	0	47	0
	2	2	1	16	0
	3	5	0	132	0
	4	3	0	48	0
<b>Plastic products</b>					
	1	4	1	0	0
	2	18	0	0	0
	3	18	0	0	1
	4	3	0	0	0

Industry	Census region	Natural gas	Coal	Renewables	Petroleum
<b>Balance of manufacturing</b>					
	1	34	3	3	11
	2	70	20	3	30
	3	96	15	17	128
	4	25	10	3	5

Source: Leidos, IDM Base Year Update with MECS 2014 Data, unpublished data prepared for the Industrial Team, Office of Energy Consumption and Efficiency Analysis, U.S. Energy Information Administration (Washington, DC, September 2017).

### *Combined heat and power*

CHP plants, which are designed to produce both electricity and useful heat, have been used in the industrial sector for many years. The CHP estimates in the module are based on the assumption that the historical relationship between industrial steam demand and CHP will continue in the future, and the rate of additional CHP penetration will depend on the economics of retrofitting CHP plants to replace steam generated from existing non-CHP boilers. The technical potential for CHP is based on supplying steam requirements. Capacity additions are then determined by

- The interaction of CHP investment payback periods (with the time value of money included) derived using operating hours reported in EIA's published statistics
- Market penetration rates for investments with those payback periods
- Regional deployment for these systems as characterized by the collaboration coefficients in Table 7

Assumed installed costs for the CHP systems are in Table 8.

**Table 7. Regional collaboration coefficients for CHP deployment**

Census region	Collaboration coefficient
1 (Northeast)	0.67
2 (Midwest)	0.35
3 (South)	0.47
4 (West)	0.51

CHP = combined heat and power

Source: Calculated from American Council for an Energy-Efficient Economy (Washington, DC, September 2017) <https://aceee.org/research-report/u1710> and Form EIA-860, *Annual Electric Generator Report*, U.S. Energy Information Administration, Office of Energy Statistics (Washington, DC, September 2018), <https://www.eia.gov/electricity/data/eia860/>.

**Table 8. Cost characteristics of industrial CHP systems**

System	Capacity (MW)	2014 overall heat rate (Btu/kWh)	2014 installed cost (2015\$/kW)	2050 overall heat rate (Btu/kWh)	2050 installed cost (2015\$/kW)
Reciprocating engine	1	9,509	\$1,884	9,447	\$1,285
	3	8,126	\$1,716	7,675	\$1,178
Gas turbine	5	12,929	\$1,611	11,834	\$1,006
	10	12,082	\$1,308	11,225	\$852
	25	10,341	\$1,038	9,503	\$662
	40	9,433	\$887	8,678	\$545
Combined cycle	103	8,528	\$1,515	7,789	\$1,032

Source: Leidos, *Review of Distributed Generation and Combined Heat and Power Technology Performance and Cost Estimates and Analytic Assumptions for the National Energy Modeling System* (Washington, DC, May 2016). Note that CHP = combined heat and power, MW = megawatt, Btu = British thermal units, kWh = kilowatthour.

### **CHP for steel, paper, and aluminum industries**

For steel and paper, boiler and CHP capacity and generation is computed as part of the PA step. Steam demand for each process is a non-energy demand for each process step. The initial steam and CHP in the IDM base year are calculated based on MECS, while a CHP share is assumed in the final projection year. Specific CHP and boiler technology shares in the IDM base year and final projection year are then chosen from a slate of user-assumed technologies with different fuels. In the intervening years, the share of CHP and boilers and the technology shares are interpolated.

For the aluminum industry, the structure is slightly different. *Boilers* (including CHP) is a distinct process step in the manufacture of alumina from bauxite. Boiler and CHP technology shares are user-assumed in the IDM base year.

### **Key assumptions—nonmanufacturing**

The nonmanufacturing sector consists of three industries: agriculture, mining, and construction. These industries all use electricity, natural gas, diesel fuel, and gasoline. The mining industry also uses coal, HGL, and residual fuel oil, and the construction industry uses other petroleum in the form of asphalt and road oil. Except for oil and natural gas extraction, almost all of the energy use in the nonmanufacturing sector takes place in the PA step. Oil and natural gas extraction uses a significant amount of residual fuel oil in the BSC component.

Unlike the manufacturing sector, the nonmanufacturing sector does not have a single source of data for energy consumption estimates. Instead, UECs for the nonmanufacturing sector are derived from various sources of data collected by a number of government agencies.

Nonmanufacturing data were revised using EIA and U.S. Census Bureau sources to provide more realistic projections of diesel and gasoline for off-road vehicle use and to allocate natural gas, HGL, and electricity consumption. We used our Fuel Oil and Kerosene Sales (FOKS) <sup>[9]</sup>, the U.S. Department of Agriculture's Agricultural Resource Management Survey (ARMS) <sup>[10]</sup>, and the U.S. Census Bureau's Census of Mining <sup>[11]</sup> and Census of Construction <sup>[12]</sup>. Nonmanufacturing consumption is no longer dictated solely by the difference between the State Energy Data System (SEDS) and MECS as it had been before AEO2014.

### *Agriculture subsector*

U.S. agriculture consists of three major industries:

- Crop production, which depends primarily on regional environments and crops demanded
- Animal production, which largely depends food demands and feed accessibility
- Forestry, logging, and all other agricultural activities

These sub-industries have historically been tightly grouped as a result of competing use of land area. For example, crops produced for animal feed cannot be consumed by humans. Similarly, forests provide the feedstock for the paper and wood industries, but they are not good for growing crops and limit or prevent animals from grazing. Forestry and logging are not modeled within NEMS.

Energy consumption in the agricultural sectors modeled in NEMS—crops and other—are disaggregated into three activities: irrigation, buildings, and vehicles. The TPC for each activity is derived from the Commercial Demand Module (CDM) and the Transportation Demand Module (TDM). Each TPC for irrigation depends on the relative change in energy intensity for ventilation from the CDM. Similarly, each TPC for buildings depends on a weighted average of the change in intensity for heating, lighting, and building shells from the CDM. Each TPC for vehicles changes over time depending on the relative intensity change of trucks from the TDM.

Baseline energy consumption data for the two agriculture sectors (crops and other agriculture) are based on data from the Census of Agriculture and a special tabulation from the U.S. Department of Agriculture, National Agricultural Statistics Service (NASS). Expenditures for four energy sources are collected from crop farms and livestock farms as part of the ARMS. These data are converted from dollar expenditures to energy quantities using fuel prices from NASS and EIA.

### *Mining subsector*

The mining sector comprises three industries: coal mining, metal and nonmetal mining, and oil and natural gas extraction. Energy use is based on the equipment and onsite vehicles used at the mine. All mines use extraction equipment and lighting, but only coal and metal mines and nonmetal mines use grinding and ventilation. As with the agriculture module described above, each TPC is influenced by efficiency changes in buildings and transportation equipment.

Coal mining production is obtained from the Coal Market Module (CMM). Currently, 70% of the coal is assumed to be mined at the surface and the rest mined underground. As these shares evolve, however, so does the energy consumed because surface mines use less energy overall than underground mines. In addition, the energy consumed for coal mining depends on coal mine productivity, which is also obtained from the CMM. Diesel fuel and electricity are the predominant fuels used in coal mining. Electricity used for coal grinding is calculated using the raw grinding process step from the cement submodule. In metal and nonmetal mining, energy use is similar to coal mining. Output used for metal and nonmetal mining is derived from the Macroeconomic Analysis Module's (MAM) variable for *other* mining that also provides the shares of each type of mining.

For oil and natural gas extraction, production is derived from the Oil and Gas Supply Module (OGSM). Energy use depends on the fuel extracted and whether the well is conventional or unconventional (e.g., extraction from tight and shale formations), percentage of dry wells, and well depth. Oil and natural gas extraction also includes fuel consumed for liquefaction of natural gas.

### *Construction subsector*

The construction sector uses diesel fuel, gasoline, electricity, and HGL as energy sources. Construction also uses asphalt and road oil as a nonfuel energy source. Asphalt and road oil use is tied to state and local government real investment in highways and streets. This investment is derived from the MAM. Each TPC for diesel and gasoline fuels is directly tied to the TDM's heavy- and medium-duty vehicle efficiency projections. For non-vehicular construction equipment, each TPC is a weighted average of vehicular TPC and highway investment.

