Energy Trends in Selected Manufacturing Sectors:

Opportunities and Challenges for Environmentally Preferable Energy Outcomes








March
2007

SectorStrategies

U.S. Environmental Protection Agency

Energy Trends in Selected Manufacturing Sectors: Opportunities and Challenges for Environmentally Preferable Energy Outcomes

Final Report

March 2007

Prepared for:
U.S. Environmental Protection Agency
Office of Policy, Economics, and Innovation
Sector Strategies Division

Prepared by:
ICF International
9300 Lee Highway
Fairfax, VA 22031
(703) 934-3000

2. Current Energy Consumption

2.1 U.S. Energy Overview

This section provides an overview of historical industrial energy consumption and fuel use trends within the larger context of U.S. energy demand, comparing industrial trends with commercial and residential energy consumption trends to illustrate key points that distinguish industrial energy consumption and fuel usage from that of other end use categories.

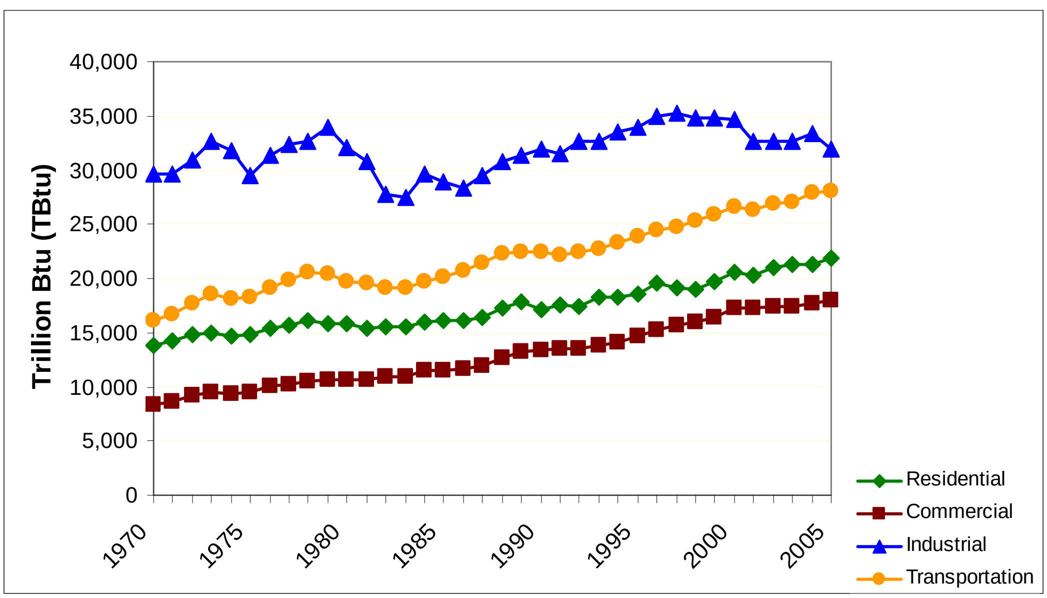
Insights

During the past 35 years, the transition away from heavy industry and towards the commercial and service sectors has contributed to slower energy consumption growth in the industrial sector than in other sectors of the U.S. economy. At the same time, the industrial sector remains the largest end user of energy, and reducing energy consumption in energy-intensive manufacturing industries offers opportunities for improving environmental performance as well as reducing operational costs in an increasingly competitive global marketplace.

2.1.1 Long-Term Energy Consumption Trends

A comprehensive overview of historical energy consumption trends from 1949 through 2005 is provided in the *Annual Energy Review* compiled by the Energy Information Administration (EIA) within the U.S. Department of Energy (DOE). Using data from the 2005 *Annual Energy Review*, Figure 1 shows U.S. energy consumption trends since 1970 across the following end use categories: industrial, transportation, residential, and commercial.

Figure 1: U.S. energy consumption trends 1970-2005: comparison of industrial, transportation, residential, and commercial end uses[2]



> **Energy Consumption Terminology**
>
> - ***Delivered energy*** (also called "site energy") is the amount of energy consumed at the facility level (purchased electricity and fossil fuel inputs as well as onsite renewable energy generation). It does not include losses from offsite energy generation, transmission, and distribution. EIA's *Manufacturing Energy Consumption Survey* (MECS) data presented in this report are in terms of delivered energy consumption.
> - ***Primary energy*** refers to energy consumed onsite plus the total amount of fuels used to generate energy offsite (i.e., by the electric power generating sector). Thus, it includes energy losses from offsite energy generation, transmission, and distribution.
> - ***Total energy*** is primary energy plus the amount of energy consumed by the electricity-generating sector to meet its own energy needs, which is allocated to the end use sectors (industrial, commercial, and residential). Energy consumption data from EIA's *Annual Energy Review* in Section 2.1.1 are in total energy terms.
>
> Source: DOE, Indicators of Energy Intensity in the United States.
> Available at http://intensityindicators.pnl.gov/terms_definitions.stm#economy.

