Delivered Energy Consumption Projections by Industry in the *Annual Energy Outlook 2002*

by
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This paper presents delivered energy consumption and intensity projections for the industries included in the industrial sector of the National Energy Modeling System (NEMS).[1] *Delivered energy consumption for the industrial sector as a whole is routinely reported in the* Annual Energy Outlook, *but the detailed projections for each of the groupings within the industrial sector are not generally discussed. The detailed projections in this paper are grouped into three categories: energy-intensive manufacturing sectors, non-intensive manufacturing sectors, and non-manufacturing industries. The results for the three groups are discussed, as well as results for the industries within each group.*

Introduction and Summary

NEMS projections for delivered energy consumption in the U.S. industrial sector are regularly reported in the aggregate; however, detailed projections usually are not discussed. The detailed projections in this paper are grouped into three categories: energy-intensive manufacturing, non-intensive manufacturing, and non-manufacturing. The industries in each category and their corresponding North American Industry Classification System (NAICS) codes are shown in Table 1.

The energy-intensive manufacturing group includes food, paper, bulk chemicals, petroleum refining, glass, cement, steel, and aluminum. The energy-intensive manufacturing industries consume large quantities of energy, have high energy intensities, or both. All the energy-intensive industries are modeled in the NEMS Industrial Sector Demand Module, except for petroleum refining, which is modeled in the Petroleum Market Model. As implied by its name, the energy-intensive group used a disproportionate share of total delivered industrial energy consumption in 1998 relative to its contribution to industrial output,[2] accounting for 22.4 percent of industrial output and 63.8 percent of delivered energy consumed for all (fuel and non-fuel) purposes within the industrial sector (Table 2). As a result, delivered energy consumption per dollar of output for the energy-intensive group was well above the industry average in 1998.

The non-intensive manufacturing group consists of (1) metal-based durables, which includes fabricated metal products, machinery, computers and electronics, and electrical and transportation equipment; and (2) the balance of manufacturing, which is a diverse collection of industries such as beverages and tobacco, textiles and apparel, printing, furniture, and plastics and rubber products. The non-intensive manufacturing group accounted for 56.7 percent of industrial output in 1998 but consumed only 17.2 percent of total delivered industrial energy.

The non-manufacturing group includes crops, other agriculture, coal mining, oil and gas extraction, other mining, and construction. In total, this group provided 20.8 percent of industrial output and consumed 19.0 percent of delivered industrial energy in 1998.

Not only did the non-intensive manufacturing group account for more than one-half of industrial output in 1998, its output is projected to grow more rapidly over the projection period than the other two categories

[1]The projections in this paper are based on the reference case NEMS model run prepared for Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001). The reference case focuses on long-term events, including the supplies and prices of fossil fuels, the development of U.S. electricity markets, technology improvement, and the impact of economic growth on projected energy demand through 2020. EIA uses NEMS to produce the *Annual Energy Outlook* and other analysis reports. See EIA, *The National Energy Modeling System: An Overview*, DOE/EIA-0581(2000) (Washington, DC, March 2000).

[2]Throughout this report, 1998 is used as the historical reference year because that is the latest data year for manufacturing delivered energy consumption collected in EIA's Manufacturing Energy Consumption Survey. Projected growth rates are from 2000 through 2020 because that is the period published in the *Annual Energy Outlook 2002*.

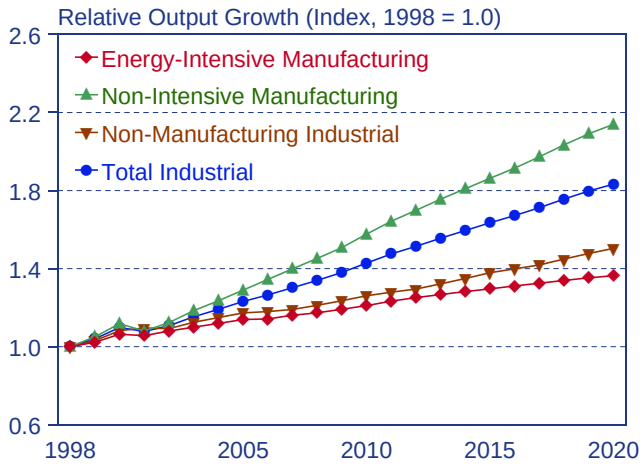
(Figure 1). As a result, the energy-intensive group is projected to fall from 22.4 percent of industrial output in 1998 to 16.7 percent in 2020, and from 63.8 percent of industrial delivered energy consumption in 1998 to 59.0 percent in 2020 (Table 3). The non-intensive manufacturing group is projected to gain share of both output and delivered energy consumption between 1998 and 2020. The output share for the non-manufacturing group is projected to decrease between 1998 and 2020, and its delivered energy consumption share is projected to increase. All three groups are projected to consume less energy per unit of output in 2020 than they did in 1998 (Figure 2).

Table 1. Sectoral Detail within the NEMS Industrial Sector Demand Module

Industry	NAICS Coverage
Energy-Intensive Manufacturing	
Food	311
Paper	322
Bulk Chemicals	325110, 325120, 325181, 325188, 325192, 325199, 325211, 325212, 325222, 325311, 325312
Petroleum Refining	32411
Glass	3272
Cement	32731
Steel	331111
Aluminum	3313
Non-Intensive Manufacturing	
Metal-Based Durables	332 through 336
Balance of Manufacturing	All remaining manufacturing NAICS codes
Non-Manufacturing	
Agriculture—Crops	111
Agriculture—Other	112 through 115
Coal Mining	2121
Oil and Gas Extraction	211
Other Mining	2122 through 2123
Construction	233 through 235

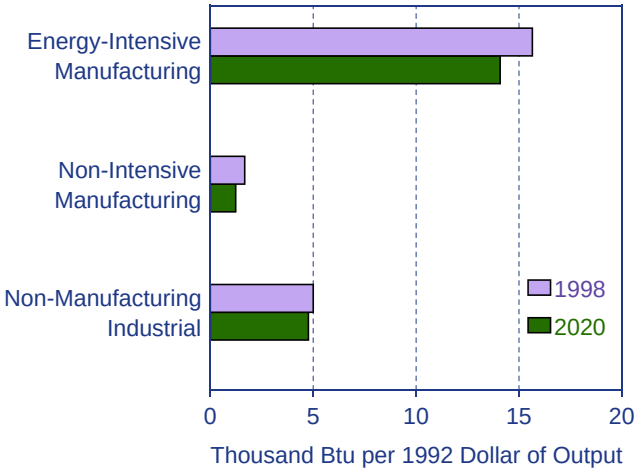
Source: Energy Information Administration, Office of Integrated Analysis and Forecasting.

Figure 1. Industrial Sector Output Growth by Industry Group, 1998-2020



Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 2. Delivered Energy Consumption per Unit of Output by Industry Group, 1998 and 2020



Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/ contents.html.

Table 2. Summary of Industry Output and Delivered Energy Consumption by Group, 1998

Industry Group	1998 Gross Output (Billion 1992 Dollars)	1998 Share of Industrial Gross Output (Percent)	1998 Delivered Energy Consumption (Trillion Btu)	1998 Share of Industrial Delivered Energy Consumption (Percent)	Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)
Energy-Intensive Manufacturing	1,034	22.4	16,178	63.8	15.65
Non-Intensive Manufacturing	2,614	56.7	4,370	17.2	1.67
Total Manufacturing	*3,648*	*79.2*	*20,548*	*81.0*	*5.63*
Non-Manufacturing	960	20.8	4,805	19.0	5.00
Total Industrial	**4,608**	**100.0**	**25,353**	**100.0**	**5.50**

Note: Totals and percentages calculated from unrounded data.
Sources: **Gross Output:** Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001). **Delivered Energy Consumption:** EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Table 3. Summary of Industry Output and Delivered Energy Consumption by Group, 2020

Industry Group	2020 Gross Output (Billion 1992 Dollars)	2020 Share of Industrial Gross Output (Percent)	2020 Delivered Energy Consumption (Trillion Btu)	2020 Share of Industrial Delivered Energy Consumption (Percent)	Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)
Energy-Intensive Manufacturing	1,410	16.7	19,865	59.0	14.09
Non-Intensive Manufacturing	5,593	66.2	6,890	20.5	1.23
Total Manufacturing	*7,003*	*82.9*	*26,755*	*79.5*	*3.82*
Non-Manufacturing	1,444	17.1	6,888	20.5	4.77
Total Industrial	**8,447**	**100.0**	**33,643**	**100.0**	**3.98**

Note: Totals and percentages calculated from unrounded data.
Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Methodology and Data

NEMS Industrial Sector Demand Module

Energy use in the industrial sector is modeled for three broad consumption categories.[3] The process and assembly (PA) component covers the energy used directly for industrial production. The building (BLD) component includes end uses such as lighting and heating, ventilation, and air conditioning (HVAC). The boiler, steam, cogeneration (BSC) component includes energy used internally to produce steam or electricity for use in the buildings and process and assembly components.

In the PA component, the NEMS industrial module uses "technology bundles" to characterize technological change over time. These bundles are defined for each production process step for five of the manufacturing industries, and for each end use in the remaining four manufacturing industries (excluding petroleum refining[4]). The five industries for which process steps are modeled are paper, glass, cement, steel, and aluminum. The activities of these industries are fairly homogeneous, making them amenable to a process step representation. The four industries for which end uses are modeled are food, bulk chemicals, metal-based durables, and the balance of manufacturing. Due to data

[3]The projection methodology for the NEMS Industrial Sector Demand Module is documented in Energy Information Administration (EIA), *Model Documentation Report: Industrial Sector Demand Module of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001). The methodology of NEMS is summarized in EIA, *The National Energy Modeling System: An Overview*, DOE/EIA-0581(2000) (Washington, DC, March 2000).

[4]Delivered energy consumption in the petroleum refining sector is modeled in the NEMS Petroleum Market Model, which is discussed separately.

limitations, energy consumption in the six non-manufacturing industries (agriculture—crops, agriculture—other, coal mining, oil and gas extraction, other mining, and construction) is modeled by fuel rather than by process step or end use.

Specific technologies are not characterized by cost and performance, but the evaluation of the likely change in energy intensity for a process step incorporates expectations about specific technologies. Overall energy intensities for discrete production process steps are used. The industrial module incorporates data from Arthur D. Little[5] about projected trends in delivered energy intensity for process steps or end uses in the manufacturing sectors.[6]

Energy intensity is measured as the unit energy consumption (UEC), defined as the energy use per ton of throughput for the process step industries, and as energy use per dollar of output for the end-use industries. For each process step or end use within an industry, three Relative Energy Intensity (REI) ratios were developed, based on engineering analysis of likely trends in technology availability and adoption. The REI 2020 for old facilities is the ratio of 2020 delivered energy intensity to 1998 delivered energy intensity for existing facilities. The REI 1998 for new facilities is the ratio of the delivered energy intensity of new state-of-the-art facilities in 1998 to the average existing delivered energy intensity in 1998. Similarly, the REI 2020 for new facilities is the projected delivered energy intensity of new state-of-the-art facilities in 2020 relative to the average existing 1998 intensity.

The REIs capture the technological trends that result in decreased delivered energy intensity over time, independent of other economic factors, such as energy prices. If energy prices increase substantially, the delivered energy intensity of added capacity could approach the REI 2020 for new facilities several years before 2020. In the model, the REIs for intervening years are extrapolated using Technology Possibility Curves (TPCs), which are linear extrapolations from 1998 to 2020. The TPCs map out a smooth transition from the energy intensity of current (1998) equipment to the energy intensity of expected future (2020) equipment.

Petroleum Market Model

Petroleum refining is modeled separately from the other industries, in the NEMS Petroleum Market Model (PMM).[7] The PMM simulates the operation of refineries in the United States,[8] including the supply and transportation of crude oil to refineries, the processing of raw materials into petroleum products, and the distribution of petroleum products to meet regional demands. The essential outputs of this model are product prices, a petroleum supply / demand balance, demands for refinery fuel use, and capacity expansion at existing refineries. Delivered energy intensity for the petroleum refining industry is measured as the refinery fuel consumed per barrel of output.

Industry Profile

The eight energy-intensive industries collectively accounted for 63.8 percent of industrial delivered energy consumption in 1998 (Table 4). The individual industry shares range from 0.8 percent (198 trillion Btu) for the glass industry to 26.4 percent (6,697 trillion Btu) for the bulk chemicals industry. At the same time, the energy-intensive industries accounted for 22.4 percent ($1,034 billion) of total industrial output in 1998.[9] Historically, these industries' outputs are small compared with total output for the industrial sector. Cement is the smallest at $5.2 billion, a 0.1-percent share. Food is the largest at $444.4 billion, a 9.6-percent share of industrial output.

The non-intensive manufacturing group provided 56.7 percent of industrial output in 1998 and accounted for only 17.2 percent of industrial delivered energy consumption. The non-manufacturing category accounted for 20.8 percent of industrial output and 19.0 percent of delivered energy consumption in 1998.

Delivered energy consumption per unit of output differs widely among the three groups. Not surprisingly, the energy-intensive category had the highest delivered energy consumption per unit of output in 1998, at 15.65 thousand Btu per 1992 dollar of output. The non-intensive manufacturing group used approximately one-tenth that much energy (1.67 thousand Btu) per unit of output in 1998. Delivered energy intensity for the

[5]Arthur D. Little, Inc., *Industrial Model: Update on Energy Use and Industrial Characteristics*, Final Report Prepared for DAC / EIA (Cambridge, MA, September 2001).

[6]The data from Arthur D. Little were revised to incorporate information from EIA's *1998 Manufacturing Energy Consumption Survey* (web site www.eia.doe.gov / emeu / mecs / mecs98 / datatables / contents.html). Previous data have been evaluated in two multi-laboratory studies: Interlaboratory Working Group, *Scenarios of U.S. Carbon Reductions*, ORNL / CON-444 and LBNL-40533 (Oak Ridge, TN: Oak Ridge National Laboratory; and Berkeley, CA: Lawrence Berkeley National Laboratory; September 1997), web site www.ornl.gov / ORNL / Energy_Eff / labweb.htm; and Interlaboratory Working Group, *Scenarios for a Clean Energy Future*, ORNL / CON-476 and LBNL-44029 (Oak Ridge, TN: Oak Ridge National Laboratory; and Berkeley, CA: Lawrence Berkeley National Laboratory; November 2000), web site www.ornl.gov / ORNL / Energy_Eff / CEF.htm.

[7]Energy Information Administration, *EIA Model Documentation: Petroleum Market Model of the National Energy Modeling System*, DOE / EIA-M059(2002) (Washington, DC, March 2002).

[8]The NEMS International Energy Module contains the representation for foreign refinery operations.

[9]The value of output is denominated in constant 1992 dollars.

Table 4. Industry Output and Delivered Energy Consumption by Sector, 1998

Industry	1998 Gross Output (Billion 1992 Dollars)	1998 Share of Industrial Gross Output (Percent)	1998 Delivered Energy Consumption (Trillion Btu)	1998 Share of Industrial Delivered Energy Consumption (Percent)	Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)
Energy-Intensive Manufacturing	**1,033.9**	**22.4**	**16,178**	**63.8**	**15.65**
Food	444.4	9.6	1,029	4.1	2.32
Paper	143.8	3.1	2,726	10.8	18.95
Bulk Chemicals	162.6	3.5	6,697	26.4	41.19
Petroleum Refining	150.7	3.3	3,127	12.3	20.75
Glass	21.3	0.5	198	0.8	9.31
Cement	5.2	0.1	356	1.4	68.01
Steel	70.6	1.5	1,590	6.3	22.53
Aluminum	35.3	0.8	454	1.8	12.87
Non-Intensive Manufacturing	**2,614.2**	**56.7**	**4,370**	**17.2**	**1.67**
Metal-Based Durables	1,586.6	34.4	1,466	5.8	0.92
Balance of Manufacturing	1,027.5	22.3	2,904	11.5	2.83
Total Manufacturing	***3,648.0***	***79.2***	***20,548***	***81.0***	***5.63***
Non-Manufacturing	**960.4**	**20.8**	**4,805**	**19.0**	**5.00**
Agriculture—Crops	103.4	2.2	711	2.8	6.87
Agriculture—Other	169.6	3.7	412	1.6	2.43
Coal Mining	30.7	0.7	87	0.3	2.85
Oil and Gas Extraction	105.3	2.3	1,509	6.0	14.32
Other Mining	27.8	0.6	310	1.2	11.13
Construction	523.4	11.4	1,776	7.0	3.39
Total Industrial	**4,608.4**	**100.0**	**25,353**	**100.0**	**5.50**

Note: Totals and percentages calculated from unrounded data.