## Legislation and regulations

### *Energy Improvement and Extension Act of 2008 (EIEA2008)*

EIEA2008 provides an Investment Tax Credit (ITC) for qualifying combined-heat-and-power (CHP) systems placed in service before January 1, 2017, which has now expired. Because this tax credit expired and CHP data was only available up to 2017, the provision was not modeled in AEO2020 for CHP units built in 2017 and later.

### *The Energy Independence and Security Act of 2007 (EISA2007)*

Under EISA2007, the motor efficiency standards established under the Energy Policy Act of 1992 (EPACT1992) are superseded for purchases made after 2011. Section 313 of EISA2007 increases or creates minimum efficiency standards for newly manufactured and imported general purpose electric motors. The efficiency standards are raised for general purpose, integral-horsepower induction motors with the exception of fire pump motors. Minimum standards were created for seven types of poly-phase, integral-horsepower induction motors and National Electrical Manufacturers Association (NEMA) design *B* motors (201–500 horsepower) that were not previously covered by EPACT standards. In 2013, the Energy Policy and Conservation Act was amended (Public Law 113-67), and efficiency standards were revised in a subsequent U.S. Department of Energy (DOE) rulemaking (10 CFR 431.25). For motors manufactured after June 1, 2016, efficiency standards for current regulated motor types<sup>[13]</sup> were expanded to include 201–500 horsepower motors. In addition, special- and definite-purpose motors from 1–500 horsepower and NEMA design *A* motors from 201–500 horsepower were subject to efficiency standards. The 2014 regulations had been modeled in the AEO2017 by modifying the specifications for new motors in electric motor technology choice module and were unchanged in AEO2020.

### *Energy Policy Act of 1992 (EPACT1992)*

EPACT1992 contains several implications for the industrial module. These implications concern efficiency standards for boilers, furnaces, and electric motors. The industrial module assumes efficiency of 80% and 82% for natural gas and oil burners, respectively. These efficiencies meet the EPACT1992 standards. EPACT1992 requires minimum efficiencies for all motors up to 200 horsepower purchased after 1998. The choices offered in the motor efficiency assumptions are all at least as efficient as the EPACT minimums.

### *Clean Air Act Amendments of 1990 (CAAA1990)*

CAAA1990 contains numerous provisions that affect industrial facilities. Three major categories of such provisions are process emissions (e.g., a chemical reaction that releases carbon), emissions related to

hazardous or toxic substances, and sulfur dioxide (SO<sub>2</sub>) emissions. Process emissions requirements were specified for several industries and activities (40 CFR 60). Similarly, 40 CFR 63 requires limitations on emissions of almost 200 hazardous or toxic substances. These requirements are not explicitly represented in the NEMS industrial model because they are not directly related to energy consumption projections.

Section 406 of the CAAA1990 requires the U.S. Environmental Protection Agency (EPA) to regulate industrial SO<sub>2</sub> emissions when total industrial SO<sub>2</sub> emissions exceed 5.6 million tons per year (42 USC 7651). Because industrial coal use (the main source of SO<sub>2</sub> emissions) has been declining, EPA does not anticipate that specific industrial SO<sub>2</sub> regulations will be required (Environmental Protection Agency, National Air Pollutant Emission Trends: 1900–1998, EPA-454/R-00-002, March 2000, Chapter 4). Further, because industrial coal use is not projected to increase, the industrial cap is not expected to be a factor in industrial energy consumption projections. Emissions from coal-to-liquids CHP plants are included with the electric power sector because they are subject to the separate emission limits of large electricity-generating plants.

### *Maximum Achievable Control Technology for Industrial Boilers (Boiler MACT)*

Section 112 of the Clean Air Act (CAA) requires regulation of air toxics through the National Standards for Hazardous Air Pollutants (NESHAP) for industrial, commercial, and institutional boilers. The final regulations, known as Boiler MACT, are modeled in AEO2020. Pollutants covered by Boiler MACT include the hazardous air pollutants: hydrogen chloride, mercury, dioxins/furans, carbon monoxide, and particulate matter. Generally, industries comply with the Boiler MACT regulations by including regular maintenance and tune-ups for smaller facilities and emission limits and performance tests for larger facilities. Boiler MACT is modeled as an upgrade cost in the MAM. These upgrade costs are classified as nonproductive costs, which are not associated with efficiency improvements. The effect of these costs in the MAM is a reduction in shipments coming into the IDM.

### *California Assembly Bill 32: Emissions Cap-and-Trade as Part of the Global Warming Solutions Act of 2006 (AB32) as Amended by California Senate Bill 32, 2016 (SB32)*

AB32 established a comprehensive, multiyear program to reduce greenhouse gas (GHG) emissions in California, including a cap-and-trade program<sup>[14]</sup>. In addition to the cap-and-trade program, AB32 authorizes the low carbon fuel standard (LCFS); energy efficiency goals and programs in transportation, buildings, and industry; combined-heat-and-power goals; and renewable portfolio standards.

For AEO2020 the cap-and-trade provisions were modeled for industrial facilities, refineries, and fuel providers. GHG emissions include both non-carbon-dioxide (non-CO<sub>2</sub>) and specific non-CO<sub>2</sub> GHG emissions. The allowance price, representing the incremental cost of complying with AB32 cap-and-trade, is modeled in the NEMS Electricity Market Module via a region-specific emissions constraint. This allowance price, when added to market fuel prices, results in higher effective fuel prices in the demand sectors. Limited banking and borrowing of allowances, as well as a price containment reserve and offsets, have been modeled in NEMS. AB32 is not modeled explicitly in the IDM, but it enters the module implicitly through higher effective fuel prices and macroeconomic effects of higher prices, all of which affect energy demand and emissions primarily in Census Region 9, the Pacific.

SB32 was enacted in September 2016 and requires California regulators to plan for a 40% reduction in GHG emissions to lower than 1990 levels by 2030 <sup>[15]</sup>. Emissions goals in the cap-and-trade program for AEO2020 are modeled assuming a ceiling on CO2 allowance prices to prevent infeasible solutions or extremely high allowance prices. The AEO2020 projections generally have a shortfall in SB32 compliance starting around 2030, when emissions exceed the declining cap. Further cost-effective emissions reductions are not available, and consequently, the allowance price is at the price ceiling. This price ceiling is assumed to be slightly higher than the price of the Tier 3 Allowance Price Containment Reserve.

The cap-and-trade program is only one part of California's GHG reduction strategy. According to the California Air Resources Board, the cap-and-trade program is assumed to comprise less than 30% of total GHG emissions reductions targets <sup>[16]</sup>. Emissions reductions targeted by the other GHG reduction programs described above affect the industrial sector only indirectly.

## Appendix Tables

The tables in this appendix are used to calculate Unit Energy Consumption (UEC) for the end-use manufacturing industries: food, bulk chemicals, metal-based durables, and other manufacturing industries. Each census region has four tables. The tables are in the Form of Table A-Nx, where N denotes the census region and x denotes the industry in the table below (A indicates it is an Appendix table). For example, Table A-1a corresponds to the food industry in Census Region 1, and Table A-3c corresponds to the five metal-based durables industries in Census Region 3.

X	Industries
A	Food
B	Bulk chemicals
C	Metal-based durables industries: fabricated metal products, machinery, computers, electronic equipment, and transportation equipment
D	Wood, plastic, and balance of manufacturing

The definitions of the items in the table are:

- *Unit Energy Consumption 2014* is energy consumption for region, industry, and end use divided by regional shipments of that industry.
- *Existing Facility Reference REI 2050* is the ratio of 2050 energy intensity to 2014 energy intensity for existing facilities in the Reference case.
- *New Facility REI 2014* is the ratio of energy intensity for new, state-of-the-art facilities to average 2014 energy intensity for existing facilities in the Reference case.
- *New Facility Reference TPC* is the ratio of 2050 energy intensity for a new state-of-the-art facility to the average 2014 energy intensity for existing facilities in the Reference case.
- *Existing Facility Reference TPC* is the annual change in energy intensity for existing facilities in the Reference case. In the table, each TPC is multiplied by 100 for easier readability. For example, a TPC of -0.500 in the table corresponds to a value of -0.005 in the IDM.
- *New Facility Reference TPC* is the annual change in energy intensity for new facilities in the Reference case. In the table, the values are multiplied by 100 for easier readability. For example, a TPC of -0.500 in the table corresponds to a value of -0.005 in the IDM.