Total energy consumption across all end uses has increased since 1970, but industrial energy consumption has shown the slowest growth over the period, increasing at an annual rate of 0.35 percent from 1970 to 2004.[h] Over the same period, total commercial energy consumption has more than doubled, with an annual growth rate of 2.1 percent, and annual growth rates for energy consumption in the transportation and residential sectors were 1.6 and 1.3 percent, respectively. At the same time, total industrial energy consumption has remained greater than total energy consumption in the other end use categories.[i] Industrial energy consumption has also shown greater responsiveness to energy price increases than the other categories, declining in 1975 and from 1980 to 1983 primarily in response to oil price spikes.[3]

The trend of relatively flat industrial energy consumption compared with other end use sectors is primarily attributable to the U.S. economy's overall shift away from traditional manufacturing industries towards the service and commercial sectors, and from energy-intensive industries towards industries with lower energy intensity, as well as to energy efficiency improvements within industrial manufacturing sectors.

2.1.2 Fuel Consumption Trends

Table 3 presents the fraction of total energy demand that is met by various energy sources and fuel types for each end use sector: industrial, commercial, residential, and transportation.[j] (Note that according to the 2005 *Annual Energy Review*, energy inputs for electricity production are approximately 50 percent coal, 19 percent nuclear, 16 percent natural gas, and 6 percent hydroelectric. The remaining energy inputs for electric power generation include petroleum, wood, waste, and other renewables such as wind, solar, and geothermal.)[4]

---

h As indicated in the *Energy Consumption Terminology* sidebar, *Annual Energy Review* data are presented in total energy terms. As EIA's 2005 data were preliminary at the time this report was written, 2004 data were used to calculate end use fractions of total U.S. energy consumption. Annual increases are the calculated average growth rate over the period.

i Delivered energy consumption by the transportation sector recently surpassed industrial delivered energy consumption.

j Percentages were calculated using 2004 total energy consumption data.

Table 3: Fraction of total energy demand met by fuel type in 2004: comparison of residential, commercial, industrial, and transportation end uses[5]

	Electricity	Coal	Coal Coke	Natural Gas	Petroleum	Renewable	TOTAL[k]
Industrial	33.5%	6.1%	0.4%	25.6%	29.3%	5.0%	**99.9%**
Commercial	76.2%	0.6%	0.0%	18.2%	4.3%	0.8%	**100.1%**
Residential	66.8%	0.1%	0.0%	23.6%	7.3%	2.3%	**100.1%**
Transportation	0.3%	0.0%	0.0%	2.2%	96.5%	1.0%	**100.0%**

It is important to note the following characteristics that distinguish industrial energy usage from that of other end use sectors, particularly residential and commercial energy consumption:

- ***Electricity.*** The industrial sector is relatively less dependent on purchased electricity than the commercial and residential sectors, in part because industry produces a greater fraction of its own power through direct fuel inputs and, for some industries, through cogeneration. A form of cogeneration is combined heat and power (CHP), which produces thermal and electric energy from a single fuel source. CHP is a key energy efficiency opportunity for sectors with high process thermal and electricity loads (see Section 2.2.6), particularly the chemical manufacturing, food manufacturing, forest products, and petroleum refining sectors.[l]
- ***Coal.*** Though still an important fuel source for some industries, coal use by the industrial sector has declined steadily since 1950 (when it was the largest fraction of industrial fuel inputs) to a relatively small fraction of industrial fuel inputs today.[6] Over the same period, coal use in electric power generation has grown rapidly (currently supplying more than 50 percent of energy inputs for electric power generation), and thus represents an important, though indirect, source of energy for all three end use categories except transportation, particularly the commercial and residential sectors.
- ***Natural gas.*** For the industrial sector, natural gas represents a larger fraction of total energy consumption than for other sectors, and industry is the largest end user of natural gas (see Figure 2 on page 2-4). Consequently, increasing natural gas prices are of particular concern for U.S. industry. In addition to fuel use, natural gas is also an important raw material in industries such as chemical manufacturing and petroleum refining.
- ***Petroleum.*** Petroleum also represents a larger fraction of industrial energy inputs than it does for the commercial and residential sectors, and petroleum consumption by industry has increased steadily since 1950—only slightly slower than the rate of increase in the transportation sector.[7] However, a large fraction of industrial petroleum consumption is not for fuel use, but rather as raw material in industries like petroleum refining and chemical manufacturing. Off-road transportation in the mining, agriculture, and construction sectors represents another substantial component of industrial petroleum use. It is also important to note that the industrial petroleum consumption data in Table 3 do not capture petroleum inputs for offsite transportation of manufactured goods, as these energy inputs are included under the transportation sector. Though not considered in depth in this analysis,

---

k For each row, sum of all columns may not equal 100% due to independent rounding.

l Additional sector-level data for onsite generation of electricity, including cogeneration and renewable power generation, is available through MECS tables 11.3 and 11.4, available at http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/excel/table11.3_02.xls.

fuels used in freight shipping represent an important energy input for manufacturing industries.

- ***Renewables.*** The industrial sector is the largest user of renewable fuels, in part due to the extensive use of biomass fuels in the forest products industry. As is the case for coal, renewable energy is also represented in electricity supplied by utilities, meeting approximately 9 percent of the country's electric power supply, primarily through hydropower.

Focusing on more recent historical trends (1989 to 2005), and comparing industrial fuel consumption with fuel consumption in the other major end use categories, Figure 2 through Figure 5 present consumption trends for natural gas, petroleum, coal, and electricity, respectively. Trends are presented for the three main end use categories—industrial, residential, and commercial—with the following exceptions: (1) the coal consumption graph, Figure 4, compares three primary industrial uses of coal with all non-industrial end uses; and (2) the petroleum consumption graph, Figure 3, also includes the consumption trend for transportation end uses.