Sources: **Gross Output:** Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001). **Delivered Energy Consumption:** EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

non-manufacturing group fell between those for the two manufacturing categories. The non-manufacturing group used about one-third as much energy as the energy-intensive manufacturing group (5.00 thousand Btu) per unit of output in 1998.

Results

Energy and output projections are presented in this section. The major determinants of industrial delivered energy consumption are discussed, followed by projection details for each of the individual industries. Two tables are provided for each sector. The first provides information on how an industry is modeled, indicating either the process steps or end uses considered and the assumed rate at which they change over the forecast period. The second table for each industry summarizes economic output, delivered energy consumption, and delivered energy intensity projections.

Two figures are also provided for each sector. The first figure compares projected gross output growth for that sector with projected gross output for the industrial sector as a whole. Both series are indexed (with the 1998 value equal to 1.0) so that projected growth for the individual sector relative to projected growth for all of industry is readily apparent. The second figure shows projected gross output, delivered energy consumption, and delivered energy intensity for the sector. Again, the three series are indexed to 1998 so that relative changes are more easily identified.

Economic Output and Energy Price Assumptions

The average intensity decline rate for each industry is determined by the REIs and by the rate and timing of new additions to capacity. The rate and timing of new additions are a function of baseline equipment retirement rates and industry growth rates. Retirement rates are estimated for the base year and held constant in the absence of energy price increases. If energy prices increase by more than 10 percent, retirement rates are increased from their baseline levels to as much as double the base year rates to reflect more rapid capital turnover when operating costs increase.

Output growth for the industrial sector has historically not kept pace with overall economic growth, as measured by real gross domestic product (GDP). Between 1978 and 2000, total industrial sector output growth averaged 1.9 percent per year, while real GDP growth averaged 3.1 percent per year (Table 5). Furthermore, within the industrial sector, the energy-intensive industries have generally grown more slowly than the industrial average. Paper was the only energy-intensive sector that matched growth for the industrial sector as a whole between 1978 and 2000. Growth for all other energy-intensive sectors was below the industrial average.

The economic projections included in the *Annual Energy Outlook 2002* continue these trends. Output growth for the industrial sector as a whole is projected to be lower than GDP growth, and the individual growth rates for the energy-intensive industries lag behind the industrial average (Table 5). Over the 2000-2020 period, the projected growth rate for the fastest growing energy-intensive industry (paper) is about 60 percent of the projected growth rate for industry as a whole.

Table 5. Industry Output Growth Rates, History and Projections, 1978-2020

Industry	Average Annual Output Growth Rate, 1978-2000 (Percent)	2000 Gross Output (Billion 1992 Dollars)	2020 Gross Output (Billion 1992 Dollars)	Average Annual Output Growth Rate, 2000-2020 (Percent)
Energy-Intensive Manufacturing	**1.0**	**1,100.2**	**1,410.2**	**1.2**
Food	1.8	479.5	624.8	1.3
Paper	2.0	154.5	214.3	1.6
Bulk Chemicals	0.6	178.7	223.2	1.1
Petroleum Refining	-0.3	152.6	181.1	0.9
Glass	1.1	22.9	29.3	1.2
Cement	0.5	5.6	7.1	1.2
Steel	-0.9	70.4	84.6	0.9
Aluminum	0.2	36.1	45.9	1.2
Non-Intensive Manufacturing	**2.4**	**2,922.2**	**5,592.8**	**3.3**
Metal-Based Durables	2.9	1,830.3	3,983.6	4.0
Balance of Manufacturing	1.6	1,091.9	1,609.1	2.0
Total Manufacturing	***2.0***	***4,022.4***	***7,003.0***	***2.8***
Non-Manufacturing	**1.9**	**1,039.2**	**1,444.4**	**1.7**
Agriculture—Crops	2.0	118.0	153.1	1.3
Agriculture—Other	2.7	185.2	232.5	1.1
Coal Mining	2.5	29.1	36.0	1.1
Oil and Gas Extraction	-0.2	107.4	140.5	1.3
Other Mining	1.0	29.0	35.9	1.1
Construction	2.1	570.4	846.5	2.0
Total Industrial	**1.9**	**5,061.6**	**8,447.4**	**2.6**
Real GDP (Billion 1996 Dollars)	**3.1**	**9,224.0**	**16,525.5**	**3.0**

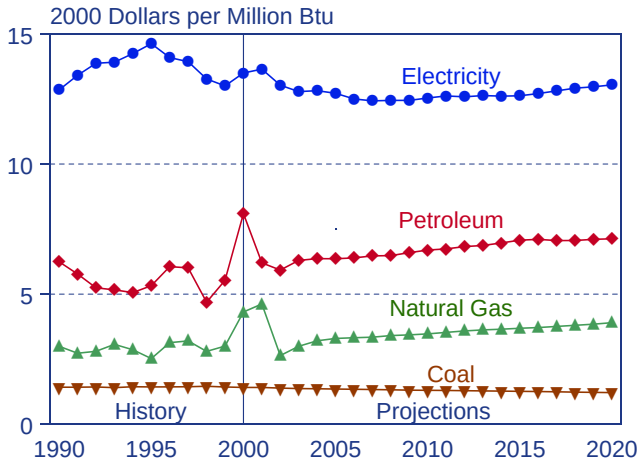
Note: Totals and percentages calculated from unrounded data.
Source: Energy Information Administration, *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Industrial energy price projections from the *Annual Energy Outlook 2002* are shown in Table 6. Petroleum and natural gas prices are projected to retreat from the high levels that prevailed in 2000 and 2001 to more normal levels in 2002. Figure 3 shows the industrial sector energy price projections. Between 2002 and 2020, natural gas and petroleum prices are projected to increase, electricity prices are projected to remain fairly constant, and steam coal prices are projected to decline. These prices are average prices for the entire industrial sector and are not specific to any particular industry.

Energy-Intensive Manufacturing Sectors

The energy-intensive manufacturing sectors are mature, basic industries. These industries are projected to grow more slowly than the total industrial sector (Table 7), with the average growth for the group (1.2 percent) projected at less than half the rate of the industrial sector total (2.6 percent). Within the group, the projected growth rates range from a low of 0.9 percent for the petroleum refining and steel industries to 1.6 percent for the paper industry.

Figure 3. Industrial Sector Delivered Energy Prices by Fuel, 1990-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Table 6. Industrial Sector Delivered Energy Prices by Fuel, 1998-2020

Fuel	Industrial Energy Prices (2000 Dollars per Million Btu)					Annual Growth Rate, 2000-2020 (Percent)	Annual Growth Rate, 2002-2020 (Percent)
	1998	2000	2002	2010	2020		
Petroleum	4.69	8.10	5.92	6.69	7.13	-0.6	1.0
Natural Gas	2.80	4.31	2.64	3.47	3.90	-0.5	2.2
Steam Coal	1.46	1.41	1.39	1.30	1.21	-0.8	-0.7
Electricity	13.27	13.50	13.03	12.54	13.04	-0.2	0.0

Note: Totals and percentages calculated from unrounded data.
Source: Energy Information Administration, *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Table 7. Economic Output for the Energy-Intensive Manufacturing Sectors, 1998-2020

Industry	Industry Output (Billion 1992 Dollars)				Annual Growth Rate, 2000-2020 (Percent)
	1998	2000	2010	2020	
Energy-Intensive Manufacturing	**1,033.9**	**1,100.2**	**1,251.2**	**1,410.2**	**1.2**
Food	444.4	479.5	541.5	624.8	1.3
Paper	143.8	154.5	183.6	214.3	1.6
Bulk Chemicals	162.6	178.7	200.6	223.2	1.1
Petroleum Refining	150.7	152.6	171.5	181.1	0.9
Glass	21.3	22.9	26.4	29.3	1.2
Cement	5.2	5.6	6.5	7.1	1.2
Steel	70.6	70.4	78.7	84.6	0.9
Aluminum	35.3	36.1	42.4	45.9	1.2
Industrial Sector Total	**4,608.4**	**5,061.6**	**6,584.5**	**8,447.4**	**2.6**

Note: Totals and percentages calculated from unrounded data.
Source: Energy Information Administration, *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Food Industry

The food industry consists of NAICS code 311. This 3-digit NAICS designation includes nine 4-digit industries: animal food manufacturing (NAICS code 3111), grain and oilseed milling (NAICS code 3112), sugar and confectionery product manufacturing (NAICS code 3113), fruit and vegetable preserving and specialty food manufacturing (NAICS code 3114), dairy product manufacturing (NAICS code 3115), animal slaughtering and processing (NAICS code 3116), seafood product preparation and packaging (NAICS code 3117), bakeries and tortilla manufacturing (NAICS code 3118), and other food manufacturing (NAICS code 3119). Beverage manufacturers were part of the food industry under the Standard Industrial Classification (SIC) system, but they are included with tobacco product manufacturing under the NAICS. In NEMS, the food industry is modeled as an end-use industry due to the wide array of physical products. The end uses are process heating, process cooling and refrigeration, machine drive, and miscellaneous end uses. The REIs for the end uses are shown in Table 8.

The food industry's gross value of output grew 1.8 percent annually over the 1978-2000 period to $479.5 billion in 2000. Over the 2000-2020 period, output is projected to grow 1.3 percent per year to $624.8 billion in 2020 (Table 9). The output growth rate for the food industry trails total industrial output growth (Figure 4).

Delivered energy consumption in the food industry, which was 1,029 trillion Btu in 1998, is projected to rise by 0.9 percent annually, from 1,098 trillion Btu in 2000 to 1,313 trillion Btu in 2020. Together with the projected output growth of 1.3 percent, this yields a projected delivered energy intensity decline of 0.4 percent per year. Natural gas is the dominant fuel in the food industry, accounting for approximately 50 percent of the energy consumed throughout the forecast period. While natural gas remains the largest energy source, consumption of renewables is projected to grow most rapidly as the industry becomes more proficient in recovering and utilizing agricultural waste. More than three-quarters of the energy consumed in the food industry is used in the process and assembly component. The remaining energy use is split fairly evenly between the buildings and boiler, steam, cogeneration components. Figure 5 shows the indexed growth of gross output, delivered energy consumption, and delivered energy intensity for the food industry.

Paper Industry

The paper industry consists of NAICS code 322. The pulp and paper industry produces pulp and a variety of paper products using fibers from timber or from recycled paper products. The pulp and paper industry is very energy intensive. However, it meets a large share of its energy demand by recovery and consumption of waste pulping fibers and wood waste. The production steps are wood preparation, waste fibers/repulping, mechanical pulping, semi-chemical pulping, chemical (kraft, sulfite) pulping, bleaching, and paper making (Table 10).

The paper industry's value of gross output grew by 2.0 percent annually from 1978 to 2000. In the forecast period of 2000 to 2020, gross output for the paper industry is projected to grow by 1.6 percent annually (Table 11). The U.S. paper industry is relatively mature and will face increasing competition in foreign markets, which reduces the projected industry growth rate. The projected output growth rate for the paper industry trails total industrial output growth (Figure 6).

Delivered energy consumption in the paper industry was 2,726 trillion Btu in 1998. Over the 2000-2020 period, delivered energy consumption is projected to increase by 0.8 percent per year, reaching 3,324 trillion Btu in 2020. Growth in delivered energy consumption is dampened by increased waste pulping, which uses less energy per ton than other pulping methods, and a rapid projected fall in delivered energy intensity for kraft pulping and papermaking, as indicated by their REIs in Table 10. Consequently, the paper industry's delivered energy intensity is projected to decline by 0.8 percent per year between 2000 and 2020.

Table 8. Food Industry Coefficients for Technology Possibility Curves

	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
Energy End Use	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Process Heating	1.000	0.918	-0.0039	0.900	0.818	-0.0044	1.7
Process Cooling	1.000	0.897	-0.0049	0.850	0.768	-0.0046	1.7
Machine Drive	1.000	0.918	-0.0039	0.960	0.861	-0.0049	1.7
Miscellaneous	1.000	0.929	-0.0033	0.915	0.828	-0.0045	1.7

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

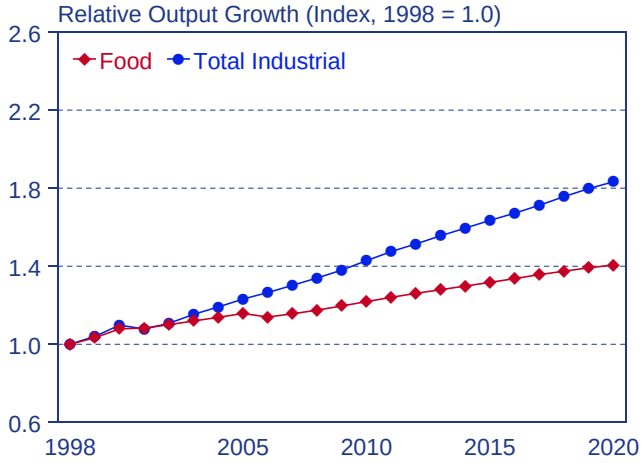
Table 9. Food Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**444.4**	**479.5**	**541.5**	**624.8**	**1.3**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	30	32	33	35	0.5
Natural Gas	536	554	601	650	0.8
Steam Coal	125	148	153	174	0.8
Renewables	130	141	168	204	1.9
Non-Electric Delivered Energy	*822*	*875*	*954*	*1,063*	*1.0*
Purchased Electricity	208	223	228	249	0.6
Total Delivered Energy	**1,029**	**1,098**	**1,182**	**1,313**	**0.9**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	0.07	0.07	0.06	0.06	-0.8
Natural Gas	1.21	1.16	1.11	1.04	-0.5
Steam Coal	0.28	0.31	0.28	0.28	-0.5
Renewables	0.29	0.29	0.31	0.33	0.5
Non-Electric Delivered Energy	*1.85*	*1.83*	*1.76*	*1.70*	*-0.4*
Purchased Electricity	0.47	0.47	0.42	0.40	-0.8
Total Delivered Energy	**2.32**	**2.29**	**2.18**	**2.10**	**-0.4**

Note: Totals and percentages calculated from unrounded data.

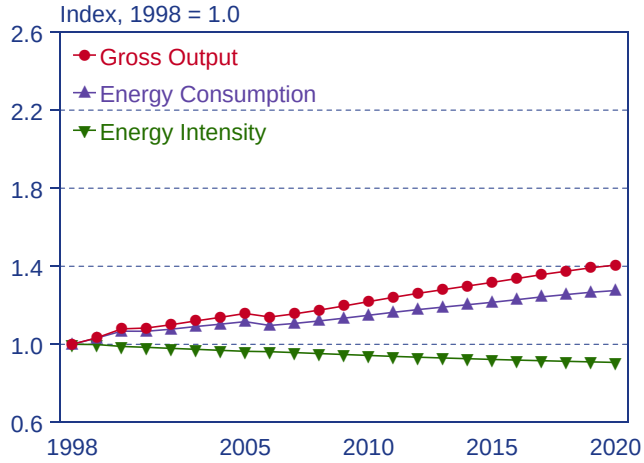
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Figure 4. Relative Changes in Gross Output: Food Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 5. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Food Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/ contents.html.

Typically, the largest improvement in delivered energy intensity occurs when existing facilities are replaced rather than from improvements in energy efficiency within existing facilities. For example, a new state-of-the-art wood preparation facility in 1998 was 87 percent as energy intensive as the average existing wood preparation plant (Table 10). By 2020, a new state-of-the-art wood preparation facility would be 85 percent as energy intensive as the average existing wood preparation plant in 1998.