Data source for all tables: Leidos, IDM Base Year Update with MECS 2014 Data, unpublished data prepared for the Industrial Team, Office of Energy Consumption and Efficiency Analysis, U.S. Energy Information Administration (Washington, DC, September 2017).

**Table A-1a. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for food industry—Region 1**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Milling</b>						
Process heating—electricity	0.006	0.933	-0.192	0.933	0.894	-0.117
Process heating—steam	0.442	0.755	-0.778	0.755	0.561	-0.822
Process heating—natural gas	0.147	0.837	-0.492	0.837	0.833	-0.013
Process cooling—electricity	0.029	0.747	-0.806	0.891	0.678	-0.756
Process cooling—natural gas	0.012	0.875	-0.370	0.965	0.875	-0.273
Machine drive—natural gas	0.004	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.006	0.809	-0.587	0.809	0.797	-0.041
Other—natural gas	0.021	0.837	-0.492	0.837	0.833	-0.013
<b>Dairy</b>						
Process heating—electricity	0.011	0.802	-0.610	0.802	0.802	0.000
Process heating—steam	0.324	0.552	-1.639	0.552	0.458	-0.516
Process heating—natural gas	0.166	0.795	-0.635	0.795	0.786	-0.032
Process cooling—electricity	0.138	0.616	-1.335	0.616	0.548	-0.326
Process cooling—natural gas	0.019	0.875	-0.370	0.965	0.875	-0.273
Machine drive—natural gas	0.011	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.011	0.699	-0.991	0.699	0.652	-0.191
Other—natural gas	0.011	0.795	-0.635	0.795	0.786	-0.032
<b>Animal processing</b>						
Process heating—electricity	0.015	0.873	-0.377	0.873	0.873	0.000
Process heating—steam	0.204	0.717	-0.920	0.717	0.669	-0.194
Process heating—natural gas	0.085	0.878	-0.361	0.878	0.878	0.000
Process cooling—electricity	0.126	0.598	-1.418	0.598	0.508	-0.453
Process cooling—natural gas	0.002	0.877	-0.370	0.965	0.877	-0.273
Machine drive—natural gas	0.004	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.010	0.723	-0.898	0.723	0.675	-0.194
Other—natural gas	0.015	0.878	-0.361	0.878	0.878	0.000
<b>Food—other</b>						
Process heating—electricity	0.015	0.800	-0.617	0.800	0.753	-0.167
Process heating—steam	0.218	0.695	-1.004	0.695	0.621	-0.314
Process heating—natural gas	0.212	0.621	-1.317	0.621	0.521	-0.483

<b>Industry, end use, and fuel</b>	<b>Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)</b>	<b>Existing facility reference REI 2050</b>	<b>Existing facility reference TPC (x100)</b>	<b>New facility REI 2014</b>	<b>New facility reference REI 2050</b>	<b>New facility reference TPC (x100)</b>
Process cooling—electricity	0.061	0.476	-2.040	0.476	0.476	0.000
Machine drive—natural gas	0.002	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.004	0.538	-1.705	0.538	0.489	-0.271
Other—natural gas	0.002	0.619	-1.317	0.619	0.521	-0.483

**Table A-1b. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for the bulk chemicals industry—Region 1**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Inorganic chemicals</b>						
Process heating—electricity	0.089	0.950	-0.141	0.999	0.933	-0.190
Process heating—natural gas	0.170	0.944	-0.160	1.000	0.920	-0.232
Process cooling—electricity	0.071	0.950	-0.141	0.999	0.933	-0.190
Process cooling—natural gas	0.003	0.944	-0.160	1.000	0.921	-0.232
Machine drive—natural gas	0.158	0.944	-0.160	1.000	0.920	-0.232
Electro-chemical process	0.838	0.950	-0.141	0.999	0.933	-0.190
Other—electricity	0.089	0.950	-0.141	0.999	0.933	-0.190
Other—natural gas	0.015	0.943	-0.160	1.000	0.920	-0.232
<b>Organic chemicals</b>						
Process heating—electricity	0.035	0.934	-0.189	0.988	0.917	-0.207
Process heating—natural gas	0.969	0.945	-0.158	0.996	0.922	-0.213
Process cooling—electricity	0.136	0.934	-0.189	0.988	0.917	-0.207
Process cooling—natural gas	0.027	0.945	-0.158	0.996	0.922	-0.213
Machine drive—natural gas	0.297	0.945	-0.158	0.996	0.922	-0.213
Electro-chemical process	0.068	0.934	-0.189	0.988	0.917	-0.207
Other—electricity	0.008	0.934	-0.189	0.988	0.917	-0.207
Other—natural gas	0.364	0.945	-0.158	0.996	0.922	-0.213
<b>Resins and synthetic rubber</b>						
Process heating—electricity	0.036	0.946	-0.153	0.999	0.931	-0.195
Process heating—natural gas	0.229	0.947	-0.150	0.999	0.925	-0.212
Process cooling—electricity	0.118	0.946	-0.153	0.999	0.931	-0.195
Process cooling—natural gas	0.021	0.947	-0.150	0.999	0.925	-0.212
Machine drive—natural gas	0.012	0.947	-0.150	0.999	0.925	-0.212
Electro-chemical process	0.382	0.946	-0.153	0.999	0.931	-0.195
Other—electricity	0.018	0.947	-0.153	0.999	0.931	-0.195
Other—natural gas	0.015	0.948	-0.150	0.999	0.926	-0.212
<b>Agricultural chemicals</b>						
Process heating—electricity	0.015	0.968	-0.090	0.997	0.955	-0.119
Process heating—steam	0.048	0.948	-0.147	0.969	0.925	-0.131
Process heating—natural gas	0.096	0.948	-0.147	0.969	0.925	-0.131
Process cooling—electricity	0.015	0.968	-0.090	0.997	0.955	-0.119

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
Process cooling—natural gas	0.000	0.949	-0.147	0.974	0.923	-0.131
Machine drive—natural gas	0.002	0.948	-0.147	0.970	0.927	-0.131
Other—natural gas	0.007	0.947	-0.147	0.969	0.924	-0.131

**Table A-1c. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for metal based durables industries—Region 1**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Fabricated metals</b>						
Process heating—electricity	0.039	0.953	-0.133	0.994	0.937	-0.162
Process heating—natural gas	0.181	0.838	-0.491	0.982	0.803	-0.556
Process cooling—electricity	0.009	0.954	-0.133	0.993	0.937	-0.162
Process cooling—natural gas	0.004	0.837	-0.491	0.982	0.803	-0.556
Machine drive—natural gas	0.004	0.837	-0.491	0.982	0.803	-0.556
Electro-chemical process	0.011	0.953	-0.133	0.993	0.937	-0.162
Other—electricity	0.009	0.954	-0.133	0.993	0.937	-0.162
Other—natural gas	0.004	0.837	-0.491	0.982	0.803	-0.556
<b>Machinery</b>						
Process heating—electricity	0.021	0.911	-0.259	0.992	0.891	-0.298
Process heating—natural gas	0.043	0.820	-0.550	0.980	0.788	-0.604
Process cooling—electricity	0.008	0.912	-0.259	0.993	0.892	-0.298
Process cooling—natural gas	0.008	0.821	-0.550	0.981	0.789	-0.604
Machine drive—natural gas	0.005	0.819	-0.550	0.979	0.787	-0.604
Electro-chemical process	0.003	0.914	-0.259	0.993	0.892	-0.298
Other—electricity	0.018	0.911	-0.260	0.972	0.889	-0.246
Other—natural gas	0.009	0.809	-0.586	0.945	0.775	-0.547
<b>Computers and electronics</b>						
Process heating—electricity	0.030	0.911	-0.260	0.972	0.890	-0.246
Process heating—natural gas	0.022	0.809	-0.586	0.945	0.775	-0.547
Process cooling—electricity	0.030	0.911	-0.260	0.972	0.890	-0.246
Electro-chemical process	0.007	0.910	-0.260	0.972	0.890	-0.246
Other—electricity	0.018	0.911	-0.260	0.972	0.889	-0.246
Other—natural gas	0.009	0.809	-0.586	0.945	0.775	-0.547
<b>Electrical equipment</b>						
Process heating—electricity	0.017	0.914	-0.248	0.983	0.892	-0.266
Process heating—steam	0.030	0.873	-0.377	0.963	0.843	-0.366
Process heating—natural gas	0.070	0.873	-0.377	0.963	0.844	-0.366
Process cooling—electricity	0.008	0.915	-0.248	0.984	0.894	-0.266
Process cooling—natural gas	0.002	0.872	-0.377	0.962	0.844	-0.366
Machine drive—natural gas	0.002	0.877	-0.377	0.963	0.845	-0.366