Figure 2: Natural gas consumption 1989-2005: comparison of industrial, residential, and commercial end uses[8]

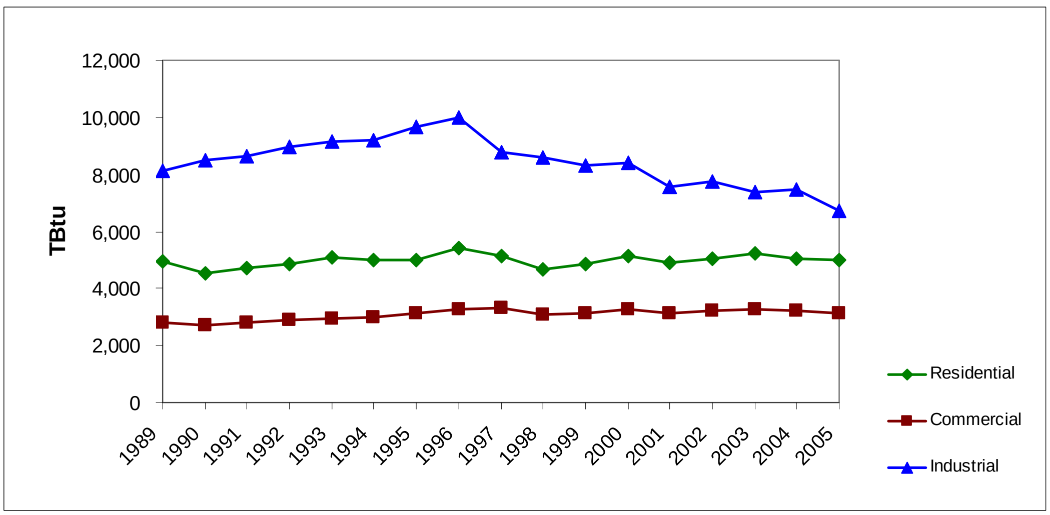


Figure 3: Petroleum consumption 1989-2005: comparison of industrial, transportation, residential, and commercial end uses[9]

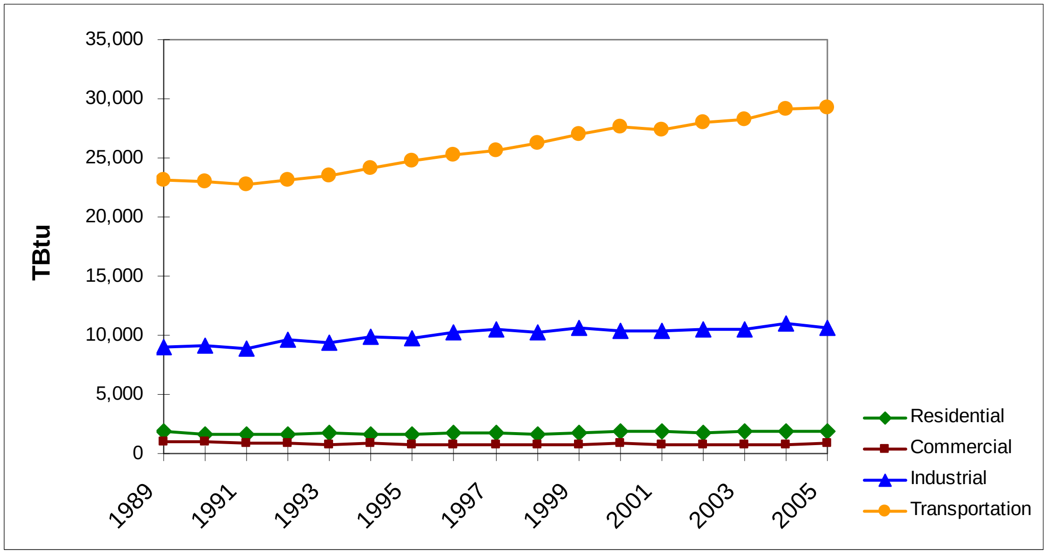
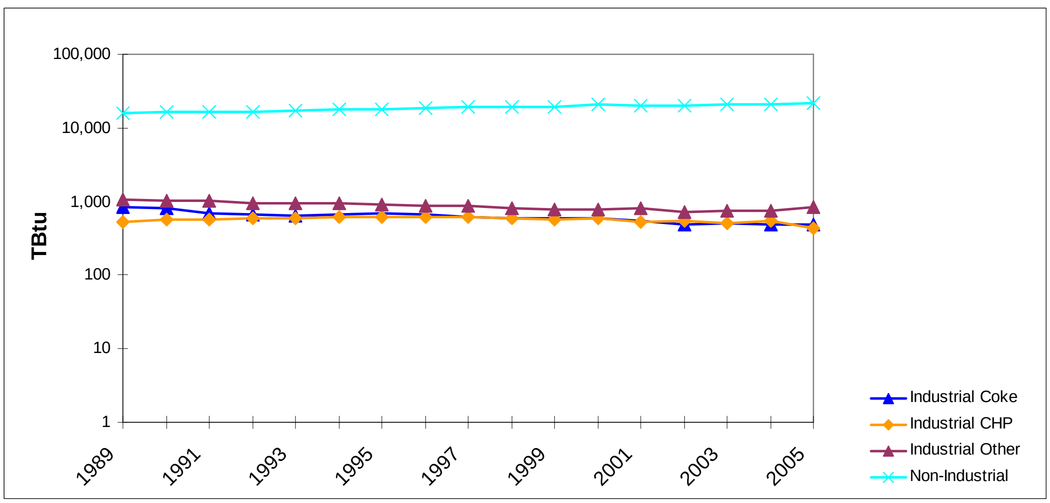
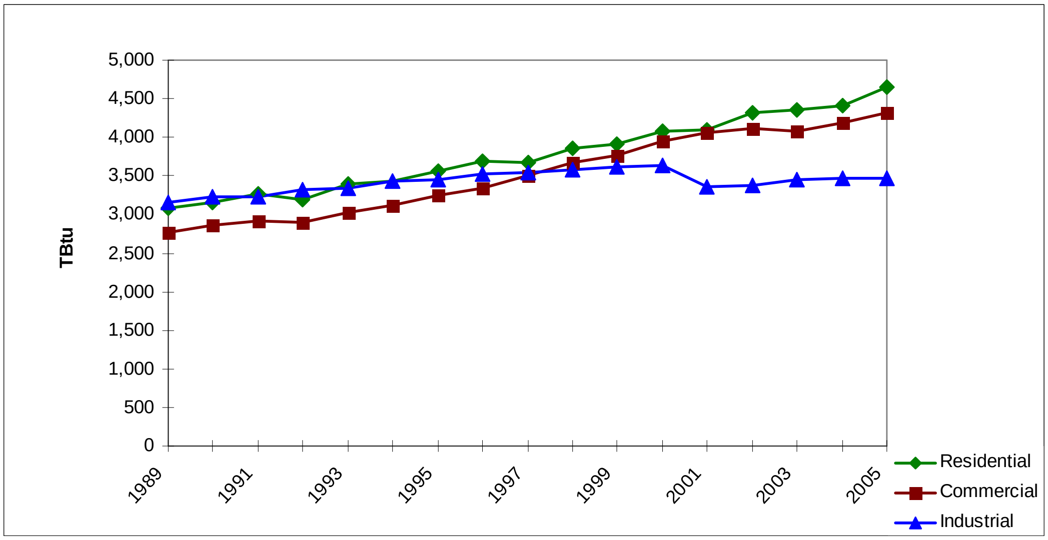