The process and assembly component consumes approximately three-quarters of the energy used in the paper industry, while the boiler, steam, cogeneration component consumes approximately one-quarter (the buildings component uses only 3 percent). The relatively large share for the boiler, steam, cogeneration component arises because the pulp and paper industry has extensive steam requirements, which are largely met through the use of renewable energy sources, primarily

Table 10. Paper Industry Coefficients for Technology Possibility Curves

Process Step	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Wood Preparation	1.000	0.937	-0.0030	0.873	0.851	-0.0012	2.3
Waste Pulping	1.000	0.952	-0.0022	0.936	0.893	-0.0022	2.3
Mechanical Pulping	1.000	0.932	-0.0032	0.868	0.840	-0.0015	2.3
Semi-Chemical Pulping	1.000	0.896	-0.0050	0.876	0.770	-0.0059	2.3
Chemical (Kraft, Sulfite) Pulping	1.000	0.847	-0.0075	0.876	0.670	-0.0121	2.3
Bleaching	1.000	0.894	-0.0051	0.900	0.769	-0.0071	2.3
Paper Making	1.000	0.831	-0.0084	0.900	0.640	-0.0154	2.3

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

Table 11. Paper Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**143.8**	**154.5**	**183.6**	**214.3**	**1.6**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	186	189	172	154	-1.0
Natural Gas	652	614	580	619	0.0
Steam Coal	326	337	294	280	-0.9
Renewables	1,318	1,403	1,674	1,978	1.7
Non-Electric Delivered Energy	*2,482*	*2,544*	*2,719*	*3,030*	*0.9*
Purchased Electricity	243	263	267	294	0.6
Total Delivered Energy	**2,726**	**2,807**	**2,986**	**3,324**	**0.8**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	1.30	1.22	0.94	0.72	-2.6
Natural Gas	4.53	3.98	3.16	2.89	-1.6
Steam Coal	2.26	2.18	1.60	1.30	-2.5
Renewables	9.17	9.08	9.12	9.23	0.1
Non-Electric Delivered Energy	*17.26*	*16.47*	*14.81*	*14.14*	*-0.8*
Purchased Electricity	1.69	1.70	1.45	1.37	-1.1
Total Delivered Energy	**18.95**	**18.17**	**16.26**	**15.51**	**-0.8**

Note: Totals and percentages calculated from unrounded data.

Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

byproducts of the wood preparation and virgin pulping processes. Biomass consumption in the paper industry is projected to increase by 1.7 percent annually, reaching 1,978 trillion Btu in 2020, 60 percent of total delivered energy consumption in the paper industry in that year. Indexed growth of output, delivered energy consumption, and delivered energy intensity are shown in Figure 7.

Bulk Chemicals Industry

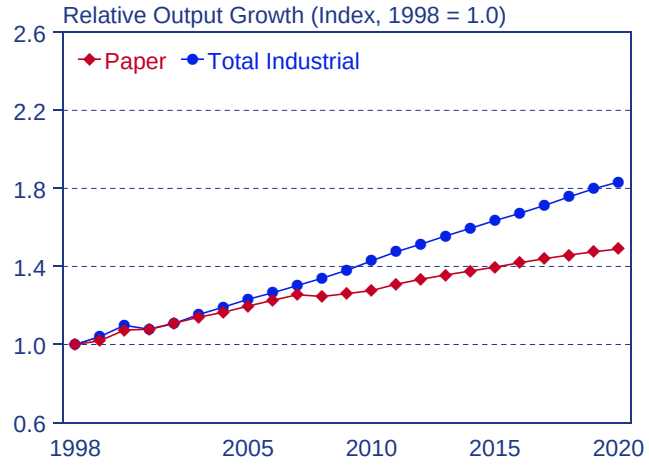
The bulk chemicals industry consists of petrochemical manufacturing (NAICS code 325110), industrial gas manufacturing (NAICS code 325120), alkalies and chlorine manufacturing (NAICS code 325181), all other basic inorganic chemical manufacturing (NAICS code 325188), cyclic crude and intermediate manufacturing (NAICS code 325192), all other basic organic chemical manufacturing (NAICS code 325199), plastics material and resin manufacturing (NAICS code 325211), synthetic rubber manufacturing (NAICS code 325212), noncellulosic organic fiber manufacturing (NAICS code 325222), nitrogenous fertilizer manufacturing (NAICS code 325311), and phosphatic fertilizer manufacturing (NAICS code 325312). This definition excludes items such as pharmaceuticals, paints, and soaps. In NEMS, the bulk chemicals industry is modeled as an end-use industry due to the wide array of physical products. The end uses are process heating, process cooling and refrigeration, machine drive, electrochemical processes, and miscellaneous end uses. The REIs for the end uses are shown in Table 12.

The bulk chemicals industry's gross value of output grew by 0.6 percent annually over the 1978-2000 period to $178.7 billion in 2000. The industry's growth rate over that period was dampened by its relatively slow recovery from the economic recession of 1991. Over the 2000-2020 period, output is projected to grow by 1.1 percent per year to $223.2 billion in 2020 (Table 13). Output growth for the bulk chemicals industry is projected to be slower than the industry average (Figure 8).

More than one-half of the energy used in the bulk chemicals industry is for feedstock purposes. The current projection does not include significant opportunities to reduce feedstock requirements because feedstock input demands are based on molecular requirements not the caloric value of the input. Future developments could lead to increased use of bioengineered feedstocks to replace hydrocarbon feedstocks.

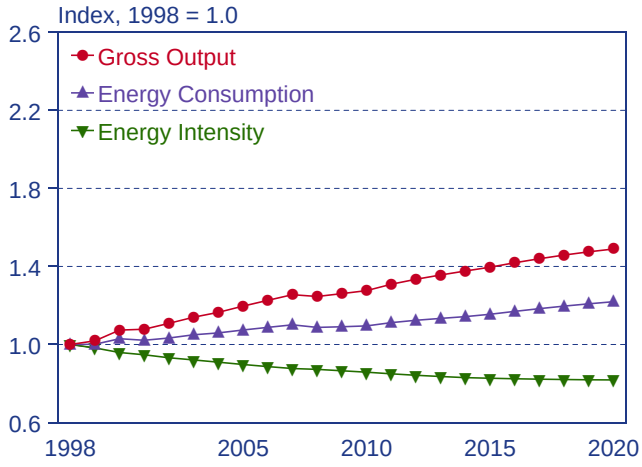
Delivered energy consumption in the bulk chemicals industry was 6,697 trillion Btu in 1998, more than one-quarter of total delivered energy consumption for the industrial sector. Approximately 90 percent of non-feedstock energy in the bulk chemicals industry was consumed in the process and assembly component. Natural gas is the dominant fuel source in the bulk chemicals industry, accounting for 60 percent of the energy used for heat and power. The industry's delivered energy intensity is projected to fall by 0.2 percent annually in the forecast period. Together with the output forecast, this yields projected delivered energy

Figure 6. Relative Changes in Gross Output: Paper Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 7. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Paper Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/ contents.html.

consumption of 8,632 trillion Btu in 2020. Figure 9 shows the indexed growth projections for gross output, delivered energy consumption, and delivered energy intensity in the bulk chemicals industry.

Petroleum Refining Industry

The petroleum refining industry is categorized under NAICS code 32411. The industry produces a variety of petroleum fuel products, including gasoline, distillate fuel oil, jet fuel, residual fuel oil, and liquefied petroleum gases. Refineries use various physical and chemical processes to convert crude oil into petroleum products. Crude oil is first distilled into various intermediate streams, which are then further processed by an array of downstream units. Refineries are categorized as simple or complex, depending on the types of downstream processes they employ. A refinery's complexity will determine the types of crude oils it can process and the composition of its product slate. The more complex refineries will produce a larger share of lighter-end products, such as gasoline, and value-added products, such as lube oil and petrochemicals.

Table 12. Bulk Chemicals Industry Coefficients for Technology Possibility Curves

Energy End Use	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Process Heating	1.000	0.918	-0.0039	0.900	0.818	-0.0044	1.7
Process Cooling	1.000	0.897	-0.0049	0.850	0.768	-0.0046	1.7
Machine Drive	1.000	0.918	-0.0039	0.960	0.861	-0.0049	1.7
Electrochemical	1.000	0.984	-0.0008	0.950	0.868	-0.0041	1.7
Miscellaneous	1.000	0.929	-0.0033	0.915	0.828	-0.0045	1.7

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

Table 13. Bulk Chemicals Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**162.6**	**178.7**	**200.6**	**223.2**	**1.1**
Delivered Energy Consumption (Trillion Btu)					
Petroleum, Including LPG Feedstocks	2,172	2,381	2,595	2,851	0.9
Natural Gas, Including Feedstocks	2,474	2,611	2,877	3,103	0.9
Steam Coal	176	208	229	260	1.1
Non-Electric Delivered Energy	*4,822*	*5,200*	*5,702*	*6,214*	*0.9*
Purchased Electricity	473	516	532	570	0.5
Petrochemical Feedstocks	1,402	1,532	1,687	1,847	0.9
Total Delivered Energy	**6,697**	**7,249**	**7,921**	**8,632**	**0.9**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum, Including LPG Feedstocks	13.36	13.32	12.94	12.78	-0.2
Natural Gas, Including Feedstocks	15.21	14.62	14.34	13.91	-0.2
Steam Coal	1.08	1.17	1.14	1.17	-0.0
Non-Electric Delivered Energy	*29.65*	*29.11*	*28.42*	*27.85*	*-0.2*
Purchased Electricity	2.91	2.89	2.65	2.56	-0.6
Petrochemical Feedstocks	8.63	8.58	8.41	8.28	-0.2
Total Delivered Energy	**41.19**	**40.57**	**39.48**	**38.68**	**-0.2**

Notes: LPG = Liquefied Petroleum Gas. Totals and percentages calculated from unrounded data.

Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Petroleum refining is a highly energy-intensive process, in which crude oil and intermediate streams are subjected to high pressure and temperature. The majority of energy consumed in a refinery is used for fluid heating and steam generation. A large share of the industry's energy demand is met with petroleum fuels produced by the same refineries that use it. The processing of crude oil results in a significant amount of process off-gas, termed still gas, which can be recovered and used as fuel in gas-fired fluid heaters and boilers. In 2000, 69 percent of refinery fuel consumption consisted of petroleum products (68 percent of petroleum products consumed was refinery still gas). Purchased natural gas accounted for 28 percent of delivered energy consumed at refineries in 2000. Machinery and other miscellaneous equipment are powered mainly by electricity, which is either cogenerated with steam in the refinery, or purchased from an electricity generator. In 2000, purchased electricity accounted for 4 percent of the delivered energy consumed in refineries.

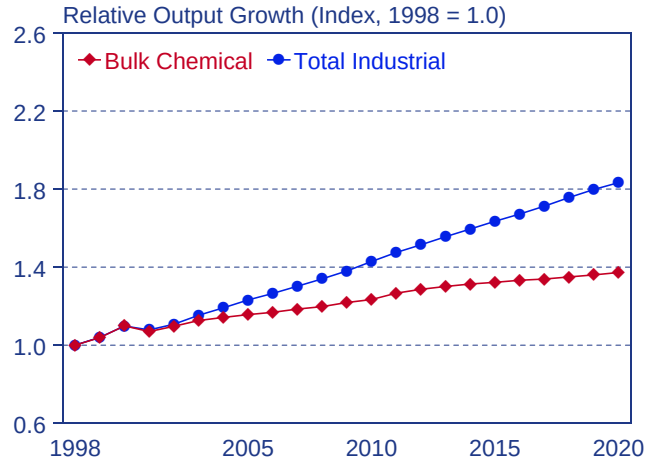
The refining industry's volume of output in barrels grew at an average yearly rate of 1.5 percent from 1990 to 2000. Refinery fuel consumption increased by 0.8 percent per year during the same period. Refineries became more energy efficient during the period, as delivered energy intensity (consumption of energy per volume of production) decreased by 0.7 percent per year.

In the future refiners will find it difficult to limit energy consumption while complying with increasingly strict environmental standards for gasoline and diesel fuel. Seventeen States, including California and New York, have plans to restrict or ban the use of methyl tertiary butyl ether (MTBE) in gasoline due to concerns about water contamination. MTBE is an important blending component for reformulated gasoline that extends volumes and dilutes unwanted compounds such as benzene and sulfur. Eliminating MTBE will force refiners to produce additional hydrocarbon volume at more stringent specification levels, requiring more energy consumption.

The "Tier 2" Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements will also require additional energy consumption by refiners. This regulation requires that the average sulfur content of gasoline be phased-down to 30 parts per million (ppm) between the years 2004 and 2007. Reducing gasoline sulfur levels will require additional processing at the refinery and additional energy expenditure. The "Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements" regulation, issued in December 2000, cuts the maximum sulfur allowed in highway diesel fuel from 500 ppm to 15 ppm. This cut in the highway diesel sulfur limit will require additional energy-intensive processing of highway diesel fuel, beginning in June 2006.

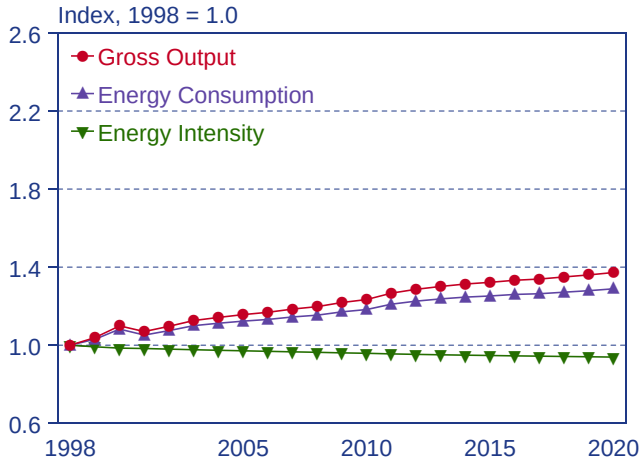
The *Annual Energy Outlook 2002* assumes that individual refinery processes will become more energy efficient at a rate of 0.3 percent per year over the forecast period. Refinery production is projected to increase by nearly 15 percent in the reference case from 2000 to 2020, or 0.7 percent per year (Figure 10), while delivered energy consumed at refineries is expected to grow by 33 percent

Figure 8. Relative Changes in Gross Output: Bulk Chemicals Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 9. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Bulk Chemicals Industry, 1998-2020

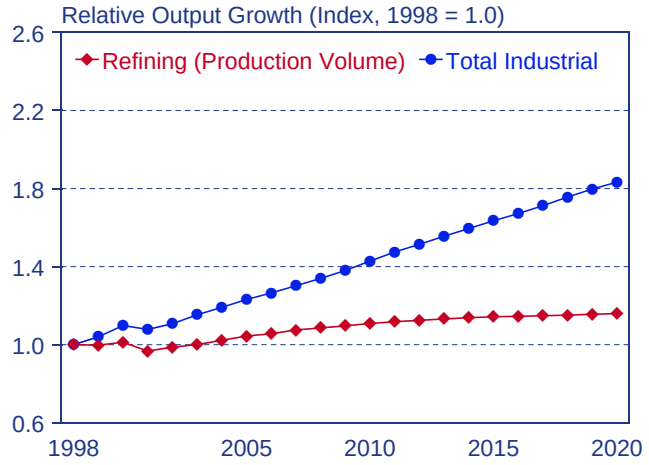


Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/ contents.html.

over the same period, or 1.4 percent per year (Table 14). Note that in this section output for the refinery sector is measured in millions of barrels processed, a physical quantity, rather than the dollar value of output used for the other industrial sectors. In the summary tables for all the other industries in this paper, output for the refinery sector is measured by dollar value in order to facilitate comparisons across sectors.