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
Electro-chemical process	0.001	0.909	-0.248	0.980	0.889	-0.266
Other—electricity	0.008	0.915	-0.248	0.984	0.894	-0.266
Other—natural gas	0.006	0.872	-0.377	0.962	0.843	-0.366
<b>Transportation equipment</b>						
Process heating—electricity	0.096	0.913	-0.253	0.983	0.892	-0.268
Process heating—natural gas	0.183	0.847	-0.460	0.956	0.817	-0.436
Process cooling—electricity	0.032	0.913	-0.253	0.983	0.892	-0.268
Process cooling—natural gas	0.004	0.846	-0.460	0.955	0.817	-0.436
Machine drive—natural gas	0.004	0.846	-0.460	0.955	0.817	-0.436
Electro-chemical process	0.032	0.913	-0.253	0.983	0.892	-0.268
Other—electricity	0.011	0.913	-0.253	0.983	0.893	-0.268
Other—natural gas	0.004	0.846	-0.460	0.955	0.817	-0.436

**Table A-1d. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for other manufacturing industries—Region 1**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Wood products</b>						
Process heating—electricity	0.062	0.919	-0.234	0.984	0.899	-0.250
Process heating—steam	2.693	0.844	-0.471	0.965	0.812	-0.477
Process heating—natural gas	0.363	0.844	-0.471	0.965	0.812	-0.477
Process cooling—electricity	0.012	0.747	-0.806	0.891	0.678	-0.756
Process cooling—natural gas	0.009	0.874	-0.370	0.965	0.874	-0.273
Machine drive—natural gas	0.026	0.844	-0.471	0.965	0.812	-0.477
Other—electricity	0.012	0.818	-0.558	0.886	0.769	-0.390
Other—natural gas	0.026	0.812	-0.578	0.895	0.775	-0.397
<b>Plastic products</b>						
Process heating—electricity	0.099	0.919	-0.234	0.984	0.899	-0.250
Process heating—steam	0.103	0.844	-0.471	0.965	0.812	-0.477
Process heating—natural gas	0.071	0.844	-0.471	0.965	0.812	-0.477
Process cooling—electricity	0.050	0.747	-0.806	0.891	0.678	-0.756
Process cooling—natural gas	0.002	0.877	-0.370	0.968	0.877	-0.273
Machine drive—natural gas	0.003	0.841	-0.471	0.964	0.812	-0.477
Electro-chemical process	0.005	0.685	-1.049	0.685	0.603	-0.355
Other—electricity	0.005	0.819	-0.558	0.887	0.770	-0.390
Other—natural gas	0.002	0.812	-0.578	0.896	0.779	-0.397
<b>Balance of Manufacturing</b>						
Process heating—electricity	0.036	0.919	-0.234	0.984	0.899	-0.250
Process heating—steam	0.158	0.844	-0.471	0.965	0.812	-0.477
Process heating—natural gas	0.260	0.844	-0.471	0.965	0.812	-0.477
Process cooling—electricity	0.015	0.747	-0.806	0.892	0.678	-0.756
Electro-chemical process	0.004	0.684	-1.049	0.684	0.601	-0.355
Other—electricity	0.004	0.818	-0.558	0.887	0.768	-0.390

**Table A-2a. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for the food industry—Region 2**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Milling</b>						
Process heating—electricity	0.013	0.933	-0.192	0.933	0.894	-0.117
Process heating—steam	1.447	0.755	-0.778	0.755	0.561	-0.822
Process heating—natural gas	0.490	0.837	-0.492	0.837	0.833	-0.013
Process cooling—electricity	0.066	0.747	-0.806	0.891	0.678	-0.756
Process cooling—natural gas	0.029	0.875	-0.370	0.965	0.875	-0.273
Machine drive—natural gas	0.014	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.013	0.809	-0.587	0.809	0.797	-0.041
Other—natural gas	0.070	0.837	-0.492	0.837	0.833	-0.013
<b>Dairy</b>						
Process heating—electricity	0.010	0.802	-0.610	0.802	0.802	0.000
Process heating—steam	0.301	0.552	-1.639	0.552	0.458	-0.516
Process heating—natural gas	0.157	0.795	-0.635	0.795	0.786	-0.032
Process cooling—electricity	0.126	0.616	-1.335	0.616	0.548	-0.326
Process cooling—natural gas	0.012	0.875	-0.370	0.965	0.875	-0.273
Machine drive—natural gas	0.010	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.010	0.698	-0.991	0.698	0.652	-0.191
Other—natural gas	0.010	0.795	-0.635	0.795	0.786	-0.032
<b>Animal processing</b>						
Process heating—electricity	0.016	0.873	-0.377	0.873	0.873	0.000
Process heating—steam	0.281	0.717	-0.920	0.717	0.669	-0.194
Process heating—natural gas	0.119	0.878	-0.361	0.878	0.878	0.000
Process cooling—electricity	0.142	0.598	-1.418	0.598	0.508	-0.453
Process cooling—natural gas	0.000	0.870	-0.370	0.957	0.870	-0.273
Machine drive—natural gas	0.005	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.011	0.722	-0.898	0.722	0.673	-0.194
Other—natural gas	0.022	0.878	-0.361	0.878	0.878	0.000
<b>Food—other</b>						
Process heating—electricity	0.026	0.800	-0.617	0.800	0.754	-0.167
Process heating—steam	0.431	0.695	-1.004	0.695	0.621	-0.314
Process heating—natural gas	0.285	0.621	-1.317	0.621	0.521	-0.483
Process cooling—electricity	0.106	0.476	-2.040	0.476	0.476	0.000
Machine drive—natural gas	0.003	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.006	0.538	-1.705	0.538	0.487	-0.271
Other—natural gas	0.003	0.618	-1.317	0.618	0.521	-0.483

**Table A-2b. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for the bulk chemicals industry—Region 2**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Inorganic chemicals</b>						
Process heating—electricity	0.103	0.950	-0.141	0.999	0.933	-0.190
Process heating—natural gas	0.537	0.944	-0.160	1.000	0.920	-0.232
Process cooling—electricity	0.083	0.950	-0.141	0.999	0.933	-0.190
Process cooling—natural gas	0.010	0.944	-0.160	1.000	0.920	-0.232
Machine drive—natural gas	0.499	0.944	-0.160	1.000	0.920	-0.232
Electro-chemical process	0.970	0.950	-0.141	0.999	0.933	-0.190
Other—electricity	0.103	0.950	-0.141	0.999	0.933	-0.190
Other—natural gas	0.048	0.944	-0.160	1.000	0.920	-0.232
<b>Organic chemicals</b>						
Process heating—electricity	0.125	0.934	-0.189	0.988	0.917	-0.207
Process heating—natural gas	4.248	0.945	-0.158	0.996	0.922	-0.213
Process cooling—electricity	0.482	0.934	-0.189	0.988	0.917	-0.207
Process cooling—natural gas	0.117	0.945	-0.158	0.996	0.922	-0.213
Machine drive—natural gas	1.300	0.945	-0.158	0.996	0.922	-0.213
Electro-chemical process	0.241	0.934	-0.189	0.988	0.917	-0.207
Other—electricity	0.027	0.934	-0.189	0.988	0.917	-0.207
Other—natural gas	1.594	0.945	-0.158	0.996	0.922	-0.213
<b>Resins &amp; synthetic rubber</b>						
Process heating—electricity	0.034	0.946	-0.153	0.999	0.931	-0.195
Process heating—natural gas	0.186	0.947	-0.150	0.999	0.925	-0.212
Process cooling—electricity	0.111	0.946	-0.153	0.999	0.931	-0.195
Process cooling—natural gas	0.017	0.947	-0.150	0.999	0.925	-0.212
Machine drive—natural gas	0.010	0.947	-0.150	0.999	0.925	-0.212
Electro—chemical process	0.360	0.946	-0.153	0.999	0.931	-0.195
Other—electricity	0.017	0.946	-0.153	0.999	0.931	-0.195
Other—natural gas	0.012	0.948	-0.150	0.999	0.925	-0.212
<b>Agricultural chemicals</b>						
Process heating—electricity	0.027	0.968	-0.090	0.997	0.955	-0.119
Process heating—steam	0.722	0.948	-0.147	0.969	0.925	-0.131
Process heating—natural gas	2.504	0.948	-0.147	0.969	0.925	-0.131
Process cooling—electricity	0.027	0.968	-0.090	0.997	0.955	-0.119
Process cooling—natural gas	0.010	0.949	-0.147	0.969	0.925	-0.131
Machine drive—natural gas	0.061	0.948	-0.147	0.969	0.925	-0.131
Other—natural gas	0.192	0.948	-0.147	0.969	0.925	-0.131