Figure 4: Coal consumption 1989-2005: comparison of industrial and non-industrial end uses[10] [m]



[m] "Industrial coke" represents coal inputs used by industrial coke plants. "Industrial CHP" contains coal inputs for CHP applications and a small number of electricity-only coal plants. "Industrial Other" contains all other coal inputs in industrial applications.

Figure 5: Purchased electricity consumption 1989-2005: comparison of industrial, residential, and commercial end uses[11]



As this analysis is concerned with energy usage trends within 12 industrial manufacturing sectors, the preceding graphs highlight several important points regarding macro-level industrial energy consumption trends:

- The industrial sector consumes more natural gas than other sectors, but industrial gas consumption trends are also more volatile than for other sectors. In some cases, price volatility in the natural gas market has contributed to decreasing industrial output as natural gas-dependent industries reduce production in response to escalating energy costs.[12] For example, approximately 50 percent of U.S. methanol production capacity and 40 percent of ammonia production capacity were idled in response to increasing natural gas prices after 2000.[13]
- Industrial petroleum consumption is second only to transportation consumption, increasing at 1.3 percent annually from 1989 to 2004. However, as mentioned previously a substantial fraction of industrial petroleum consumption is not for fuel use but rather as a raw material in specific industries.[n] Off-road transportation in the mining, agriculture, and construction sectors represents another substantial component of industrial petroleum use.
- Industrial coal consumption has fallen 2 percent annually from 1989 to 2004. Growth in non-industrial coal use is attributable to expansion of coal use for electric power generation, which has increased steadily since 1950.[14]
- Residential and commercial consumption of purchased electricity exceeded industrial consumption in the mid 1990s. Industrial electricity consumption has remained fairly steady, growing at an annual rate just under 0.4 percent from 1989 to 2004.

---

[n] EIA petroleum consumption data include feedstock use. According to 2004 data, 35 percent of industrial petroleum consumption was categorized as "other petroleum," which is defined as: "Pentanes plus petrochemical feedstocks, still gas (refinery gas), waxes, and miscellaneous products. Beginning in 1964, [other petroleum] also includes special naphthas. Beginning in 1983, [other petroleum] also includes crude oil burned as fuel."

It is important to note that as the figures in this section are based on total energy consumption data, they include energy used as feedstocks or raw material inputs in the manufacturing process. Although some manufacturing industries have minimal feedstock energy use, fuels are an important raw material for certain industries. For example, natural gas and petroleum feedstocks are critical to chemical manufacturing and petroleum refining, and both coal and coke are important feedstocks used in iron and steel production. However, feedstock energy inputs may or may not contribute to criteria air pollutant (CAP) and greenhouse gas (GHG) emissions, depending on the specific process in which the feedstock is used, and whether the potential emissions are embedded in the final product. In addition, feedstock inputs do not represent an opportunity for reducing the environmental impacts associated with energy consumption. As the objective of this report is to support the development of strategies for reducing CAP and GHG emissions stemming from energy consumption, the remainder of this analysis focuses on energy inputs for fuel use only and does not address feedstock energy use.

2.2 Sector Energy Overview

Insights

To develop effective sector-level energy management strategies for promoting preferred environmental outcomes, it is important to understand multiple energy usage characteristics: total energy usage, fuel mix, energy intensity, and the relative magnitude of end use applications of energy.