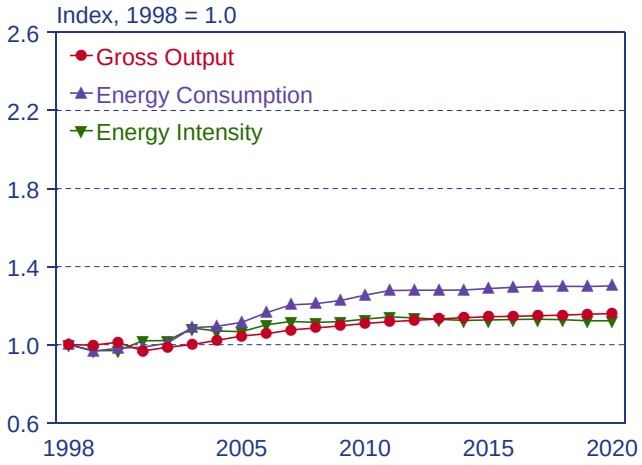
Overall, refinery delivered energy intensity is projected to increase, averaging 0.7 percent per year between 2000 and 2020. The increase in refinery delivered energy

Figure 10. Relative Changes in Gross Output: Domestic Petroleum Refining Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 11. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Domestic Petroleum Refining Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/ contents.html.

Table 14. Domestic Petroleum Refining Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Production (Million Barrels)	**6,216**	**6,293**	**6,892**	**7,207**	**0.7**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	2,113	2,105	2,757	3,001	1.8
Natural Gas	903	853	977	869	0.1
Non-Electric Delivered Energy	*3,016*	*2,959*	*3,733*	*3,870*	*1.4*
Purchased Electricity	111	112	188	200	2.9
Total Delivered Energy	**3,127**	**3,071**	**3,922**	**4,070**	**1.4**
Delivered Energy Consumption per Unit of Production (Thousand Btu per Barrel)					
Petroleum	340	335	400	416	1.1
Natural Gas	145	136	142	121	-0.6
Non-Electric Delivered Energy	*485*	*470*	*542*	*537*	*0.7*
Purchased Electricity	18	18	27	28	2.2
Total Delivered Energy	**503**	**488**	**569**	**565**	**0.7**

Notes: Totals include small quantities of steam coal. Totals and percentages calculated from unrounded data.

Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/ contents.html.

intensity can be attributed to a changing product slate, including low-sulfur gasoline and diesel fuel, that requires additional processing to produce and a crude oil slate that includes a higher proportion of heavy, high-sulfur crude oil that is more difficult to process. Figure 11 shows the indexed growth for volume of production, delivered energy consumption, and delivered energy intensity in the petroleum refining industry.

Glass Industry

The glass industry consists of NAICS code 3272. The industry uses energy primarily in melting furnaces. The production steps are batch preparation, melting/refining, forming, and post-forming. The REIs for the end uses are shown in Table 15. Glass industry output grew by 1.1 percent annually from 1978 to 2000. Future growth of the industry is projected to be slightly faster, 1.2 percent per year, over the 2000-2020 period (Table 16). The projected faster growth rate is largely driven by strong demand for flat glass in the automotive and construction industries. The output growth rate for the glass industry is less than half the average for the industrial sector (Figure 12).

Delivered energy consumption in the glass industry was 198 trillion Btu in 1998. Over the 2000-2020 forecast period, glass industry delivered energy consumption is projected to increase by 0.4 percent annually, reaching 225 trillion Btu in 2020 (Table 16). Natural gas accounts for three-quarters of the energy consumed in the glass industry and electricity one-fifth. The vast majority (95 percent) of all the energy is used in the process and assembly component.

Table 15. Glass Industry Coefficients for Technology Possibility Curves

	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
Process Step	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Batch Preparation	1.000	0.952	-0.0023	0.882	0.882	0.0000	1.3
Melting/Refining	1.000	0.758	-0.0125	0.900	0.485	-0.0277	1.3
Forming	1.000	0.921	-0.0037	0.982	0.838	-0.0072	1.3
Post-Forming	1.000	0.938	-0.0029	0.968	0.870	-0.0048	1.3

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020. REIs apply to both virgin and recycled materials. Use of recycled glass has a lower delivered energy intensity, but the relative delivered energy intensities are assumed to be the same as for virgin glass.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

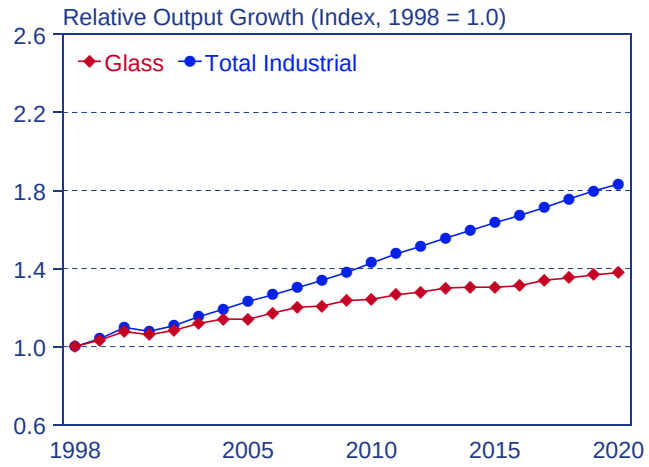
Table 16. Glass Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**21.3**	**22.9**	**26.4**	**29.3**	**1.2**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	2	3	2	2	-0.5
Natural Gas	154	161	169	172	0.3
Non-Electric Delivered Energy	*156*	*164*	*171*	*175*	*0.3*
Purchased Electricity	42	45	48	51	0.6
Total Delivered Energy	**198**	**208**	**219**	**225**	**0.4**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	0.10	0.11	0.08	0.08	-1.7
Natural Gas	7.25	7.04	6.40	5.88	-0.9
Non-Electric Delivered Energy	*7.35*	*7.15*	*6.48*	*5.95*	*-0.9*
Purchased Electricity	1.96	1.95	1.82	1.73	-0.6
Total Delivered Energy	**9.31**	**9.10**	**8.30**	**7.68**	**-0.8**

Note: Totals and percentages calculated from unrounded data.

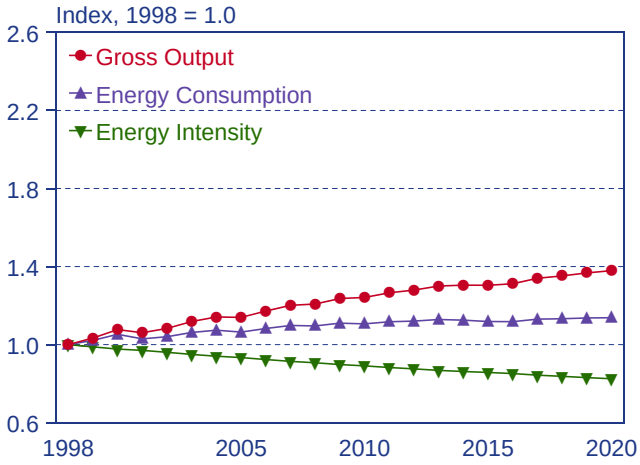
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Figure 12. Relative Changes in Gross Output: Glass Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 13. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Glass Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/ contents.html.

Glass industry delivered energy intensity over the forecast is projected to decline by 0.8 percent annually. This result is due primarily to projected improvements in delivered energy intensity for the melting / refining process. A relatively small REI 2020 indicates that delivered energy intensity for that process step is projected to decline more rapidly than for steps with relatively large REI 2020s. Indexed gross output, delivered energy consumption, and delivered energy intensity are shown in Figure 13.

Cement Industry

The cement industry consists of NAICS code 32731. The production steps for the cement industry are dry process, wet process, and finish grinding (Table 17). Although tiny in terms of its share of industrial gross output (0.1 percent in 1998), the cement industry is important from an energy perspective because of its high energy intensity. In 1998, delivered energy intensity for the cement industry was 68.0 thousand Btu per 1992 dollar of output; the average for the energy-intensive manufacturing sectors was 15.6 thousand Btu per 1992 dollar of output; and the average for the entire industrial sector was 5.5 thousand Btu per 1992 dollar of output. From 1978 to 2000, the cement industry's value of output increased by 0.5 percent annually to reach $5.6 billion. Over the 2000-2020 period, cement industry value of output is projected to grow by 1.2 percent per year, below the growth rate expected for the industrial sector as a whole (Figure 14).

Delivered energy consumption in the cement industry was 356 trillion Btu in 1998. Almost all (97 percent) of the energy is used for process and assembly. Coal is the largest energy source, providing two-thirds of the energy delivered to the cement industry. Over the 2000-2020 period, delivered energy consumption is projected to increase by 0.5 percent per year (Table 18). Cement industry delivered energy intensity is projected to fall by

Table 17. Cement Industry Coefficients for Technology Possibility Curves

Process Step	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Dry Process	1.000	0.868	-0.0064	0.889	0.716	-0.0098	1.2
Wet Process[a]	1.000	0.947	-0.0025	NA	NA	NA	1.2
Finish Grinding	1.000	0.865	-0.0066	0.950	0.718	-0.0127	1.2

[a]No new plants are likely to be built that use this technology.

Notes: NA = Not Applicable. REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

0.7 percent per year over the 2000-2020 period. It is assumed that all new capacity will use the dry process, which has a much lower REI than existing capacity. Indexed gross output, delivered energy consumption, and delivered energy intensity are shown in Figure 15.

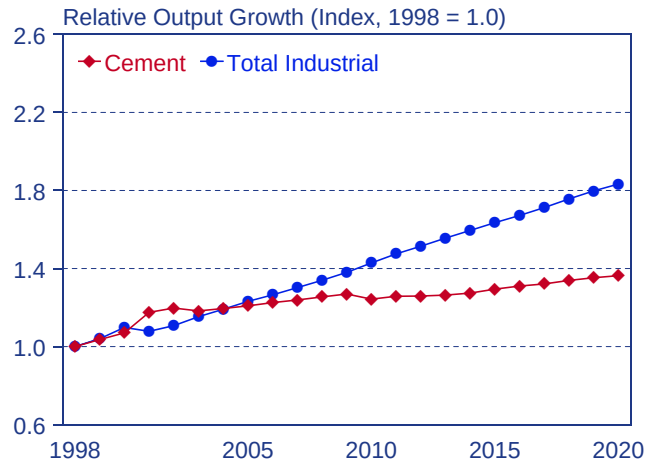
Table 18. Cement Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**5.2**	**5.6**	**6.5**	**7.1**	**1.2**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	58	60	64	65	0.4
Natural Gas	25	20	26	24	0.8
Steam Coal	233	250	265	276	0.5
Non-Electric Delivered Energy	*317*	*331*	*355*	*366*	*0.5*
Purchased Electricity	39	41	44	46	0.6
Total Delivered Energy	**356**	**372**	**399**	**412**	**0.5**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	11.13	10.77	9.85	9.16	-0.8
Natural Gas	4.86	3.57	3.97	3.30	-0.4
Steam Coal	44.57	44.64	40.63	38.70	-0.7
Non-Electric Delivered Energy	*60.56*	*58.99*	*54.45*	*51.17*	*-0.7*
Purchased Electricity	7.45	7.34	6.82	6.48	-0.6
Total Delivered Energy	**68.01**	**66.32**	**61.28**	**57.65**	**-0.7**

Note: Totals and percentages calculated from unrounded data.

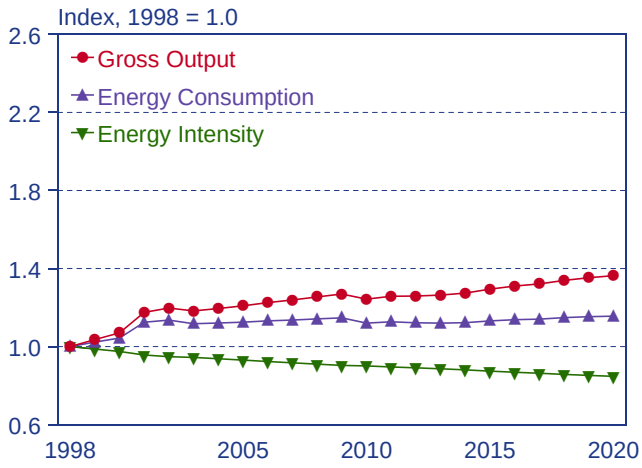
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Figure 14. Relative Changes in Gross Output: Cement Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 15. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Cement Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/ contents.html.

Steel Industry

The steel industry consists of NAICS code 331111. This definition includes blast furnaces and steel mills. The production steps for the steel industry are coke ovens, blast furnace with basic oxygen furnace, electric arc furnace, continuous casting, ingot casting / primary rolling, hot rolling, and cold rolling and finishing (Table 19). No new ingot casting facilities are projected to be built because it is an obsolescent technology.

From 1978 to 2000, the steel industry's value of output decreased by an average of 0.9 percent annually to reach $70.4 billion. Over the 2000-2020 period, steel industry value of output is projected to grow by 0.9 percent per year. While this represents a significant turnaround for the steel industry, the projected growth is still well below the overall industry average (Figure 16).

Delivered energy consumption in the steel sector was 1,590 trillion Btu in 1998. Coal and natural gas are the major fuels consumed in the steel industry, and 94 percent of the energy is used for process and assembly. Steel industry delivered energy intensity is projected to fall by 1.1 percent per year over the 2000-2020 period (Table 20). Increased use of electric arc furnaces and near-net-shape casting developments are primary drivers for the projected fall in delivered energy intensity. However, the potential decline in electricity intensity is dampened due to the greater use of electric arc furnaces. Over the 2000-2020 period, delivered energy consumption is projected to decrease by 0.2 percent per year, while purchased electricity consumption is projected to increase by 0.9 percent annually. Figure 17 shows indexed gross output, delivered energy consumption, and delivered energy intensity for the steel industry.

The REIs for the steel industry process steps are given in Table 19. The hot and cold rolling steps have low REI 2020 values due to a combination of lower intensity and reduced rolling requirements resulting from the growth of near-net-shape casting. For NEMS forecasting purposes, no coke ovens are assumed to be added to replace the retiring ovens. While increased electric arc furnace capacity reduces coke requirements, coke imports are projected to increase over the forecast period.

Aluminum Industry

The aluminum industry consists of NAICS code 3313, which includes both the primary and secondary aluminum sectors. The production steps are alumina refining, primary smelting, secondary / scrap melting, semi-fabrication (sheet), and semi-fabrication (other) (Table 21). The aluminum industry's output grew by 0.2 percent annually from 1978 to 2000, reaching $36.1 billion in 2000. Over the 2000-2020 period, output is projected to grow by 1.2 percent annually, well below the overall industry growth of 2.6 percent (Figure 18).

Delivered energy consumption in the aluminum industry was 454 trillion Btu in 1998, 90 percent of which was used in process and assembly. Electricity and natural gas are the most used energy sources. Delivered energy consumption is projected to decrease over the forecast period by 0.7 percent per year, reaching 393 trillion Btu in 2020 (Table 22). The retirement of existing facilities, the assumption that no new primary smelting capacity will be added, and some growth in recycling result in a projected intensity decline of 1.9 percent per year. Indexed gross output, delivered energy consumption, and delivered energy intensity are shown in Figure 19. Energy and production cost savings in primary smelting could be achieved through the development of new technologies such as inert anodes and cathodes and also through new casting technologies.

Table 19. Steel Industry Coefficients for Technology Possibility Curves

	Old Facilities			New Facilities			Annual Equipment Retirement Rate
Process Step	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	(Percent of Existing Stock)
Coke Oven[a]	1.000	0.930	-0.0033	0.874	0.838	-0.0019	1.5
BF/Basic Oxygen Furnace	1.000	0.992	-0.0004	1.000	0.984	-0.0008	1.0
Electric Arc Furnace	1.000	0.996	-0.0002	0.990	0.990	0.0000	1.5
Ingot Casting[a]	1.000	1.000	0.0000	NA	NA	NA	2.9
Continuous Casting	1.000	1.000	0.0000	1.000	1.000	0.0000	2.9
Hot Rolling	1.000	0.785	-0.0110	0.750	0.527	-0.0160	2.9
Cold Rolling	1.000	0.781	-0.0112	0.924	0.537	-0.0244	2.9

[a]No new plants are likely to be built that use this technology.