**Table A-2c. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for metal based durables industries—Region 2**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Fabricated metals</b>						
Process heating—electricity	0.081	0.953	-0.133	0.994	0.937	-0.162
Process heating—natural gas	0.538	0.838	-0.491	0.982	0.803	-0.556
Process cooling—electricity	0.018	0.953	-0.133	0.994	0.938	-0.162
Process cooling—natural gas	0.011	0.837	-0.491	0.981	0.803	-0.556
Machine drive—natural gas	0.011	0.837	-0.491	0.981	0.803	-0.556
Electro-chemical process	0.022	0.953	-0.133	0.994	0.938	-0.162
Other—electricity	0.018	0.953	-0.133	0.994	0.938	-0.162
Other—natural gas	0.011	0.837	-0.491	0.981	0.803	-0.556
<b>Machinery</b>						
Process heating—electricity	0.023	0.911	-0.259	0.992	0.891	-0.298
Process heating—natural gas	0.073	0.820	-0.550	0.980	0.788	-0.604
Process cooling—electricity	0.008	0.910	-0.259	0.992	0.892	-0.298
Process cooling—natural gas	0.011	0.820	-0.550	0.979	0.788	-0.604
Machine drive—natural gas	0.008	0.820	-0.550	0.982	0.788	-0.604
Electro-chemical process	0.003	0.908	-0.259	0.989	0.890	-0.298
Other—electricity	0.016	0.910	-0.260	0.972	0.889	-0.246
Other—natural gas	0.015	0.810	-0.586	0.945	0.776	-0.547
<b>Computers and electronics</b>						
Process heating—electricity	0.025	0.911	-0.260	0.972	0.890	-0.246
Process heating—natural gas	0.037	0.809	-0.586	0.945	0.776	-0.547
Process cooling—electricity	0.025	0.911	-0.260	0.972	0.890	-0.246
Electro-chemical process	0.006	0.910	-0.260	0.971	0.889	-0.246
Other—electricity	0.016	0.910	-0.260	0.972	0.889	-0.246
Other—natural gas	0.015	0.810	-0.586	0.945	0.776	-0.547
<b>Electrical equipment</b>						
Process heating—electricity	0.018	0.914	-0.248	0.983	0.893	-0.266
Process heating—steam	0.028	0.873	-0.377	0.963	0.844	-0.366
Process heating—natural gas	0.064	0.873	-0.377	0.963	0.844	-0.366
Process cooling—electricity	0.008	0.914	-0.248	0.982	0.893	-0.266
Process cooling—natural gas	0.002	0.871	-0.377	0.962	0.844	-0.366
Machine drive—natural gas	0.002	0.871	-0.377	0.959	0.842	-0.366
Electro-chemical process	0.001	0.913	-0.248	0.981	0.894	-0.266
Other—electricity	0.008	0.914	-0.248	0.982	0.893	-0.266
Other—natural gas	0.006	0.873	-0.377	0.963	0.844	-0.366
<b>Transportation equipment</b>						
Process heating—electricity	0.062	0.913	-0.253	0.983	0.892	-0.268

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
Process heating—natural gas	0.086	0.847	-0.460	0.956	0.817	-0.436
Process cooling—electricity	0.021	0.913	-0.253	0.983	0.892	-0.268
Process cooling—natural gas	0.002	0.844	-0.460	0.955	0.816	-0.436
Machine drive—natural gas	0.002	0.844	-0.460	0.955	0.816	-0.436
Electro-chemical process	0.021	0.913	-0.253	0.983	0.892	-0.268
Other—electricity	0.007	0.912	-0.253	0.982	0.892	-0.268
Other—natural gas	0.002	0.844	-0.460	0.955	0.816	-0.436

**Table A-2d. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for other manufacturing industries—Region 2**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Wood products</b>						
Process heating—electricity	0.034	0.919	-0.234	0.984	0.899	-0.250
Process heating—steam	2.438	0.844	-0.471	0.965	0.812	-0.477
Process heating—natural gas	0.346	0.844	-0.471	0.965	0.812	-0.477
Process cooling—electricity	0.007	0.747	-0.806	0.891	0.678	-0.756
Process cooling—natural gas	0.004	0.876	-0.370	0.968	0.876	-0.273
Machine drive—natural gas	0.025	0.844	-0.471	0.965	0.812	-0.477
Other—electricity	0.007	0.818	-0.558	0.885	0.770	-0.390
Other—natural gas	0.025	0.812	-0.578	0.895	0.776	-0.397
<b>Plastic products</b>						
Process heating—electricity	0.124	0.919	-0.234	0.984	0.899	-0.250
Process heating—steam	0.190	0.844	-0.471	0.965	0.812	-0.477
Process heating—natural gas	0.134	0.844	-0.471	0.965	0.812	-0.477
Process cooling—electricity	0.062	0.747	-0.806	0.891	0.678	-0.756
Process cooling—natural gas	0.003	0.873	-0.370	0.966	0.873	-0.273
Machine drive—natural gas	0.006	0.844	-0.471	0.966	0.813	-0.477
Electro-chemical process	0.006	0.684	-1.049	0.684	0.602	-0.355
Other—electricity	0.006	0.818	-0.558	0.885	0.769	-0.390
Other—natural gas	0.003	0.812	-0.578	0.894	0.774	-0.397
<b>Balance of Manufacturing</b>						
Process heating—electricity	0.075	0.919	-0.234	0.984	0.899	-0.250
Process heating—steam	0.338	0.844	-0.471	0.965	0.812	-0.477
Process heating—natural gas	0.513	0.844	-0.471	0.965	0.812	-0.477
Process cooling—electricity	0.031	0.747	-0.806	0.891	0.678	-0.756
Electro-chemical process	0.007	0.684	-1.049	0.684	0.601	-0.355
Other—electricity	0.009	0.818	-0.558	0.886	0.770	-0.390

**Table A-3a. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for food industry—Region 3**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Milling</b>						
Process heating—electricity	0.012	0.933	-0.192	0.933	0.895	-0.117
Process heating—steam	1.020	0.755	-0.778	0.755	0.561	-0.822
Process heating—natural gas	0.351	0.837	-0.492	0.837	0.833	-0.013
Process cooling—electricity	0.061	0.747	-0.806	0.891	0.678	-0.756
Process cooling—natural gas	0.021	0.875	-0.370	0.966	0.875	-0.273
Machine drive—natural gas	0.010	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.012	0.809	-0.587	0.809	0.797	-0.041
Other—natural gas	0.050	0.837	-0.492	0.837	0.833	-0.013
<b>Dairy</b>						
Process heating—electricity	0.016	0.802	-0.610	0.802	0.802	0.000
Process heating—steam	0.190	0.552	-1.639	0.552	0.458	-0.516
Process heating—natural gas	0.101	0.795	-0.635	0.795	0.786	-0.032
Process cooling—electricity	0.196	0.616	-1.335	0.616	0.548	-0.326
Process cooling—natural gas	0.007	0.875	-0.370	0.966	0.875	-0.273
Machine drive—natural gas	0.007	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.016	0.698	-0.991	0.698	0.652	-0.191
Other—natural gas	0.007	0.794	-0.635	0.794	0.786	-0.032
<b>Animal processing</b>						
Process heating—electricity	0.021	0.873	-0.377	0.873	0.873	0.000
Process heating—steam	0.326	0.717	-0.920	0.717	0.669	-0.194
Process heating—natural gas	0.137	0.878	-0.361	0.878	0.878	0.000
Process cooling—electricity	0.182	0.598	-1.418	0.598	0.508	-0.453
Process cooling—natural gas	0.001	0.878	-0.370	0.976	0.878	-0.273
Machine drive—natural gas	0.006	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.014	0.722	-0.898	0.722	0.674	-0.194
Other—natural gas	0.025	0.878	-0.361	0.878	0.878	0.000
<b>Food—other</b>						
Process heating—electricity	0.018	0.800	-0.617	0.800	0.754	-0.167
Process heating—steam	0.678	0.695	-1.004	0.695	0.621	-0.314
Process heating—natural gas	0.239	0.621	-1.317	0.621	0.521	-0.483
Process cooling—electricity	0.077	0.476	-2.040	0.476	0.476	0.000
Machine drive—natural gas	0.003	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.005	0.538	-1.705	0.538	0.488	-0.271
Other—natural gas	0.003	0.620	-1.317	0.620	0.523	-0.483