2.2.1 Delivered Energy

Within the constraints of data availability (as noted in table footnotes), Table 4 presents in descending order each sector's energy consumption and energy intensity data compiled in EIA's most recent (2002) MECS, which is produced every four years. While the 2002 MECS is the most recent and comprehensive data set addressing energy consumption across the sectors considered in this analysis, it is important to note that energy trends since 2002—most notably price increases for petroleum-based fuels and natural gas—have affected energy consumption across these sectors. Current energy consumption in some sectors (e.g., iron and steel, forest products, and some components of the chemical manufacturing industry) is likely to be lower than 2002 values as production has declined in light of energy cost trends and other economic factors.

Energy consumption data represent annual fuel-related energy inputs. Energy intensity is the ratio of fuel-related energy consumption to economic production in terms of dollar value of shipments and will be discussed in greater detail in Section 2.2.4.

Table 4: Sector energy consumption and energy intensity in 2002[15]

NAICS	Sector	Energy Consumption (TBtu)	Energy Consumption per Dollar Value of Shipments (thousand Btu (KBtu))
325	Chemical manufacturing	3,769	8.5
324110	Petroleum refining	3,086	16.1
322	Pulp and paper (within forest products)	2,361	15.2
331111	Iron and steel	1,455	27.8
311	Food manufacturing	1,116	2.6
336	Transportation equipment[o]	424	0.7
327310	Cement	409	56.0
332	Fabricated metal products[p]	387	1.7
321	Wood products (within forest products)	375	4.2
3313	Alumina and aluminum	351	12.2
3315	Metal casting[q]	157	5.6

o As MECS does not contain sector-level data for motor vehicle manufacturing (NAICS 33611), motor vehicle parts manufacturing (NAICS 3363), or shipbuilding and ship repair (NAICS 336611), in Table 4 through Table 8 these three sectors are represented by the larger NAICS category, transportation equipment (NAICS 336).

p As MECS does not contain sector-level data for metal finishing (NAICS 332813), in Table 4 through Table 8 this sector is represented by the larger NAICS category, fabricated metal products (NAICS 332).

q MECS data refer to NAICS 3315 as "foundries."

In general, the sectors shown in Table 4 with the largest energy requirements are also highly energy-intensive, as is the case for petroleum refining, pulp and paper, and iron and steel. However, some less energy-intensive sectors such as food manufacturing also have substantial energy requirements.

- Energy-intensive industries generally seek to control energy costs by investing in energy efficiency to the degree possible within capital constraints and competition with other uses for capital. It is possible that the easiest energy efficiency opportunities have already been exploited by these industries,[r] but the business case for energy efficiency improvement is also more clear-cut when energy represents a relatively larger fraction of production costs.
- For less energy-intensive industries with high energy usage, multifaceted energy efficiency strategies may be needed due to the wider range in energy end uses within these sectors and typically fewer business incentives to control energy costs through increased energy efficiency.

Energy consumption and energy intensity data do not present the full picture of sector energy use and associated emissions. In assessing the environmental impacts associated with energy consumption, fuel mix is of particular importance, as will be discussed in following sections. In addition, some sectors have unique energy consumption characteristics that distinguish them from other manufacturing industries, which also have implications in terms of energy-related emissions. For example, the forest products industry (pulp and paper and wood products) meets more than half of its energy requirements with renewable biomass fuels that are manufacturing process byproducts. A strategic approach to promoting energy efficiency within the industrial sector would ideally address the largest end users of energy but also consider energy intensity and other energy usage factors such as fuel mix.

2.2.2 Energy Consumption by Fuel Type

In addition to affecting energy-related air emissions, fuel mix is also important in terms of understanding how sectors may respond to changing fuel prices. Table 5 presents MECS 2002 data on annual fuel inputs by sector (energy use as fuel only, not including feedstock energy inputs). Table 6 presents the same data as a fraction of each sector's total fuel energy consumption, with the two largest fuel input fractions highlighted in gray. For comparison purposes in both tables, the line "All Industrial Codes with Figures" provides total fuel usage for all industries included in the MECS survey, including those sectors that are the subject of this analysis.

[r] A recent paper published by the American Council for an Energy-Efficient Economy, *Ripe for the Picking: Have We Exhausted the Low-Hanging Fruit in the Industrial Sector?* offers a detailed discussion of whether all easy energy efficiency opportunities have already been exploited for the industrial sector. Available at http://aceee.org/.

Table 5: Sector energy consumption by fuel type in 2002[16] [s] [t]

NAICS	Sector	Total (TBtu)[u]	Net Electricity[v] (TBtu)	Residual Fuel Oil (TBtu)	Distillate Fuel Oil (TBtu)	Nat. Gas (TBtu)	LPG & NGL[w] (TBtu)	Coal (TBtu)	Coke & Breeze (TBtu)	Other[x] (TBtu)
All Industrial Codes with Figures		**16,276**	**2,839**	**211**	**142**	**5,794**	**103**	**1,182**	**574**	**5,431**
325	Chemical manufacturing	**3,769**	522	43	14	1,678	37	314	1	1,158
324110	Petroleum refining	**3,086**	121	21	5	821	20	1	0	2,097
322	Pulp and paper (within forest products)	**2,361**	223	100	13	504	6	234	4	1,276
331111	Iron and steel	**1,455**	184	1	10	388	*	36	526	311
311	Food manufacturing	**1,116**	230	13	19	575	5	184	1	90
336	Transportation equipment	**424**	172	6	3	203	4	8	0	28
327310	Cement	**409**	43	1	6	21	*	236	8	95
332	Fabricated metal products	**387**	161	Q	6	209	3	1	Q	2
321	Wood products (within forest products)	**375**	72	1	10	57	5	1	0	229
3313	Alumina and aluminum	**351**	193	*	1	130	1	0	*	26
3315	Metal casting	**157**	54	*	1	77	1	1	23	*