Notes: NA = Not Applicable. REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

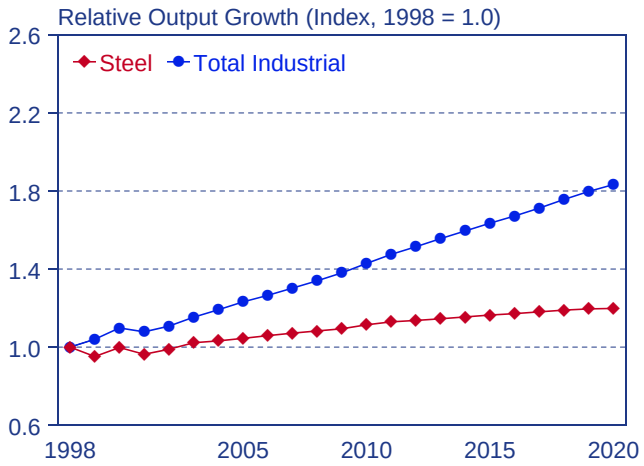
Table 20. Steel Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**70.6**	**70.4**	**78.7**	**84.6**	**0.9**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	53	48	38	35	-1.5
Natural Gas	517	514	533	527	0.1
Coal	865	851	786	748	-0.6
Non-Electric Delivered Energy	*1,435*	*1,412*	*1,356*	*1,310*	*-0.4*
Purchased Electricity	156	157	174	188	0.9
Total Delivered Energy	**1,590**	**1,570**	**1,531**	**1,497**	**-0.2**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	0.75	0.68	0.48	0.41	-2.4
Natural Gas	7.32	7.29	6.77	6.23	-0.8
Coal	12.25	12.08	9.99	8.84	-1.5
Non-Electric Delivered Energy	*20.32*	*20.05*	*17.24*	*15.48*	*-1.3*
Purchased Electricity	2.21	2.24	2.21	2.22	-0.0
Total Delivered Energy	**22.53**	**22.28**	**19.45**	**17.70**	**-1.1**

Note: Totals and percentages calculated from unrounded data.

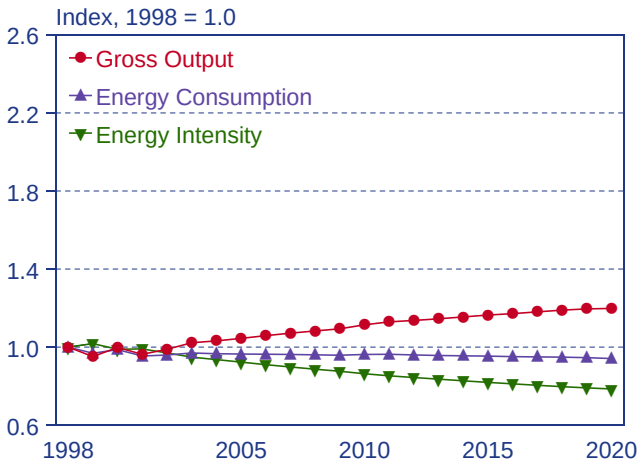
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Figure 16. Relative Changes in Gross Output: Steel Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 17. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Steel Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/ contents.html.

Non-Intensive Manufacturing Sectors

The non-intensive manufacturing sectors, particularly the balance of manufacturing sector, are heterogeneous collections of the remaining manufacturing industries. The metal-based durables industry includes fabricated metal products, machinery, computers and electronics, electrical equipment, appliances, and transportation equipment. The balance of manufacturing sector includes beverages and tobacco, textiles, apparel, leather, wood products, printing, asphalt, other chemicals, plastics and rubber products, other nonmetallic

Table 21. Aluminum Industry Coefficients for Technology Possibility Curves

Process Step	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Alumina Refining	1.000	0.943	-0.0027	0.900	0.868	-0.0016	1.0
Primary Smelting	1.000	0.925	-0.0035	0.950	0.840	-0.0056	1.0
Secondary	1.000	0.817	-0.0091	0.750	0.593	-0.0107	1.0
Semi-Fabrication (Sheet)	1.000	0.787	-0.0108	0.900	0.549	-0.0222	1.0
Semi-Fabrication (Other)	1.000	0.897	-0.0050	0.950	0.783	-0.0088	1.0

[a]No new plants are likely to be built that use this technology.

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

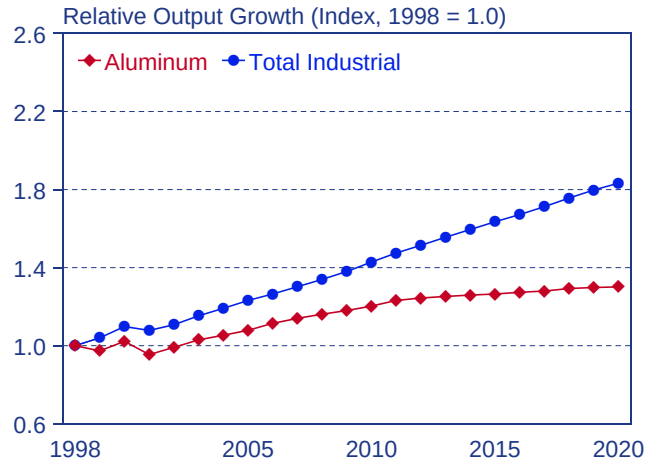
Table 22. Aluminum Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**35.3**	**36.1**	**42.4**	**45.9**	**1.2**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	6	6	5	5	-1.2
Natural Gas	146	148	151	148	-0.0
Steam Coal	74	72	62	51	-1.6
Non-Electric Delivered Energy	*226*	*225*	*218*	*204*	*-0.5*
Purchased Electricity	227	230	210	189	-1.0
Total Delivered Energy	**454**	**455**	**428**	**393**	**-0.7**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	0.17	0.17	0.12	0.10	-2.4
Natural Gas	4.15	4.10	3.56	3.22	-1.2
Steam Coal	2.10	1.99	1.46	1.12	-2.8
Non-Electric Delivered Energy	*6.42*	*6.25*	*5.14*	*4.44*	*-1.7*
Purchased Electricity	6.44	6.38	4.95	4.12	-2.2
Total Delivered Energy	**12.87**	**12.63**	**10.10**	**8.56**	**-1.9**

Note: Totals and percentages calculated from unrounded data.

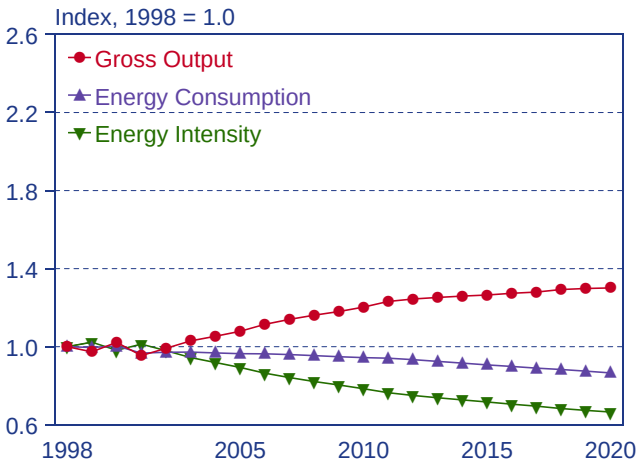
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Figure 18. Relative Changes in Gross Output: Aluminum Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 19. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Aluminum Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/ contents.html.

mineral products, other primary metals, furniture, and miscellaneous manufacturing. Because these sectors are so diverse, they are modeled based on generic end uses, rather than process steps. The metal-based durables sector, which includes the rapidly growing computer and semiconductor industries, is the only industrial sector for which output is projected to grow faster than the industry average (Table 23).

Metal-Based Durables Industry

The metal-based durables industry consists of fabricated metal product manufacturing (NAICS code 332); machinery manufacturing (NAICS code 333); computer and electronic product manufacturing (NAICS code 334); electrical equipment, appliance, and component manufacturing (NAICS code 335); and transportation equipment manufacturing (NAICS code 336). Typical processes in this sector include remelting operations followed by casting or molding, shaping, heat treating processes, coating, and joining and assembly. Given this diversity of processes, the sector's delivered energy consumption is characterized by five generic end uses: process heating, process cooling and refrigeration, machine drive, electrochemical processes, and miscellaneous end uses. The REIs for the end uses are shown in Table 24.

The metal-based durables industry's output grew by 2.9 percent annually from 1978 to 2000, reaching $1,830.3 billion in 2000. Over the 2000-2020 period, output is projected to grow by 4.0 percent annually, far outpacing total industrial output growth (Figure 20).

Delivered energy consumption in the metal-based durables sector was 1,466 trillion Btu in 1998. Nearly two-thirds of the energy was used for process and assembly, one-third in the buildings component, and

Table 23. Economic Output for the Non-Intensive Manufacturing Sectors, 1998-2020

Industry	Industry Output (Billion 1992 Dollars)				Annual Growth Rate, 2000-2020 (Percent)
	1998	2000	2010	2020	
Non-Intensive Manufacturing . .	**2,614.2**	**2,922.2**	**4,122.2**	**5,592.8**	**3.3**
Metal-Based Durables	1,586.6	1,830.3	2,772.7	3,983.6	4.0
Balance of Manufacturing	1,027.5	1,091.9	1,349.5	1,609.1	2.0
Industrial Sector Total	**4,608.4**	**5,061.6**	**6,584.5**	**8,447.4**	**2.6**

Note: Totals and percentages calculated from unrounded data.
Source: Energy Information Administration, *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

less than 4 percent in the boilers, steam, cogeneration component. Electricity and natural gas are the most used energy sources, each accounting for approximately 45 percent of the energy consumed in the sector. Delivered energy consumption in the metal-based durables industry is projected to increase by 2.9 percent per year over the forecast period, reaching 2,902 trillion Btu in 2020 (Table 25). Together with the output forecast, this yields a projected decline in delivered energy intensity of 1.0 percent per year. Figure 21 shows indexed gross output, delivered energy consumption, and delivered energy intensity over the projection period.

Balance of Manufacturing Sector

The balance of manufacturing sector is an amalgam consisting of all of the remaining manufacturing NAICS codes not elsewhere classified. This includes beverage and tobacco product manufacturing (NAICS code 312), textile mills (NAICS code 313), apparel product mills (NAICS code 314), apparel manufacturing (NAICS code

Table 24. Metal-Based Durables Industry Coefficients for Technology Possibility Curves

Energy End Use	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Process Heating	1.000	0.918	-0.0039	0.900	0.818	-0.0044	1.3
Process Cooling	1.000	0.897	-0.0049	0.850	0.768	-0.0046	1.3
Machine Drive	1.000	0.918	-0.0039	0.960	0.861	-0.0049	1.3
Electrochemical	1.000	0.984	-0.0008	0.950	0.868	-0.0041	1.3
Miscellaneous	1.000	0.929	-0.0033	0.915	0.828	-0.0045	1.3

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

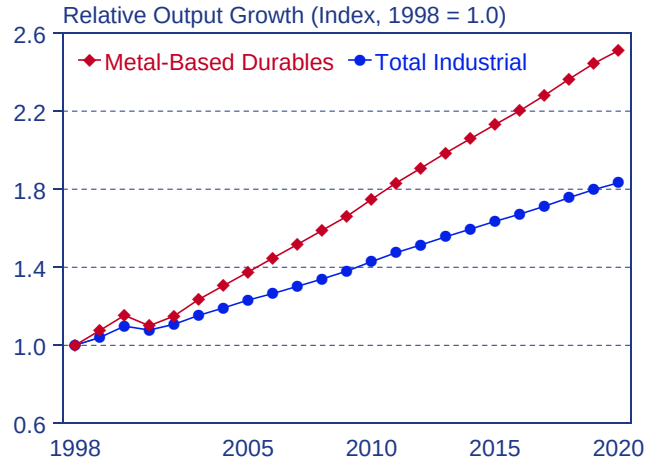
Table 25. Metal-Based Durables Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**1,586.6**	**1,830.3**	**2,772.7**	**3,983.6**	**4.0**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	44	49	67	90	3.1
Natural Gas	665	729	981	1,276	2.8
Steam Coal	59	64	72	84	1.4
Renewables	38	44	69	101	4.2
Non-Electric Delivered Energy	*808*	*886*	*1,189*	*1,551*	*2.8*
Purchased Electricity	659	737	1,010	1,351	3.1
Total Delivered Energy	**1,466**	**1,623**	**2,199**	**2,902**	**2.9**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	0.03	0.03	0.02	0.02	-0.9
Natural Gas	0.42	0.40	0.35	0.32	-1.1
Steam Coal	0.04	0.03	0.03	0.02	-2.4
Renewables	0.02	0.02	0.02	0.03	0.2
Non-Electric Delivered Energy	*0.51*	*0.48*	*0.43*	*0.39*	*-1.1*
Purchased Electricity	0.42	0.40	0.36	0.34	-0.9
Total Delivered Energy	**0.92**	**0.89**	**0.79**	**0.73**	**-1.0**

Note: Totals and percentages calculated from unrounded data.

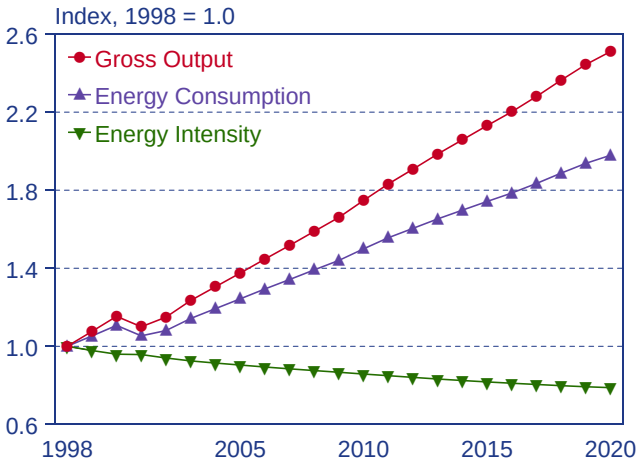
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Figure 20. Relative Changes in Gross Output: Metal-Based Durables Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 21. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Metal-Based Durables Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/ contents.html.

315), leather and allied product manufacturing (NAICS code 316), wood product manufacturing (NAICS code 321), printing and related support activities (NAICS code 323), asphalt and miscellaneous products of petroleum and coal (NAICS code 324, excluding 32411), other chemicals (NAICS code 325, excluding those sectors included in bulk chemicals), plastics and rubber products manufacturing (NAICS code 326), other nonmetallic mineral product manufacturing (NAICS code 327, excluding 3272 and 32731), other primary metal manufacturing (NAICS code 331, excluding 331111 and 3313), furniture and related product manufacturing (NAICS code 337), and miscellaneous manufacturing (NAICS code 339). Given this assortment of industries, there are no typical processes. Instead, this sector's delivered energy consumption is characterized by five generic end uses: process heating, process cooling and refrigeration, machine drive, electrochemical processes, and miscellaneous end uses. The REIs for the end uses are shown in Table 26.

The output of the balance of manufacturing sector grew by 1.6 percent annually from 1978 to 2000, reaching $1,091.9 billion in 2000. Over the 2000-2020 period, output is projected to grow by 2.0 percent annually, below the 2.6-percent annual growth projected for the entire industrial sector (Figure 22).