**Table A-3b. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for the bulk chemicals industry—Region 3**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Inorganic chemicals</b>						
Process heating—electricity	0.167	0.950	-0.141	0.999	0.933	-0.190
Process heating—natural gas	2.817	0.944	-0.160	1.000	0.920	-0.232
Process cooling—electricity	0.133	0.950	-0.141	0.999	0.933	-0.190
Process cooling—natural gas	0.050	0.944	-0.160	1.000	0.920	-0.232
Machine drive—natural gas	2.616	0.944	-0.160	1.000	0.920	-0.232
Electro-chemical process	1.566	0.950	-0.141	0.999	0.933	-0.190
Other—electricity	0.167	0.950	-0.141	0.999	0.933	-0.190
Other—natural gas	0.251	0.944	-0.160	1.000	0.920	-0.232
<b>Organic chemicals</b>						
Process heating—electricity	0.036	0.934	-0.189	0.988	0.917	-0.207
Process heating—natural gas	1.660	0.945	-0.158	0.996	0.922	-0.213
Process cooling—electricity	0.137	0.934	-0.189	0.988	0.917	-0.207
Process cooling—natural gas	0.046	0.945	-0.158	0.996	0.922	-0.213
Machine drive—natural gas	0.508	0.945	-0.158	0.996	0.922	-0.213
Electro-chemical process	0.069	0.934	-0.189	0.988	0.917	-0.207
Other—electricity	0.008	0.934	-0.189	0.988	0.917	-0.207
Other—natural gas	0.623	0.945	-0.158	0.996	0.922	-0.213
<b>Resins and synthetic rubber</b>						
Process heating—electricity	0.064	0.946	-0.153	0.999	0.931	-0.195
Process heating—natural gas	1.511	0.947	-0.150	0.999	0.925	-0.212
Process cooling—electricity	0.207	0.946	-0.153	0.999	0.931	-0.195
Process cooling—natural gas	0.139	0.947	-0.150	0.999	0.925	-0.212
Machine drive—natural gas	0.080	0.947	-0.150	0.999	0.925	-0.212
Electro-chemical process	0.668	0.946	-0.153	0.999	0.931	-0.195
Other—electricity	0.032	0.946	-0.153	0.999	0.931	-0.195
Other—natural gas	0.099	0.947	-0.150	0.999	0.925	-0.212
<b>Agricultural chemicals</b>						
Process heating—electricity	0.033	0.968	-0.090	0.997	0.955	-0.119
Process heating—steam	1.338	0.948	-0.147	0.969	0.925	-0.131
Process heating—natural gas	4.661	0.948	-0.147	0.969	0.925	-0.131
Process cooling—electricity	0.033	0.968	-0.090	0.997	0.955	-0.119
Process cooling—natural gas	0.019	0.948	-0.147	0.970	0.925	-0.131
Machine drive—natural gas	0.113	0.948	-0.147	0.969	0.925	-0.131
Other—natural gas	0.357	0.948	-0.147	0.969	0.925	-0.131

**Table A-3c. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for metal based durables industries—Region 3**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Fabricated metals</b>						
Process heating—electricity	0.068	0.953	-0.133	0.994	0.937	-0.162
Process heating—natural gas	0.187	0.838	-0.491	0.982	0.803	-0.556
Process cooling—electricity	0.015	0.953	-0.133	0.994	0.938	-0.162
Process cooling—natural gas	0.004	0.837	-0.491	0.982	0.804	-0.556
Machine drive—natural gas	0.004	0.837	-0.491	0.982	0.804	-0.556
Electro-chemical process	0.019	0.953	-0.133	0.994	0.937	-0.162
Other—electricity	0.015	0.953	-0.133	0.994	0.938	-0.162
Other—natural gas	0.004	0.837	-0.491	0.982	0.804	-0.556
<b>Machinery</b>						
Process heating—electricity	0.022	0.911	-0.259	0.993	0.891	-0.298
Process heating—natural gas	0.030	0.820	-0.550	0.980	0.789	-0.604
Process cooling—electricity	0.008	0.911	-0.259	0.993	0.891	-0.298
Process cooling—natural gas	0.005	0.820	-0.550	0.981	0.788	-0.604
Machine drive—natural gas	0.003	0.821	-0.550	0.982	0.790	-0.604
Electro-chemical process	0.003	0.911	-0.259	0.993	0.888	-0.298
Other—electricity	0.014	0.911	-0.260	0.972	0.890	-0.246
Other—natural gas	0.005	0.810	-0.586	0.945	0.775	-0.547
<b>Computers and Electronics</b>						
Process heating—electricity	0.023	0.911	-0.260	0.972	0.889	-0.246
Process heating—natural gas	0.014	0.809	-0.586	0.945	0.775	-0.547
Process cooling—electricity	0.023	0.911	-0.260	0.972	0.889	-0.246
Electro-chemical process	0.005	0.911	-0.260	0.973	0.890	-0.246
Other—electricity	0.014	0.911	-0.260	0.972	0.890	-0.246
Other—natural gas	0.005	0.810	-0.586	0.945	0.775	-0.547
<b>Electrical equipment</b>						
Process heating—electricity	0.025	0.914	-0.248	0.982	0.893	-0.266
Process heating—steam	0.029	0.873	-0.377	0.962	0.844	-0.366
Process heating—natural gas	0.066	0.873	-0.377	0.963	0.844	-0.366
Process cooling—electricity	0.012	0.915	-0.248	0.983	0.893	-0.266
Process cooling—natural gas	0.002	0.873	-0.377	0.961	0.842	-0.366
Machine drive—natural gas	0.002	0.876	-0.377	0.960	0.842	-0.366
Electro-chemical process	0.001	0.912	-0.248	0.980	0.892	-0.266
Other—electricity	0.012	0.915	-0.248	0.983	0.893	-0.266
Other—natural gas	0.006	0.873	-0.377	0.963	0.844	-0.366
<b>Transportation equipment</b>						
Process heating—electricity	0.100	0.913	-0.253	0.983	0.892	-0.268

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
Process heating—natural gas	0.170	0.847	-0.460	0.956	0.817	-0.436
Process cooling—electricity	0.033	0.913	-0.253	0.983	0.892	-0.268
Process cooling—natural gas	0.004	0.845	-0.460	0.955	0.817	-0.436
Machine drive—natural gas	0.004	0.845	-0.460	0.955	0.817	-0.436
Electro-chemical process	0.033	0.913	-0.253	0.983	0.892	-0.268
Other—electricity	0.011	0.913	-0.253	0.983	0.892	-0.268
Other—natural gas	0.004	0.845	-0.460	0.955	0.817	-0.436

**Table A-3d. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for other manufacturing industries—Region 3**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Wood products</b>						
Process heating—electricity	0.086	0.919	-0.234	0.984	0.899	-0.250
Process heating—steam	2.265	0.844	-0.471	0.965	0.812	-0.477
Process heating—natural gas	0.355	0.844	-0.471	0.965	0.812	-0.477
Process cooling—electricity	0.017	0.747	-0.806	0.891	0.678	-0.756
Process cooling—natural gas	0.005	0.874	-0.370	0.964	0.874	-0.273
Machine drive—natural gas	0.025	0.844	-0.471	0.965	0.812	-0.477
Other—electricity	0.017	0.817	-0.558	0.885	0.769	-0.390
Other—natural gas	0.025	0.812	-0.578	0.895	0.775	-0.397
<b>Plastic products</b>						
Process heating—electricity	0.167	0.919	-0.234	0.984	0.899	-0.250
Process heating—steam	0.185	0.844	-0.471	0.965	0.812	-0.477
Process heating—natural gas	0.127	0.844	-0.471	0.965	0.812	-0.477
Process cooling—electricity	0.083	0.747	-0.806	0.891	0.678	-0.756
Process cooling—natural gas	0.003	0.874	-0.370	0.964	0.874	-0.273
Machine drive—natural gas	0.006	0.843	-0.471	0.964	0.812	-0.477
Electro-chemical process	0.008	0.684	-1.049	0.684	0.601	-0.355
Other—electricity	0.008	0.818	-0.558	0.886	0.770	-0.390
Other—natural gas	0.003	0.812	-0.578	0.895	0.776	-0.397
<b>Balance of manufacturing</b>						
Process heating—electricity	0.079	0.919	-0.234	0.984	0.899	-0.250
Process heating—steam	0.372	0.844	-0.471	0.965	0.812	-0.477
Process heating—natural gas	0.475	0.844	-0.471	0.965	0.812	-0.477
Process cooling—electricity	0.033	0.747	-0.806	0.891	0.678	-0.756
Electro-chemical process	0.008	0.684	-1.049	0.684	0.601	-0.355
Other—electricity	0.009	0.817	-0.558	0.885	0.769	-0.390