s In Tables 4 through 7 that report MECS data, we have used the "missing data" symbols used in MECS data tables. MECS defines these symbols as follows: *=estimate less than 0.5; W=Withheld to avoid disclosing data for individual establishments; and Q=Withheld because Relative Standard Error (RSE) is greater than 50 percent.

t As noted by EIA, double-counting of fuel inputs may occur when the thermal energy content of an energy input is not completely consumed for the production of heat, power, or electricity generation. These residual energy leftovers may be subsequently consumed for fuel purposes (for example, in steel manufacturing, blast furnace gas may be recovered as a byproduct from coke and other inputs that were not completely consumed and used as fuel). In such cases, fuel consumption estimates will be inflated.

u Total column may not equal the sum of rows for one or more of the following reasons: (1) data on individual fuel inputs may be withheld for reasons noted in previous footnote; or (2) independent rounding of fuel input data.

v "Net electricity" value is obtained by summing electricity purchases, transfers in, and generation from noncombustible renewables, and subtracting quantities of electricity transferred and sold. Thus, it provides a rough approximation of purchased power.

w Liquefied petroleum gases (LPG) and natural gas liquids (NGL).

x "Other" includes net steam (the sum of purchases, generation from renewables, and net transfers) and other energy that respondents indicated was used to produce heat and power.

Table 6: Sector fuel inputs as fraction of total energy requirements in 2002[17]

NAICS	Sector	Total[y]	Net Electricity	Residual Fuel Oil	Distillate Fuel Oil	Nat. Gas	LPG & NGL	Coal	Coke & Breeze	Other
All Industrial Codes with Figures		**100.0%**	**17.4%**	**1.3%**	**0.9%**	**35.6%**	**0.6%**	**7.3%**	**3.5%**	**33.4%**
325	Chemical manufacturing	**99.9%**	13.8%	1.1%	0.4%	44.5%	1.0%	8.3%	0.0%	30.7%
324110	Petroleum refining	**100.0%**	3.9%	0.7%	0.2%	26.6%	0.6%	0.0%	0.0%	68.0%
322	Pulp and paper (within forest products)	**100.0%**	9.4%	4.2%	0.6%	21.3%	0.3%	9.9%	0.2%	54.0%
331111	Iron and steel	**100.1%**	12.6%	0.1%	0.7%	26.7%	*	2.5%	36.2%	21.4%
311	Food manufacturing	**100.1%**	20.6%	1.2%	1.7%	51.5%	0.4%	16.5%	0.1%	8.1%
336	Transportation equipment	**100.0%**	40.6%	1.4%	0.7%	47.9%	0.9%	1.9%	0.0%	6.6%
327310	Cement	**100.2%**	10.5%	0.2%	1.5%	5.1%	*	57.7%	2.0%	23.2%
332	Fabricated metal products	**98.7%**	41.6%	Q	1.6%	54.0%	0.8%	0.3%	Q	0.5%
321	Wood products (within forest products)	**100.0%**	19.2%	0.3%	2.7%	15.2%	1.3%	0.3%	0.0%	61.1%
3313	Alumina and aluminum	**100.0%**	55.0%	*	0.3%	37.0%	0.3%	0.0%	*	7.4%
3315	Metal casting	**100.0%**	34.4%	*	0.6%	49.0%	0.6%	0.6%	14.6%	*

As indicated by the "All Industrial Codes with Figures" data, the sectors shown in the above tables account for approximately 85 percent of all industrial energy consumption reported to MECS in 2002. The five sectors with the largest energy requirements—chemical manufacturing, petroleum refining, pulp and paper, iron and steel, and food manufacturing—represent more than 70 percent of all industrial energy consumption reported in the 2002 MECS. The following points are important to note about fuel consumption by these industrial manufacturing sectors:

- The composition of the "other" category varies from sector to sector. For chemical manufacturing, "other" fuels include petroleum-derived byproduct gases and solids, woody materials, hydrogen, and waste materials.[18] For petroleum refining, "other" fuels consist primarily of fuel gas generated in the refining process. For forest products (pulp and paper and wood products), "other" fuels are primarily biomass—black liquor, pulping liquor, and wood residues and byproducts—used to generate renewable energy. For iron and steel, the "other" category is largely composed of byproduct fuels such as coke oven gas and blast furnace gas (coal-based in origin).[19] For the cement industry, "other" includes petroleum coke as well as waste materials that are incinerated for fuel, such as old tires and municipal solid waste.[20]
- Petroleum consumption is detailed in three fuel categories: residual fuel oil, distillate fuel oil, and LPG/NGL (which contains both liquefied petroleum gas and natural gas liquids). Petroleum fuel inputs are relatively small for the sectors considered in this analysis (less than 3 percent of total fuel consumption shown in Table 5). Some additional petroleum inputs are contained in the "other" category. For petroleum refining and chemical manufacturing, these petroleum-based fuels are byproduct fuels. For cement and

---

y Total column may not equal 100 percent for one or more of the following reasons: (1) for sectors that exported energy produced on site, it was not possible to subtract exported energy from fuel inputs, because MECS does not indicate which fuel was used to produce the exported energy (chemical manufacturing and iron and steel report energy shipments); (2) data on individual fuel inputs may be withheld for reasons noted in previous footnotes; or (3) independent rounding of fuel input data.

aluminum, these fuels are petroleum coke. (Table 3 indicated that petroleum accounts for roughly 30 percent of total industrial energy consumption, but the majority of these inputs are used as feedstocks or for off-road transportation in sectors such as mining and construction, as mentioned in Section 2.1.2.)