Delivered energy consumption for the balance of manufacturing sector was 2,904 trillion Btu in 1998. Three-quarters of the energy was used in the process and assembly component. Natural gas and electricity are the most used energy sources, but renewables are projected to increase the most rapidly over the forecast horizon. The renewables are largely wood residues and byproducts from mill processing in the lumber and furniture industries. Delivered energy consumption in the balance of manufacturing sector is projected to increase by 1.4 percent per year between 2000 and 2020, reaching

Table 26. Balance of Manufacturing Sector Coefficients for Technology Possibility Curves

	Old Facilities			New Facilities			Annual Equipment Retirement Rate
Energy End Use	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	(Percent of Existing Stock)
Process Heating	1.000	0.918	-0.0039	0.900	0.818	-0.0044	1.3
Process Cooling	1.000	0.897	-0.0049	0.850	0.768	-0.0046	1.3
Machine Drive	1.000	0.918	-0.0039	0.960	0.861	-0.0049	1.3
Electrochemical	1.000	0.984	-0.0008	0.950	0.868	-0.0041	1.3
Miscellaneous	1.000	0.929	-0.0033	0.915	0.828	-0.0045	1.3

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

3,988 trillion Btu in 2020 (Table 27). With the projected output growth of 2.0 percent per year, this yields a projected intensity decline of 0.6 percent per year. Indexed gross output, delivered energy consumption, and delivered energy intensity are shown in Figure 23.

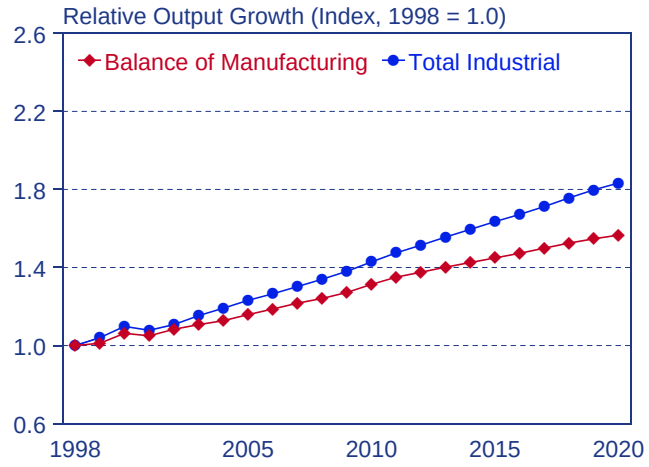
Table 27. Balance of Manufacturing Sector Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**1,027.5**	**1,091.9**	**1,349.5**	**1,609.1**	**2.0**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	141	148	159	180	1.0
Natural Gas	1,329	1,359	1,586	1,786	1.4
Steam Coal	237	264	297	345	1.4
Renewables	327	344	422	506	1.9
Non-Electric Delivered Energy	*2,034*	*2,114*	*2,465*	*2,817*	*1.4*
Purchased Electricity	870	912	1,038	1,171	1.3
Total Delivered Energy	**2,904**	**3,026**	**3,503**	**3,988**	**1.4**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	0.14	0.14	0.12	0.11	-0.9
Natural Gas	1.29	1.24	1.18	1.11	-0.6
Steam Coal	0.23	0.24	0.22	0.21	-0.6
Renewables	0.32	0.32	0.31	0.31	-0.0
Non-Electric Delivered Energy	*1.98*	*1.94*	*1.83*	*1.75*	*-0.5*
Purchased Electricity	0.85	0.84	0.77	0.73	-0.7
Total Delivered Energy	**2.83**	**2.77**	**2.60**	**2.48**	**-0.6**

Note: Totals and percentages calculated from unrounded data.

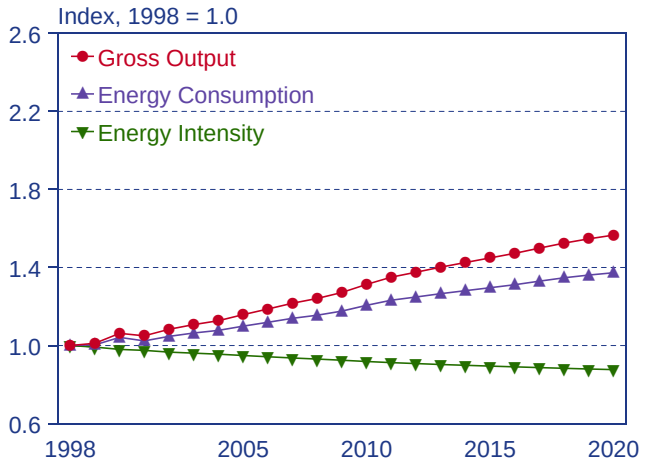
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Figure 22. Relative Changes in Gross Output: Balance of Manufacturing Sector and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 23. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Balance of Manufacturing Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/ contents.html.

Non-Manufacturing Sectors

The non-manufacturing sectors are modeled in less detail than the manufacturing sectors in the NEMS Industrial Energy Demand Module. This group includes two agriculture sectors (agriculture—crops, NAICS code 111; and agriculture—other, NAICS codes 112 through 115), three mining sectors (coal mining, NAICS code 2121; oil and gas extraction, NAICS code 211; and metal and other non-metallic mining, NAICS codes 2122 through 2123), and construction (NAICS codes 233 through 235). Due to limited data, these sectors are not represented with specific process steps or end uses. Instead they are represented as having a unit energy consumption (UEC) value for each fuel. Also because of data limitations, energy use in buildings is not estimated separately in the non-manufacturing sectors.

All of these industries are projected to grow more slowly than the total industrial sector, with the average growth for the group projected at 1.7 percent per year between 2000 and 2020, compared with 2.6 percent for the industrial sector total (Table 28). Within the group the projected growth rate ranges from a low of 1.1 percent (agriculture—other, coal mining, and metal and other non-metallic mining) to 2.0 percent (construction).

Agriculture—Crops Industry

The agriculture—crops industry consists of NAICS code 111. The crops industry is not modeled using process steps or end uses, but with fuel-specific UECs. Although specific technologies are not represented, the energy intensity of the sector is projected to decline over time (Table 29). Output for the crops sector grew by 2.0 percent annually from 1978 to 2000, reaching $118.0 billion in 2000. Over the 2000-2020 period, output is projected to grow by 1.3 percent annually. Output in the crops sector is projected to grow more slowly than aggregate industrial output (Figure 24).

Delivered energy consumption in the crops sector was 711 trillion Btu in 1998. Three-quarters of the energy is accounted for by petroleum products. Delivered energy consumption in the crops sector is projected to increase moderately over the forecast period, reaching 982 trillion Btu in 2020 (Table 30). Delivered energy intensity is projected to decline by 0.3 percent per year. Figure 25 shows indexed gross output, delivered energy consumption, and delivered energy intensity.

Agriculture—Other Industry

The agriculture—other industry consists of animal production (NAICS code 112), forestry and logging (NAICS code 113), fishing, hunting, and trapping (NAICS code 114), and support activities for agriculture and forestry (NAICS code 115). The other agriculture industry is not modeled using process steps or end uses but with fuel-specific UECs. Energy intensity of the sector is projected to decline over time as more efficient equipment is

Table 28. Economic Output for the Non-Intensive Manufacturing Sectors, 1998-2020

Industry	Industry Output (Billion 1992 Dollars)				Annual Growth Rate, 2000-2020 (Percent)
	1998	2000	2010	2020	
Non-Manufacturing	**960.4**	**1,039.2**	**1,211.0**	**1,444.4**	**1.7**
Agriculture—Crops	103.4	118.0	133.4	153.1	1.3
Agriculture—Other	169.6	185.2	195.7	232.5	1.1
Coal Mining	30.7	29.1	33.8	36.0	1.1
Oil and Gas Extraction	105.3	107.4	118.8	140.5	1.3
Other Mining	27.8	29.0	32.9	35.9	1.1
Construction	523.4	570.4	696.3	846.5	2.0
Industrial Sector Total	**4,608.4**	**5,061.6**	**6,584.5**	**8,447.4**	**2.6**

Note: Totals and percentages calculated from unrounded data.
Source: Energy Information Administration, *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Table 29. Agriculture—Crops Industry Coefficients for Technology Possibility Curves

Industry	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Agriculture—Crops	1.000	0.978	-0.001	0.900	0.861	-0.002	1.0

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.
Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

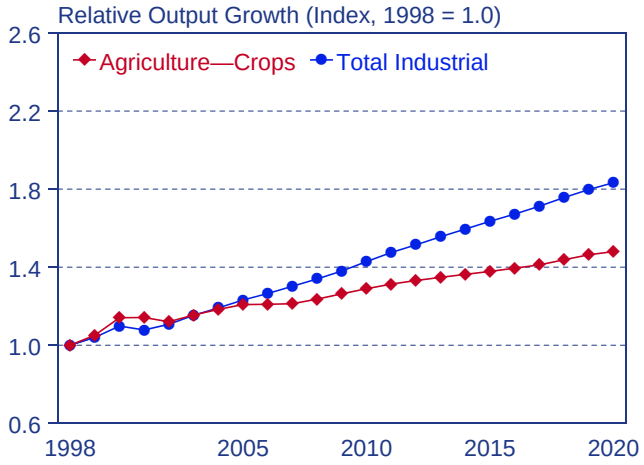
Table 30. Agriculture—Crops Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**103.4**	**118.0**	**133.4**	**153.1**	**1.3**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	533	598	658	736	1.0
Natural Gas	67	74	81	90	1.0
Steam Coal	0	0	0	0	-0.0
Renewables	14	16	18	21	1.5
Non-Electric Delivered Energy	*614*	*688*	*757*	*848*	*1.0*
Purchased Electricity	97	109	120	134	1.0
Total Delivered Energy	**711**	**797**	**877**	**982**	**1.0**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	5.15	5.07	4.93	4.81	-0.3
Natural Gas	0.65	0.63	0.61	0.59	-0.3
Steam Coal	0.00	0.00	0.00	0.00	-1.3
Renewables	0.13	0.13	0.14	0.14	0.2
Non-Electric Delivered Energy	*5.93*	*5.83*	*5.67*	*5.54*	*-0.3*
Purchased Electricity	0.94	0.92	0.90	0.88	-0.3
Total Delivered Energy	**6.87**	**6.75**	**6.57**	**6.41**	**-0.3**

Note: Totals and percentages calculated from unrounded data.

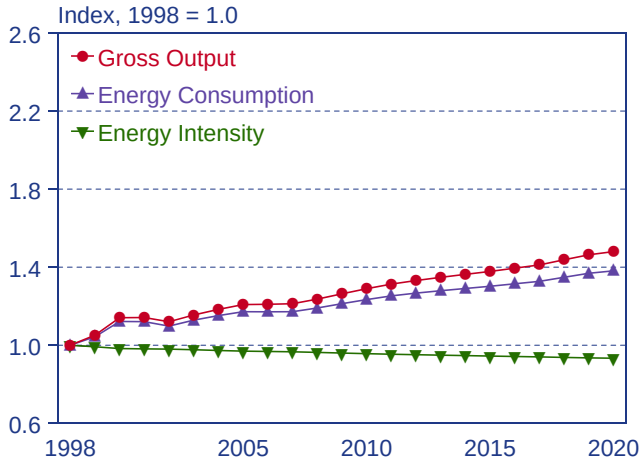
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Figure 24. Relative Changes in Gross Output: Agriculture—Crops Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 25. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Agriculture—Crops Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

added (Table 31). Output for the other agriculture sector grew by 2.7 percent annually from 1978 to 2000, reaching $185.2 billion in 2000. Over the 2000-2020 period, output is projected to grow by 1.1 percent annually, slower than aggregate industrial output (Figure 26).

Delivered energy consumption in the other agriculture sector was 412 trillion Btu in 1998. Petroleum is the major energy source for the sector. Delivered energy consumption in the other agriculture sector is projected to increase moderately over the forecast period, reaching 530 trillion Btu in 2020 (Table 32). Delivered energy intensity is projected to decline by 0.3 percent per year. Figure 27 shows indexed gross output, delivered energy consumption, and delivered energy intensity.

Table 31. Agriculture—Other Industry Coefficients for Technology Possibility Curves

Industry	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Agriculture—Other	1.000	0.978	-0.001	0.900	0.861	-0.002	1.0

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

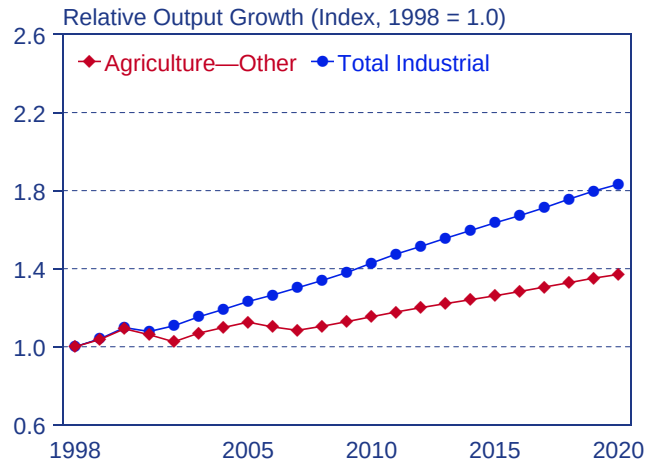
Table 32. Agriculture—Other Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**169.6**	**185.2**	**195.7**	**232.5**	**1.1**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	303	327	337	389	0.9
Natural Gas	21	23	24	27	0.9
Steam Coal	0	0	0	0	NA
Renewables	7	8	8	10	1.3
Non-Electric Delivered Energy	*332*	*358*	*369*	*426*	*0.9*
Purchased Electricity	81	87	90	104	0.9
Total Delivered Energy	**412**	**445**	**459**	**530**	**0.9**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	1.79	1.76	1.72	1.67	-0.3
Natural Gas	0.13	0.12	0.12	0.12	-0.3
Steam Coal	0.00	0.00	0.00	0.00	NA
Renewables	0.04	0.04	0.04	0.04	0.2
Non-Electric Delivered Energy	*1.95*	*1.93*	*1.89*	*1.83*	*-0.3*
Purchased Electricity	0.48	0.47	0.46	0.45	-0.3
Total Delivered Energy	**2.43**	**2.40**	**2.35**	**2.28**	**-0.3**

Note: Totals and percentages calculated from unrounded data.

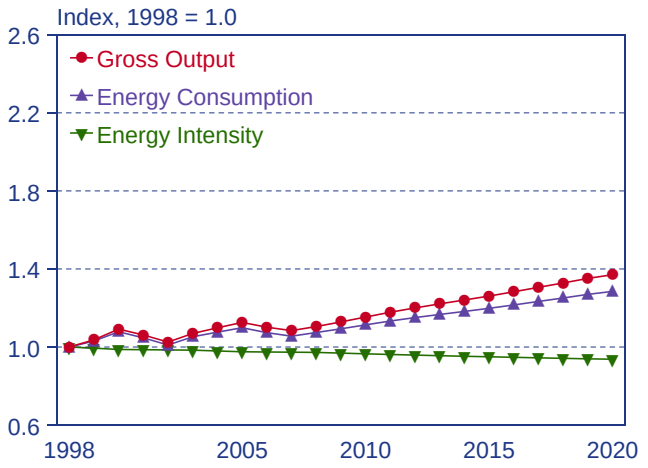
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Figure 26. Relative Changes in Gross Output: Agriculture—Other Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 27. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Agriculture—Other Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Coal Mining Industry

The coal mining industry consists of NAICS code 2121. This industry is not modeled using process steps or end uses but with fuel-specific UECs. Although specific technologies are not represented, the energy intensity of the sector is projected to decline over time as new equipment replaces less efficient retired capital stock (Table 33). Output for the coal mining industry grew by 2.5 percent annually from 1978 to 2000, reaching $29.1 billion in 2000. Over the 2000-2020 period, output is projected to grow by 1.1 percent annually, much more slowly than aggregate industrial output (Figure 28).

Delivered energy consumption in the coal mining sector was 87 trillion Btu in 1998. Electricity and petroleum are the major energy sources for the coal mining industry. Delivered energy consumption is projected to increase by 0.8 percent per year over the forecast period, reaching 97 trillion Btu in 2020 (Table 34). Delivered energy intensity is projected to decline by 0.3 percent per year. Indexed gross output, delivered energy consumption, and delivered energy intensity are shown in Figure 29.