**Table A-4a. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for food industry—Region 4**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Milling</b>						
Process heating—electricity	0.010	0.934	-0.192	0.934	0.895	-0.117
Process heating—steam	0.696	0.755	-0.778	0.755	0.561	-0.822
Process heating—natural gas	0.242	0.837	-0.492	0.837	0.833	-0.013
Process cooling—electricity	0.048	0.747	-0.806	0.891	0.678	-0.756
Process cooling—natural gas	0.016	0.875	-0.370	0.966	0.875	-0.273
Machine drive—natural gas	0.007	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.010	0.809	-0.587	0.809	0.798	-0.041
Other—natural gas	0.035	0.837	-0.492	0.837	0.833	-0.013
<b>Dairy</b>						
Process heating—electricity	0.015	0.803	-0.610	0.803	0.803	0.000
Process heating—steam	0.484	0.552	-1.639	0.552	0.458	-0.516
Process heating—natural gas	0.260	0.795	-0.635	0.795	0.786	-0.032
Process cooling—electricity	0.182	0.616	-1.335	0.616	0.548	-0.326
Process cooling—natural gas	0.018	0.875	-0.370	0.965	0.875	-0.273
Machine drive—natural gas	0.017	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.015	0.699	-0.991	0.699	0.652	-0.191
Other—natural gas	0.017	0.795	-0.635	0.795	0.786	-0.032
<b>Animal processing</b>						
Process heating—electricity	0.011	0.872	-0.377	0.872	0.872	0.000
Process heating—steam	0.225	0.717	-0.920	0.717	0.669	-0.194
Process heating—natural gas	0.094	0.878	-0.361	0.878	0.878	0.000
Process cooling—electricity	0.098	0.598	-1.418	0.598	0.508	-0.453
Process cooling—natural gas	0.001	0.873	-0.370	0.975	0.873	-0.273
Machine drive—natural gas	0.004	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.008	0.723	-0.898	0.723	0.674	-0.194
Other—natural gas	0.017	0.878	-0.361	0.878	0.878	0.000
<b>Food—other</b>						
Process heating—electricity	0.021	0.800	-0.617	0.800	0.754	-0.167
Process heating—steam	0.775	0.695	-1.004	0.695	0.621	-0.314
Process heating—natural gas	0.539	0.621	-1.317	0.621	0.521	-0.483
Process cooling—electricity	0.089	0.476	-2.040	0.476	0.476	0.000
Machine drive—natural gas	0.006	1.000	0.000	1.000	1.000	0.000
Other—electricity	0.005	0.539	-1.705	0.539	0.489	-0.271
Other—natural gas	0.006	0.621	-1.317	0.621	0.521	-0.483

**Table A-4b. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for the bulk chemicals industry—Region 4**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Inorganic chemicals</b>						
Process heating—electricity	0.223	0.950	-0.141	0.999	0.933	-0.190
Process heating—natural gas	1.373	0.944	-0.160	1.000	0.920	-0.232
Process cooling—electricity	0.179	0.950	-0.141	0.999	0.933	-0.190
Process cooling—natural gas	0.025	0.944	-0.160	1.000	0.920	-0.232
Machine drive—natural gas	1.275	0.944	-0.160	1.000	0.920	-0.232
Electro-chemical process	2.098	0.950	-0.141	0.999	0.933	-0.190
Other—electricity	0.223	0.950	-0.141	0.999	0.933	-0.190
Other—natural gas	0.123	0.944	-0.160	1.000	0.920	-0.232
<b>Organic chemicals</b>						
Process heating—electricity	0.119	0.934	-0.189	0.988	0.917	-0.207
Process heating—natural gas	0.118	0.945	-0.158	0.996	0.922	-0.213
Process cooling—electricity	0.460	0.934	-0.189	0.988	0.917	-0.207
Process cooling—natural gas	0.003	0.945	-0.158	0.997	0.920	-0.213
Machine drive—natural gas	0.036	0.945	-0.158	0.996	0.922	-0.213
Electro-chemical process	0.230	0.934	-0.189	0.988	0.917	-0.207
Other—electricity	0.026	0.934	-0.189	0.988	0.917	-0.207
Other—natural gas	0.044	0.945	-0.158	0.996	0.922	-0.213
<b>Resins and synthetic rubber</b>						
Process heating—electricity	0.018	0.946	-0.153	0.999	0.931	-0.195
Process heating—natural gas	0.102	0.947	-0.150	0.999	0.925	-0.212
Process cooling—electricity	0.060	0.946	-0.153	0.999	0.931	-0.195
Process cooling—natural gas	0.009	0.947	-0.150	0.999	0.925	-0.212
Machine drive—natural gas	0.005	0.946	-0.150	0.998	0.924	-0.212
Electro-chemical process	0.193	0.946	-0.153	0.999	0.931	-0.195
Other—electricity	0.009	0.946	-0.153	0.999	0.932	-0.195
Other—natural gas	0.007	0.948	-0.150	1.000	0.926	-0.212
<b>Agricultural chemicals</b>						
Process heating—electricity	0.076	0.968	-0.090	0.997	0.955	-0.119
Process heating—steam	0.789	0.948	-0.147	0.969	0.925	-0.131
Process heating—natural gas	2.690	0.948	-0.147	0.969	0.925	-0.131
Process cooling—electricity	0.076	0.968	-0.090	0.997	0.955	-0.119
Process cooling—natural gas	0.011	0.948	-0.147	0.969	0.924	-0.131
Machine drive—natural gas	0.065	0.949	-0.147	0.969	0.925	-0.131
Other—natural gas	0.206	0.948	-0.147	0.969	0.925	-0.131

**Table A-4c. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for metal-based durables industries—Region 4**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Fabricated metals</b>						
Process heating—electricity	0.051	0.953	-0.133	0.994	0.937	-0.162
Process heating—natural gas	0.198	0.838	-0.491	0.982	0.803	-0.556
Process cooling—electricity	0.012	0.953	-0.133	0.994	0.938	-0.162
Process cooling—natural gas	0.004	0.837	-0.491	0.981	0.803	-0.556
Machine drive—natural gas	0.004	0.837	-0.491	0.981	0.803	-0.556
Electro-chemical process	0.014	0.953	-0.133	0.994	0.937	-0.162
Other—electricity	0.012	0.953	-0.133	0.994	0.938	-0.162
Other—natural gas	0.004	0.837	-0.491	0.981	0.803	-0.556
<b>Machinery</b>						
Process heating—electricity	0.017	0.911	-0.259	0.993	0.891	-0.298
Process heating—natural gas	0.012	0.820	-0.550	0.980	0.788	-0.604
Process cooling—electricity	0.007	0.911	-0.259	0.992	0.891	-0.298
Process cooling—natural gas	0.002	0.817	-0.550	0.978	0.786	-0.604
Machine drive—natural gas	0.001	0.818	-0.550	0.978	0.788	-0.604
Electro-chemical process	0.002	0.912	-0.259	0.991	0.889	-0.298
Other—electricity	0.022	0.911	-0.260	0.972	0.890	-0.246
Other—natural gas	0.009	0.809	-0.586	0.946	0.776	-0.547
<b>Computers and electronics</b>						
Process heating—electricity	0.036	0.911	-0.260	0.972	0.889	-0.246
Process heating—natural gas	0.023	0.809	-0.586	0.945	0.775	-0.547
Process cooling—electricity	0.036	0.911	-0.260	0.972	0.889	-0.246
Electro-chemical process	0.008	0.910	-0.260	0.972	0.889	-0.246
Other—electricity	0.022	0.911	-0.260	0.972	0.890	-0.246
Other—natural gas	0.009	0.809	-0.586	0.946	0.776	-0.547
<b>Electrical equipment</b>						
Process heating—electricity	0.015	0.914	-0.248	0.982	0.892	-0.266
Process heating—steam	0.020	0.873	-0.377	0.963	0.844	-0.366
Process heating—natural gas	0.048	0.873	-0.377	0.963	0.844	-0.366
Process cooling—electricity	0.007	0.913	-0.248	0.982	0.893	-0.266
Process cooling—natural gas	0.001	0.878	-0.377	0.964	0.849	-0.366
Machine drive—natural gas	0.001	0.874	-0.377	0.961	0.843	-0.366
Electro-chemical process	0.001	0.912	-0.248	0.978	0.890	-0.266
Other—electricity	0.007	0.913	-0.248	0.982	0.893	-0.266
Other—natural gas	0.004	0.873	-0.377	0.962	0.844	-0.366
<b>Transportation equipment</b>						
Process heating—electricity	0.060	0.913	-0.253	0.983	0.892	-0.268