- Natural gas meets a substantial fraction of energy demand for nine of the sectors listed in the previous tables—an indication of the overall importance of natural gas to industrial manufacturing sectors. Accordingly, manufacturing industries are particularly sensitive to fluctuations in the price of natural gas.
- For sectors with substantial coal consumption, the majority of coal inputs are used to power boilers and process equipment with large thermal energy requirements such as cement kilns.
- Energy-related emissions associated with offsite electric power generation occur at the generating source (usually an electric utility), which means that for sectors where purchased electricity represents a large component of energy consumption (such as aluminum, food manufacturing, metal casting, metal finishing, motor vehicle manufacturing, and motor vehicle parts manufacturing), substantial energy-related emissions occur outside the facility.

It is important to understand which fuel inputs represent the largest fraction of an industry's energy demand in order to anticipate expected responses to rising energy costs, and it is also critical to understand the constraints on an industry's capacity to shift from one energy source to another. Fuel-switching potential is discussed in the following Section 2.2.3. Possible future fuel-switching trends under "base case" and "best case" energy scenarios for each sector will be discussed in Chapter 3.

2.2.3 Fuel-Switching Potential

From an environmental perspective, one concern is that as natural gas prices increase, industries will switch away from natural gas towards more emissions-intensive energy sources such as coal. In the converse, environmentally preferable energy scenarios could involve switching from emissions-intensive energy sources such as coal toward less emissions-intensive energy sources. It is important to note that natural gas prices are sufficiently high at the present time that most facilities that can readily use coal or an alternative fuel are already using it. For existing facilities, switching from coal to natural gas is very difficult to justify on a cost basis, and promoting such fuel-switching is politically sensitive from a policy perspective.

There are considerable constraints on an industrial facility's ability to engage in fuel-switching, including technical constraints, regulatory constraints, and supply constraints.[21] Fuel-switching ability also varies according to fuel type. For example, it is easier to switch from natural gas to petroleum than from natural gas to coal. On the technical side, switching from natural gas to coal requires major changes to fuel handling equipment and boilers. On the regulatory side, if a facility is permitted for natural gas, switching to coal would trigger New Source Review under the Clean Air Act. Supply constraints relate to the cost and availability of fuel substitutes, which vary according to the location of the facility in relation to fuel transportation infrastructure. Supply constraints reduce the magnitude of environmentally preferable switching potential (e.g., from coal to natural gas) as natural gas supply infrastructure may be unable to reliably meet the fuel requirements of large industrial applications, as well as the potential for environmentally detrimental fuel-switching due to transportation infrastructure constraints affecting coal.

The MECS survey instrument asks respondents to indicate the amount of six major fuel inputs that could potentially be switched (within 30 days of the switching decision) to an alternate fuel given constraints imposed by existing equipment configurations and legal obligations such as binding supply contracts and environmental regulations.[z] Based on these survey responses, Table 7 summarizes data from the 2002 MECS on each sector's potential to switch from natural gas to one of seven alternate fuel sources, and Table 8 summarizes similar data for coal. (Data do not include fuels consumed as feedstock.) In each Table, the first three columns show the fraction of each sector's fuel consumption that could be switched to an alternate fuel source, as well as the fraction that is non-switchable, and the fraction that was unreported as either switchable or non-switchable. The remaining columns show the percentage of the switchable fuel fraction that could be met by each of the alternate fuels. (Note that there is double-counting in the alternate fuels columns—for example, a portion of the natural gas fraction could be switched to either distillate or residual fuel oil—so the sum of the alternate fuels columns will not equal 100 percent.)

As we have done with other tables using MECS data, for comparison purposes we also report the totals for all industries included in the MECS survey, including those sectors that are the subject of this analysis. These data appear in the lines entitled "All Industrial Codes with Figures."

Table 7: Sector fuel-switching potential in 2002: natural gas to alternate fuels[22] [aa]

		Natural Gas Switching Potential			Alternate Fuels That Could Be Substituted for Natural Gas (shown as percentage of switchable fraction)						
NAICS	Sector	Switchable Fraction	Non-Switchable Fraction	Non-Reported Fraction	Electric Receipts[bb]	Distillate Fuel Oil	Residual Fuel Oil	LPG	Coal	Coke & Breeze	Other[cc]
All Industrial Codes with Figures		**19%**	**63%**	**18%**	**10%**	**38%**	**22%**	**34%**	**4%**	**0%**	**7%**
3313	Alumina and aluminum	9%	77%	14%	*	27%	9%	64%	0%	0%	*
327310	Cement	29%	62%	10%	17%	17%	33%	17%	67%	17%	17%
325	Chemical manufacturing	10%	64%	26%	9%	45%	32%	13%	Q	0%	7%
332	Fabricated metal products	Q	57%	43%	*	*	*	Q	Q	*	Q
311	Food manufacturing	28%	53%	19%	13%	45%	26%	41%	1%	*	Q
331111	Iron and steel	12%	78%	10%	*	11%	62%	Q	13%	4%	9%
3315	Metal casting	20%	68%	12%	13%	13%	*	73%	*	*	*
324110	Petroleum refining	18%	64%	18%	8%	19%	5%	58%	*	*	27%
322	Pulp and paper (within forest products)	32%	58%	10%	16%	45%	35%	9%	5%	*	4%
336	Transportation equipment	18%	64%	18%	11%	33%	17%	42%	11%	*	*
321	Wood products (within forest products)	20%	68%	13%	9%	27%	9%	36%	*	*	27%