Oil and Gas Extraction Industry

The oil and gas extraction industry consists of NAICS code 211. The industry is not modeled using process steps or end uses. The average efficiency of equipment in the sector is projected to increase over time as more advanced technology enters the market (Table 35). Output for the oil and gas extraction industry fell by 0.2 percent per year between 1978 and 2000, reaching $107 billion in 2000. Output for the sector is projected to grow by 1.3 percent annually over the 2000-2020 period; however, within NAICS 211 crude oil production is projected to fall slightly, while natural gas production rises. Value of output for the aggregate oil and gas extraction sector is projected to grow more slowly than total industrial output (Figure 30).

Table 33. Coal Mining Industry Coefficients for Technology Possibility Curves

Industry	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Coal Mining	1.000	0.978	-0.001	0.900	0.861	-0.002	1.0

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

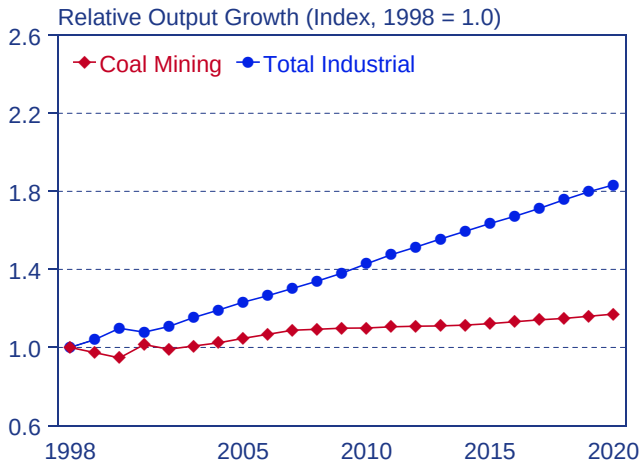
Table 34. Coal Mining Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**30.7**	**29.1**	**33.8**	**36.0**	**1.1**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	48	45	51	53	0.8
Natural Gas	1	1	1	1	0.8
Steam Coal	5	5	5	5	0.8
Non-Electric Delivered Energy	*54*	*51*	*57*	*60*	*0.8*
Purchased Electricity	34	32	36	37	0.8
Total Delivered Energy	**87**	**83**	**93**	**97**	**0.8**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	1.56	1.56	1.51	1.48	-0.3
Natural Gas	0.03	0.03	0.03	0.03	-0.3
Steam Coal	0.16	0.16	0.15	0.15	-0.3
Non-Electric Delivered Energy	*1.75*	*1.74*	*1.69*	*1.65*	*-0.3*
Purchased Electricity	1.10	1.10	1.06	1.04	-0.3
Total Delivered Energy	**2.85**	**2.84**	**2.76**	**2.69**	**-0.3**

Note: Totals and percentages calculated from unrounded data.

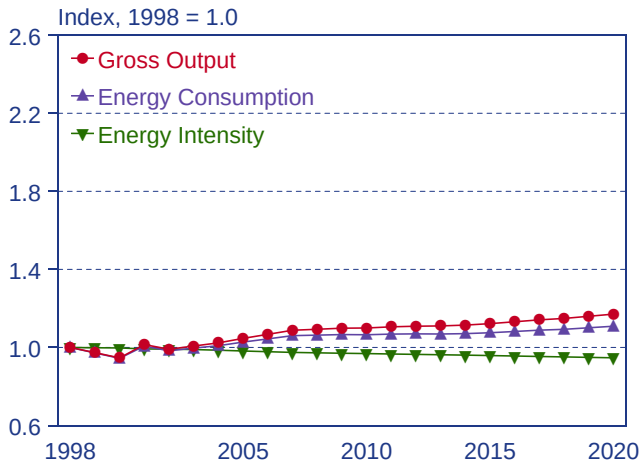
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Figure 28. Relative Changes in Gross Output: Coal Mining Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 29. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Coal Mining Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Delivered energy consumption in the oil and gas extraction industry was 1,509 trillion Btu in 1998. Delivered energy consumption is projected to increase by 2.2 percent per year over the forecast period, reaching 2,228 trillion Btu in 2020 (Table 36). Lease and plant fuel,[10] which accounted for 80 percent of all delivered energy consumed within the sector in 1998, is projected to increase by 2.4 percent per year. The rate of growth for lease and plant fuel is tied to the increase in natural gas production. More energy is required to produce each dollar of output as the shallower, more easily exploited resources are depleted. Because of the growth in lease and plant fuel consumption, delivered energy intensity is projected to increase by 0.8 percent per year between 2000 and 2020. Figure 31 shows indexed gross output, delivered energy consumption, and delivered energy intensity.

Other Mining Industry

The other mining industry consists of metal ore mining (NAICS code 2122) and nonmetallic mineral mining and quarrying (NAICS code 2123). The other mining industry is not modeled using process steps or end uses but with fuel-specific UECs. The efficiency of the sector is projected to increase over time (Table 37). The other mining industry's output grew by 1.0 percent annually

Table 35. Oil and Gas Extraction Industry Coefficients for Technology Possibility Curves

Industry	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Oil and Gas Extraction	1.000	0.978	-0.001	0.900	0.861	-0.002	1.0

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

Table 36. Oil and Gas Extraction Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

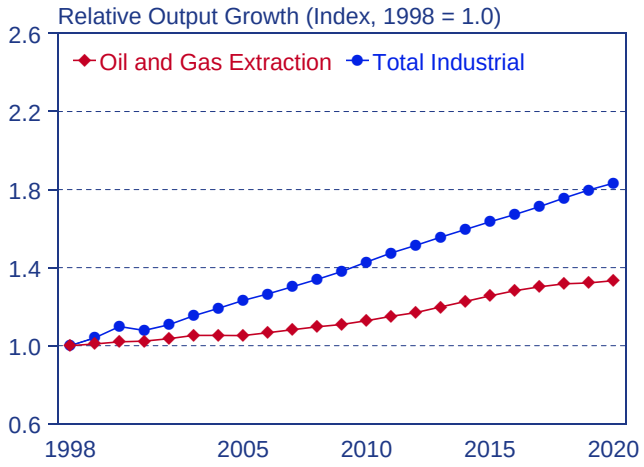
Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**105.3**	**107.4**	**118.8**	**140.5**	**1.3**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	105	106	114	131	1.1
Natural Gas	97	98	107	124	1.2
Lease and Plant Fuel	1,205	1,147	1,536	1,847	2.4
Renewables	1	1	1	1	1.1
*Non-Electric Delivered Energy	*1,407*	*1,352*	*1,758*	*2,103*	*2.2*
Purchased Electricity	101	102	109	125	1.0
Total Delivered Energy	**1,509**	**1,454**	**1,867**	**2,228**	**2.2**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	0.99	0.99	0.96	0.93	-0.3
Natural Gas	0.92	0.91	0.90	0.88	-0.2
Lease and Plant Fuel	11.44	10.67	12.92	13.15	1.1
Renewables	0.01	0.01	0.01	0.01	-0.3
*Non-Electric Delivered Energy	*13.36*	*12.58*	*14.79*	*14.98*	*0.9*
Purchased Electricity	0.96	0.95	0.92	0.89	-0.4
Total Delivered Energy	**14.32**	**13.54**	**15.71**	**15.86**	**0.8**

Note: Totals and percentages calculated from unrounded data.

Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

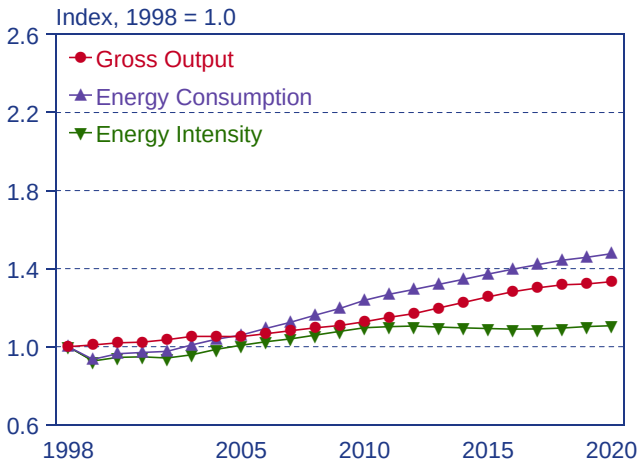
[10]Lease and plant fuel is natural gas used in well, field, and lease operations (such as gas used in drilling operations, heaters, dehydrators, and field compressors) or used as fuel in natural gas processing plants. Lease and plant fuel consumption is modeled in the Oil and Gas Supply Module of NEMS.

Figure 30. Relative Changes in Gross Output: Oil and Gas Extraction Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 31. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Oil and Gas Extraction Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

between 1978 to 2000, reaching $29.0 billion in 2000. Over the 2000-2020 period, output is projected to grow by 1.1 percent annually. Other mining output is projected to grow more slowly than aggregate industrial output (Figure 32).

Delivered energy consumption in the other mining sector was 310 trillion Btu in 1998, with no dominant source of energy. Delivered energy consumption is projected to increase over the forecast period by 0.7 percent per year, reaching 384 trillion Btu in 2020 (Table 38). Delivered energy intensity is projected to decline by 0.3 percent per year. Figure 33 shows indexed gross output, delivered energy consumption, and delivered energy intensity.

Construction Industry

The construction industry includes building, developing, and general contracting (NAICS 233), heavy construction (NAICS 234), and special trade contractors (NAICS 235). The construction industry is not modeled using process steps or end uses. Although specific technologies are not represented, the energy intensity of the sector is projected to decrease over time as more efficient equipment is added to replace retired capital stock and produce the increasing output (Table 39). The construction industry's output grew by 2.1 percent annually from 1978 to 2000, reaching $570.4 billion in 2000. Over the 2000-2020 period, output is projected to grow by 2.0 percent annually, somewhat slower than aggregate industrial output (Figure 34).

Delivered energy consumption in the construction sector was 1,776 trillion Btu in 1998. More than 70 percent of the energy consumed in the construction industry was for non-fuel use in the form of asphalt. Delivered energy consumption is projected to increase by 1.7 percent per year over the forecast period, reaching 2,668 trillion Btu in 2020 (Table 40). Delivered energy intensity is projected to decline by 0.3 percent per year. Indexed gross output, delivered energy consumption, and delivered energy intensity are shown in Figure 35.

Table 37. Other Mining Industry Coefficients for Technology Possibility Curves

Industry	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Other Mining	1.000	0.978	-0.001	0.900	0.861	-0.002	1.0

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

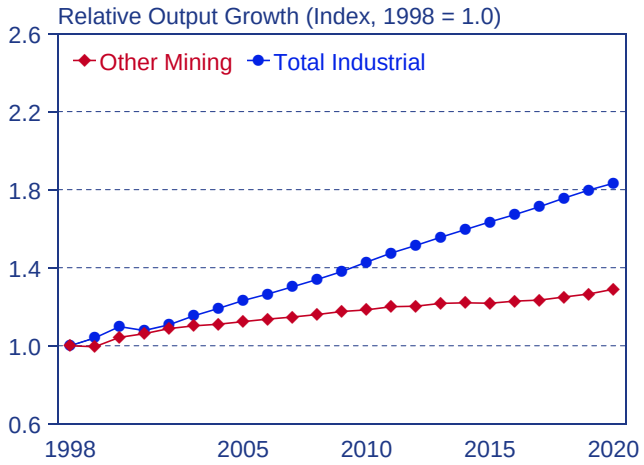
Table 38. Other Mining Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**27.8**	**29.0**	**32.9**	**35.9**	**1.1**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	78	80	89	94	0.8
Natural Gas	79	83	88	94	0.6
Steam Coal	55	67	73	76	0.7
Non-Electric Delivered Energy	*212*	*230*	*250*	*264*	*0.7*
Purchased Electricity	98	101	112	120	0.8
Total Delivered Energy	**310**	**331**	**362**	**384**	**0.7**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	2.79	2.77	2.69	2.63	-0.3
Natural Gas	2.85	2.84	2.68	2.61	-0.4
Steam Coal	1.97	2.29	2.21	2.12	-0.4
Non-Electric Delivered Energy	*7.61*	*7.91*	*7.58*	*7.36*	*-0.4*
Purchased Electricity	3.51	3.49	3.41	3.35	-0.2
Total Delivered Energy	**11.13**	**11.40**	**10.99**	**10.70**	**-0.3**

Note: Totals and percentages calculated from unrounded data.

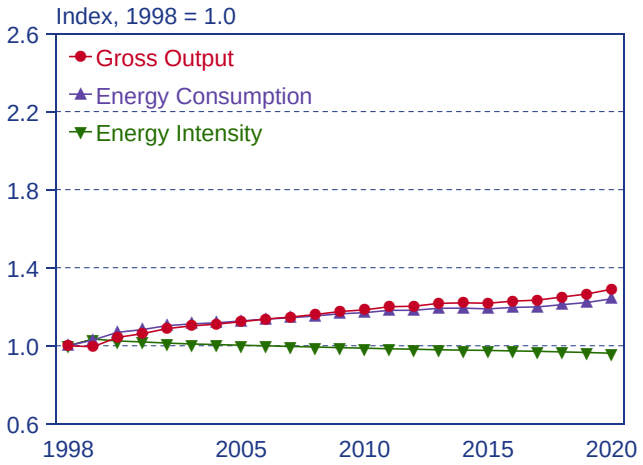
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Figure 32. Relative Changes in Gross Output: Other Mining Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 33. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Other Mining Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Table 39. Construction Industry Coefficients for Technology Possibility Curves

Industry	Old Facilities			New Facilities			Annual Equipment Retirement Rate (Percent of Existing Stock)
	REI 1998	REI 2020	TPC	REI 1998	REI 2020	TPC	
Construction	1.000	0.978	-0.001	0.900	0.861	-0.002	1.0

Notes: REI = Relative Energy Intensity. TPC = Technology Possibility Curve. The coefficient values shown for TPCs indicate the average annual change from 1998 through 2020.

Source: Energy Information Administration, *Model Documentation Report: Industrial Sector Energy Demand Model of the National Energy Modeling System*, DOE/EIA-M064(2002) (Washington, DC, December 2001).

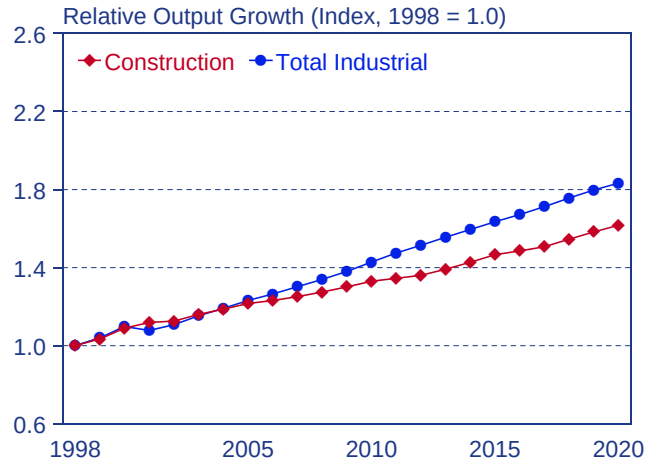
Table 40. Construction Industry Output and Delivered Energy Consumption by Fuel, 1998-2020

Fuel	1998	2000	2010	2020	Annual Growth Rate, 2000-2020 (Percent)
Industry Output (Billion 1992 Dollars)	**523.4**	**570.4**	**696.3**	**846.5**	**2.0**
Delivered Energy Consumption (Trillion Btu)					
Petroleum	304	327	386	456	1.7
Natural Gas	97	105	123	146	1.7
Non-Electric Delivered Energy	*401*	*432*	*510*	*602*	*1.7*
Purchased Electricity	113	121	143	169	1.7
Total Fuel and Electricity	*514*	*553*	*653*	*772*	*1.7*
Asphalt and Road Oil	1,263	1,359	1,604	1,896	1.7
Total Delivered Energy	**1,776**	**1,912**	**2,257**	**2,668**	**1.7**
Delivered Energy Consumption per Unit of Output (Thousand Btu per 1992 Dollar of Output)					
Petroleum	0.58	0.57	0.55	0.54	-0.3
Natural Gas	0.19	0.18	0.18	0.17	-0.3
Non-Electric Delivered Energy	*0.77*	*0.76*	*0.73*	*0.71*	*-0.3*
Purchased Electricity	0.22	0.21	0.21	0.20	-0.3
Total Fuel and Electricity	*0.98*	*0.97*	*0.94*	*0.91*	*-0.3*
Asphalt and Road Oil	2.41	2.38	2.30	2.24	-0.3
Total Delivered Energy	**3.39**	**3.35**	**3.24**	**3.15**	**-0.3**

Note: Totals and percentages calculated from unrounded data.