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
Process heating—natural gas	0.153	0.847	-0.460	0.956	0.817	-0.436
Process cooling—electricity	0.020	0.913	-0.253	0.983	0.893	-0.268
Process cooling—natural gas	0.003	0.846	-0.460	0.956	0.818	-0.436
Machine drive—natural gas	0.003	0.846	-0.460	0.956	0.818	-0.436
Electro-chemical process	0.020	0.913	-0.253	0.983	0.893	-0.268
Other—electricity	0.007	0.913	-0.253	0.984	0.894	-0.268
Other—natural gas	0.003	0.846	-0.460	0.956	0.818	-0.436

**Table A-4d. Industrial Demand Module base year unit energy consumption, relative energy intensities (REI) and technology possibility curves (TPC) for other manufacturing industries—Region 4**

Industry, end use, and fuel	Unit energy consumption 2014 (trillion British thermal units per billion 2012\$)	Existing facility reference REI 2050	Existing facility reference TPC (x100)	New facility REI 2014	New facility reference REI 2050	New facility reference TPC (x100)
<b>Wood products</b>						
Process heating—electricity	0.049	0.919	-0.234	0.984	0.899	-0.250
Process heating—steam	2.239	0.844	-0.471	0.965	0.812	-0.477
Process heating—natural gas	0.346	0.844	-0.471	0.965	0.812	-0.477
Process cooling—electricity	0.010	0.748	-0.806	0.892	0.678	-0.756
Process cooling—natural gas	0.003	0.877	-0.370	0.965	0.877	-0.273
Machine drive—natural gas	0.025	0.844	-0.471	0.965	0.812	-0.477
Other—electricity	0.010	0.817	-0.558	0.886	0.769	-0.390
Other—natural gas	0.025	0.812	-0.578	0.895	0.775	-0.397
<b>Plastic products</b>						
Process heating—electricity	0.221	0.919	-0.234	0.984	0.899	-0.250
Process heating—steam	0.093	0.844	-0.471	0.965	0.812	-0.477
Process heating—natural gas	0.065	0.844	-0.471	0.965	0.812	-0.477
Process cooling—electricity	0.110	0.747	-0.806	0.891	0.678	-0.756
Process cooling—natural gas	0.001	0.879	-0.370	0.964	0.879	-0.273
Machine drive—natural gas	0.003	0.846	-0.471	0.968	0.814	-0.477
Electro-chemical process	0.011	0.684	-1.049	0.684	0.602	-0.355
Other—electricity	0.011	0.817	-0.558	0.886	0.769	-0.390
Other—natural gas	0.001	0.814	-0.578	0.893	0.779	-0.397
<b>Balance of manufacturing</b>						
Process heating—electricity	0.039	0.919	-0.234	0.984	0.899	-0.250
Process heating—steam	0.196	0.844	-0.471	0.965	0.812	-0.477
Process heating—natural gas	0.242	0.844	-0.471	0.965	0.812	-0.477
Process cooling—electricity	0.016	0.747	-0.806	0.891	0.678	-0.756
Electro-chemical process	0.004	0.683	-1.049	0.683	0.603	-0.355
Other—electricity	0.005	0.817	-0.558	0.886	0.769	-0.390

## Notes and sources

- [1] U.S. Energy Information Administration, State Energy Data System (SEDS), based on energy consumption by state 2016, (Washington, DC, June 19, 2018), [www.eia.gov/state/seds/](http://www.eia.gov/state/seds/).
- [2] U. S. Energy Information Administration, *Manufacturing Energy Consumption Survey 2014*, (Washington, DC, October 2017), <https://www.eia.gov/consumption/manufacturing/data/2014/>.
- [3] U.S. Department of Energy (2007). Motor Master+ 4.0 software database; available at updated link <http://www1.eere.energy.gov/manufacturing/downloads/MM41Setup.exe> (paste into browser). User manual: [https://www.energy.gov/sites/prod/files/2014/04/f15/motormaster\\_user\\_manual.pdf](https://www.energy.gov/sites/prod/files/2014/04/f15/motormaster_user_manual.pdf).
- [4] In NEMS, hydrocarbon gas liquids (HGL), which comprise natural gas liquids (NGL) and olefins, are reported as “Liquefied Petroleum Gas and Other” (LPG).
- [5] Roop, Joseph M., “The Industrial Sector in CIMS-US,” Pacific Northwest National Laboratory, 28th Industrial Energy Technology Conference, May 2006.
- [6] U.S. Department of the Interior, U.S. Geological Survey, Minerals Yearbook; cement data were made available under a non-disclosure agreement, <http://minerals.usgs.gov/minerals/pubs/commodity/cement/myb1-2012-cemen.pdf>.
- [7] Portland Cement Association, U.S. and Canadian Portland Cement Industry Plant Information Summary, cement data were made available under a non-disclosure agreement, <https://www.cement.org/>
- [8] Personal correspondence with the Council of Industrial Boiler Owners.
- [9] U.S. Energy Information Administration, *Fuel Oil and Kerosene Sales (FOKS)*, (Washington, DC, December 19, 2017), [http://www.eia.gov/dnav/pet/pet\\_cons\\_821usea\\_dcu\\_nus\\_a.htm](http://www.eia.gov/dnav/pet/pet_cons_821usea_dcu_nus_a.htm).
- [10] U.S. Department of Agriculture, Economic Research Service, Agriculture Research Management Survey (ARMS), [https://www.nass.usda.gov/Surveys/Guide\\_to\\_NASS\\_Surveys/Ag\\_Resource\\_Management/](https://www.nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Ag_Resource_Management/).
- [11] U.S. Census Bureau, 2012 Economic Census Mining: Industry Series: Selected Supplies, Minerals Received for Preparation, Purchased Machinery, and Fuels Consumed by Type for the United States: 2012 (Washington, DC, February 27, 2015), [https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ECN\\_2012\\_US\\_215M1&prodType=table](https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ECN_2012_US_215M1&prodType=table).
- [12] U.S. Census Bureau, 2012 Economic Census; Construction: Industry Series: Detailed Statistics by Industry for the United States: 2012 (Washington, DC, January 12, 2015), [https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ECN\\_2012\\_US\\_235G01&prodType=table](https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ECN_2012_US_235G01&prodType=table).
- [13] Federal Register 79 FR 103, pp. 30934-31014, Washington, DC, May 29, 2014, <http://www.gpo.gov/fdsys/pkg/FR-2014-05-29/pdf/2014-11201.pdf>.

[14] California Air Resources Board “California Code of Regulations, Title 17, Division 3, Chapter 1, Subchapter 10, Article 5 §95800 - §96022” (Sacramento, CA, June 14, 2014), <https://www.arb.ca.gov/regact/2014/capandtrade14/candtfroal.pdf>.

[15] California Global Warming Solutions Act §38566 as amended (Sacramento, CA, September 8, 2016), [http://leginfo.legislature.ca.gov/faces/billCompareClient.xhtml?bill\\_id=201520160SB32\\_](http://leginfo.legislature.ca.gov/faces/billCompareClient.xhtml?bill_id=201520160SB32_)

[16] Based on personal communication with CARB staff and calculations of Table II-3, page 43, of California Air Resources Board “The 2017 Climate Change Scoping Plan Update,” (Sacramento, CA, January 20, 2017), <https://www.arb.ca.gov/cc/scopingplan/scopingplan.htm>.