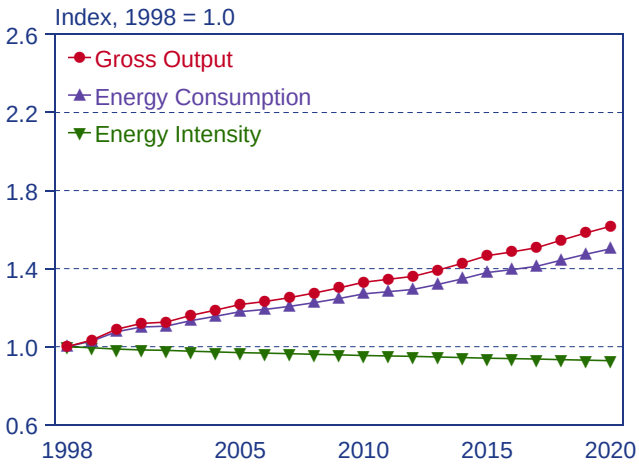
Sources: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001); and EIA, *1998 Manufacturing Energy Consumption Survey*, web site www.eia.doe.gov/emeu/mecs/mecs98/datatables/contents.html.

Figure 34. Relative Changes in Gross Output: Construction Industry and Total Industrial Sector, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 35. Relative Changes in Gross Output, Delivered Energy Consumption, and Energy Intensity: Construction Industry, 1998-2020



Source: Energy Information Administration (EIA), *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Summary

The projected output growth rates over the 2000-2020 period for the energy-intensive industries discussed in this paper are all less than the 2.6-percent growth rate projected for the industrial sector as a whole (Table 41).[11] Of the energy-intensive industries, output from the paper industry is projected to grow the fastest, averaging 1.6 percent per year between 2000 and 2020, and output from the food industry is next with projected growth of 1.3 percent per year. Of the three groups modeled in the NEMS Industrial Sector Demand Module, only the non-intensive manufacturing category is projected to grow faster than the industrial sector as a whole. In fact, metal-based durables is the only individual sector which has projected growth above the industrial average. Because of its large share of output (36.2 percent in 2000) and rapid growth (4.0 percent per year between 2000 and 2020), metal-based durables has a large influence on the aggregate output growth rate.

Delivered energy consumption in the industrial sector is projected to increase by 1.2 percent per year between 2000 and 2020 (Table 42). In part due to its relatively slow projected output growth, the energy-intensive group is projected to increase delivered energy consumption by only 0.8 percent per year over the same period. The energy-intensive group is projected to continue to consume the largest share of delivered energy in the industrial sector, but its share is projected to fall from 63.5 percent in 2000 to 59.0 percent in 2020. The bulk chemicals industry is projected to remain the largest energy consumer, reaching 8,632 trillion Btu in 2020; however, more than one-half of the energy consumed in the bulk chemicals industry is used for non-fuel purposes in the form of feedstocks.

All the industry groups in the industrial sector are projected to decrease their delivered energy consumption per unit of output, except for the petroleum refining and oil and gas extraction industries (Figure 36). The cumulative delivered energy intensity decline for the individual sectors varies, depending on the particulars of each industry (Figure 37). In the energy-intensive manufacturing group, the bulk chemicals industry is projected to improve the least, because there is little ability to reduce feedstock intensity. Cumulative delivered energy intensity for the bulk chemicals industry is projected to decline by only 4.7 percent between 2000 and 2020. The aluminum industry is projected to improve the most, with cumulative delivered energy intensity falling by 32.2 percent between 2000 and 2020. This result is due in large part to the assumption that no new primary aluminum capacity, which has a higher delivered energy intensity than the rest of the industry, will be added. The cumulative delivered energy intensity decline for the metal-based durables industry is projected at 17.9 percent. The rapid output growth for this sector requires additional capacity, which has lower delivered energy consumption per unit of output than existing facilities.

[11] In the separate petroleum refining section earlier in the paper, output is measured in barrels. In order to make cross industry comparisons, output from the petroleum refining sector in this summary is expressed in dollar terms. The projected growth rates using both measures are nearly identical.

The main determinants of delivered energy consumption in the Industrial Sector Demand Module of NEMS are industry output and energy prices. The reference case projections in the *Annual Energy Outlook 2002* include relatively low projected output growth rates for the energy-intensive industries and small changes in projected energy prices. Given the output and energy price assumptions used, overall industrial delivered energy intensity is projected to decline over the projection period, falling by an average of 1.4 percent per year between 2000 and 2020.

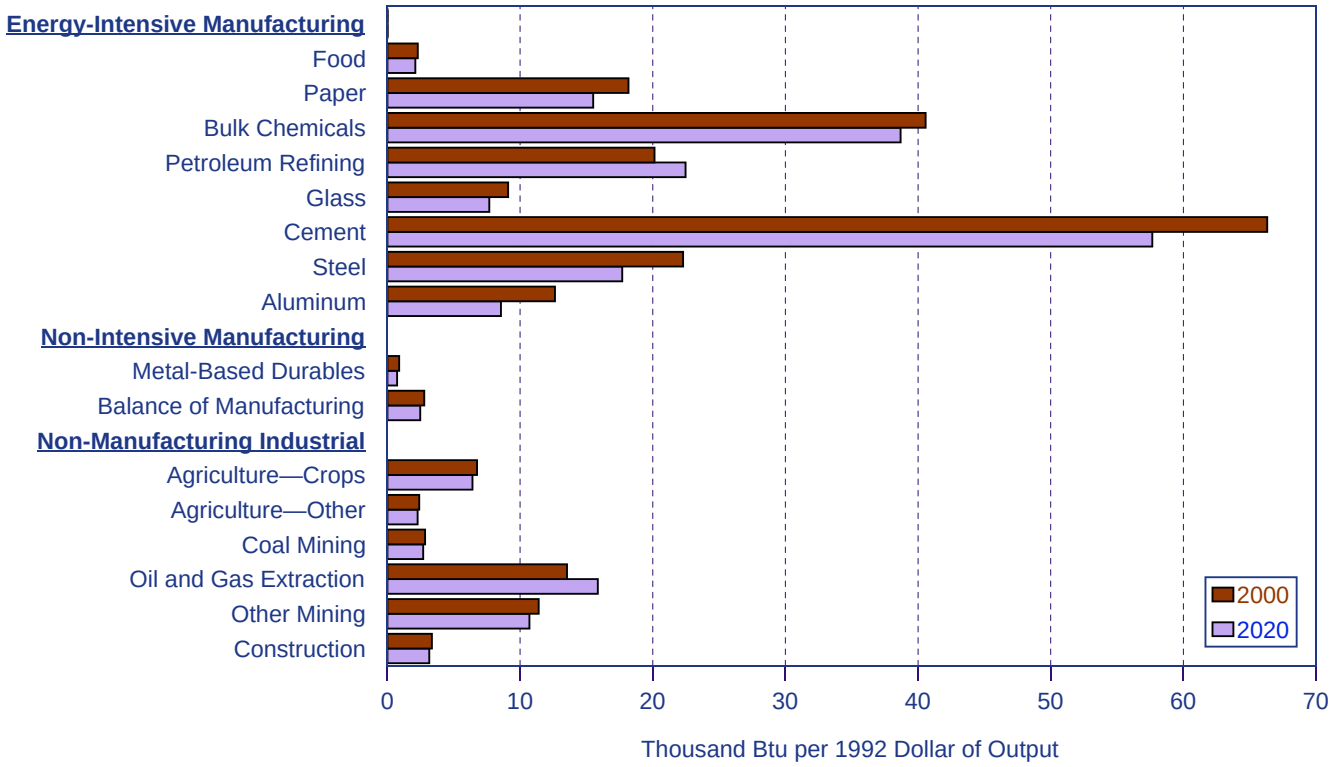
Table 41. Industrial Sector Output by Industry Group, 2000 and 2020

Industry	2000		2020		Average Annual Output Growth Rate, 2000-2020 (Percent)
	Gross Output (Billion 1992 Dollars)	Share of Industrial Sector Total (Percent)	Gross Output (Billion 1992 Dollars)	Share of Industrial Sector Total (Percent)	
Energy-Intensive Manufacturing	**1,100.2**	**21.7**	**1,410.2**	**16.7**	**1.2**
Food	479.5	9.5	624.8	7.4	1.3
Paper	154.5	3.1	214.3	2.5	1.6
Bulk Chemicals	178.7	3.5	223.2	2.6	1.1
Petroleum Refining	152.6	3.0	181.1	2.1	0.9
Glass	22.9	0.5	29.3	0.3	1.2
Cement	5.6	0.1	7.1	0.1	1.2
Steel	70.4	1.4	84.6	1.0	0.9
Aluminum	36.1	0.7	45.9	0.5	1.2
Non-Intensive Manufacturing	**2,922.2**	**57.7**	**5,592.8**	**66.2**	**3.3**
Metal-Based Durables	1,830.3	36.2	3,983.6	47.2	4.0
Balance of Manufacturing	1,091.9	21.6	1,609.1	19.0	2.0
Total Manufacturing	***4,022.4***	***79.5***	***7,003.0***	***82.9***	***2.8***
Non-Manufacturing	**1,039.2**	**20.5**	**1,444.4**	**17.1**	**1.7**
Agriculture—Crops	118.0	2.3	153.1	1.8	1.3
Agriculture—Other	185.2	3.7	232.5	2.8	1.1
Coal Mining	29.1	0.6	36.0	0.4	1.1
Oil and Gas Extraction	107.4	2.1	140.5	1.7	1.3
Other Mining	29.0	0.6	35.9	0.4	1.1
Construction	570.4	11.3	846.5	10.0	2.0
Industrial Sector Total	**5,061.6**	**100.0**	**8,447.4**	**100.0**	**2.6**

Note: Totals and percentages calculated from unrounded data.

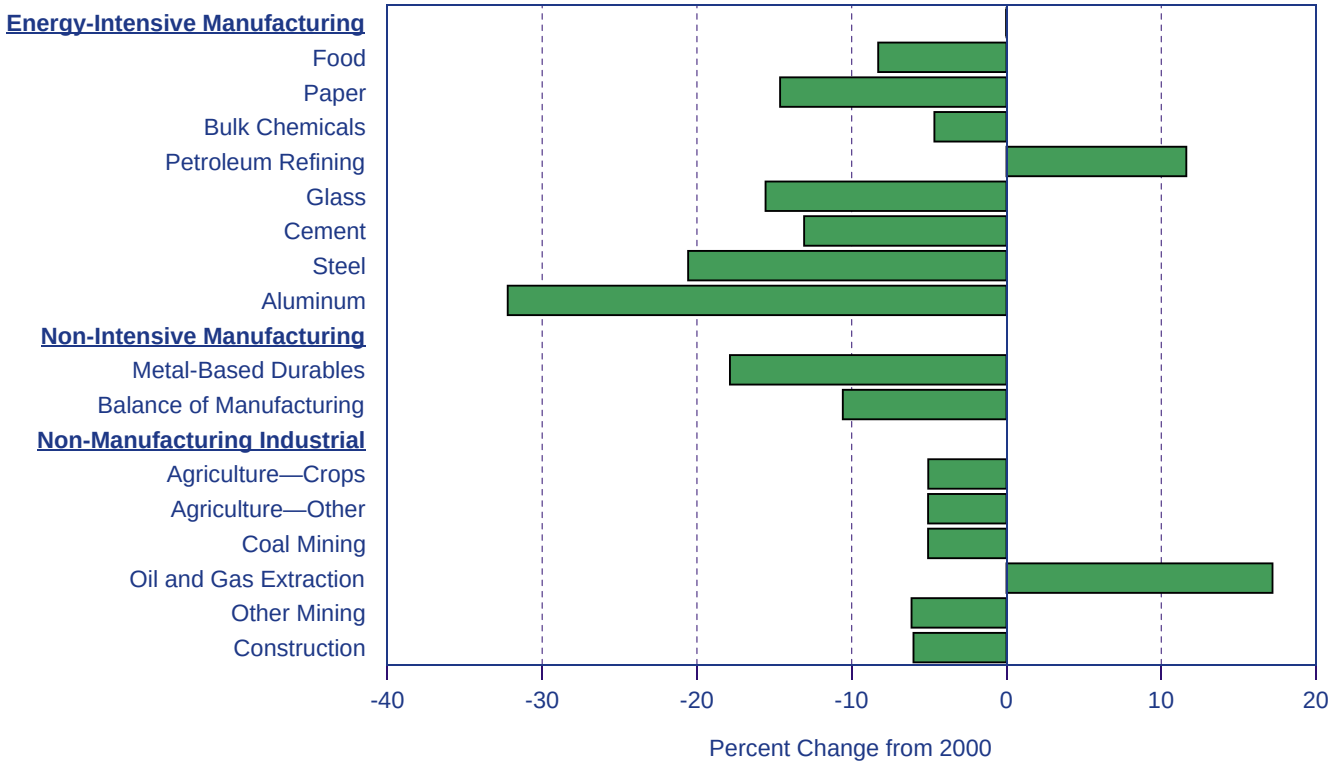
Source: Energy Information Administration, *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 36. Delivered Energy Consumption per Unit of Output by Industry Group, 2000 and 2020



Source: Energy Information Administration, *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Figure 37. Cumulative Change in Delivered Energy Consumption per Unit of Output by Industry Group, 2000-2020



Source: Energy Information Administration, *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).

Table 42. Industrial Sector Delivered Energy Consumption by Industry Group, 2000 and 2020

Industry	2000		2020		Average Annual Output Growth Rate, 2000-2020 (Percent)
	Delivered Energy Consumption (Trillion Btu)	Share of Industrial Sector Total (Percent)	Delivered Energy Consumption (Trillion Btu)	Share of Industrial Sector Total (Percent)	
Energy-Intensive Manufacturing	**16,831**	**63.5**	**19,865**	**59.0**	**0.8**
Food	1,098	4.1	1,313	3.9	0.9
Paper	2,807	10.6	3,324	9.9	0.8
Bulk Chemicals	7,249	27.4	8,632	25.7	0.9
Petroleum Refining	3,071	11.6	4,070	12.1	1.4
Glass	208	0.8	225	0.7	0.4
Cement	372	1.4	412	1.2	0.5
Steel	1,570	5.9	1,497	4.5	-0.2
Aluminum	455	1.7	393	1.2	-0.7
Non-Intensive Manufacturing	**4,649**	**17.5**	**6,890**	**20.5**	**2.0**
Metal-Based Durables	1,623	6.1	2,902	8.6	2.9
Balance of Manufacturing	3,026	11.4	3,988	11.9	1.4
Total Manufacturing	***21,480***	***81.1***	***26,755***	***79.5***	***1.1***
Non-Manufacturing	**5,022**	**18.9**	**6,888**	**20.5**	**1.6**
Agriculture—Crops	797	3.0	982	2.9	1.0
Agriculture—Other	445	1.7	530	1.6	0.9
Coal Mining	83	0.3	97	0.3	0.8
Oil and Gas Extraction	1,454	5.5	2,228	6.6	2.2
Other Mining	331	1.2	384	1.1	0.7
Construction	1,912	7.2	2,668	7.9	1.7
Industrial Sector Total	**26,503**	**100.0**	**33,643**	**100.0**	**1.2**

Note: Totals and percentages calculated from unrounded data.

Source: Energy Information Administration, *Annual Energy Outlook 2002*, DOE/EIA-0383(2002) (Washington, DC, December 2001).