z For a detailed description of MECS approach and assumptions related to defining fuel-switching capability, see http://www.eia.doe.gov/emeu/mecs/mecs2002/methodology_02/meth_02.html#cfsc.

aa In Tables 4 through 7 that report MECS data, we have used the "missing data" symbols used in MECS data tables. MECS defines these symbols as follows: *=estimate less than 0.5; W=Withheld to avoid disclosing data for individual establishments; and Q=Withheld because Relative Standard Error (RSE) is greater than 50 percent.

bb "Electric receipts" includes quantities of purchased electric power and has not been adjusted to account for any quantities that might have been resold or transferred out. It does not include electricity generated onsite.

cc "Other" includes all other types of fuel that respondents indicated could have been consumed and not otherwise listed.

Table 8: Sector fuel-switching potential in 2002: coal to alternate fuels[23]

		Coal Switching Potential			Alternate Fuels That Could Be Substituted for Coal (shown as percentage of switchable fraction)					
NAICS	Sector	Switchable Fraction	Non-Switchable Fraction	Non-Reported Fraction	Electric Receipts[dd]	Natural Gas	Distillate Fuel Oil	Residual Fuel Oil	LPG	Other
All Industrial Codes with Figures		**30%**	**58%**	**12%**	**3%**	**80%**	**18%**	**17%**	**4%**	**6%**
3313	Alumina and aluminum	0%	0%	100%	0%	0%	0%	0%	0%	0%
327310	Cement	51%	45%	3%	W	91%	W	W	4%	8%
325	Chemical manufacturing	36%	62%	2%	1%	82%	14%	11%	0%	W
332	Fabricated metal products	0%	100%	0%	0%	0%	0%	0%	0%	0%
311	Food manufacturing	20%	80%	0%	0%	83%	Q	13%	19%	0%
331111	Iron and steel	3%	97%	0%	0%	40%	0%	0%	0%	60%
3315	Metal casting	0%	100%	0%	0%	0%	0%	0%	0%	0%
324110	Petroleum refining	W	W	W	0%	W	W	0%	0%	0%
322	Pulp and paper (within forest products)	23%	37%	40%	10%	57%	28%	38%	W	10%
336	Transportation equipment	W	W	W	4%	94%	14%	0%	1%	1%
321	Wood products (within forest products)	W	W	W	0%	W	0%	0%	W	0%

In terms of sectors switching from natural gas to alternate fuel inputs, Table 7 illustrates the following points:

- In all cases, the non-switchable fraction is larger than the switchable fraction, indicating the importance of the aforementioned constraints to fuel-switching (technical, regulatory, and supply constraints).
- In general, there is greater potential for sectors to replace natural gas inputs with petroleum fuel inputs (distillate and residual fuel oil, as well as LPG), and relatively less potential to replace natural gas with purchased electricity or coal.
- For sectors with the largest natural gas consumption (chemical manufacturing, food manufacturing, petroleum refining, and pulp and paper, as shown in Table 5), there is a wide range in ability to switch from natural gas to other fuels. The chemicals sector, which has the highest natural gas consumption, has a particularly low switchable fraction.

In terms of switching from coal to alternate fuel inputs, Table 8 illustrates the following points:

- In all cases except cement, the non-switchable fraction is larger than the switchable fraction.
- Natural gas has the greatest potential as a substitute for coal, which would lead to a decrease in energy-related emissions. However, factors such as the substantially higher cost of natural gas and constraints imposed by natural gas supply infrastructure limit the viability of this opportunity for energy-related environmental improvement.

[dd] "Electric receipts" includes quantities of purchased electric power and has not been adjusted to account for any quantities that might have been resold or transferred out.

- For the four sectors with the largest coal consumption (cement, chemical manufacturing, iron and steel, and pulp and paper, as shown in Table 5), there is again a wide range in the potential for switching to alternate fuel sources. In particular, iron and steel has limited ability to switch away from coal consumption, which is why the industry is interested in the development of technologies that reduce the emissions-intensity of coal consumption.[24]

2.2.4 Energy Intensity

As mentioned previously, energy intensity is the ratio of energy consumed as fuel (i.e., not including energy feedstocks) to economic production. Energy-intensive industries may be more receptive to efforts to increase energy efficiency due to the economic impacts associated with rising fuel input costs. Energy intensity can be measured in terms of energy consumption per volume of production (physical energy intensity) or in terms of energy consumption per dollar value of output (economic energy intensity). In this report, we primarily use metrics of economic energy intensity, supplementing with physical energy intensity metrics where data are available. It is important to note that economic energy intensity is affected both by energy consumption and the value of the product, which contributes to the magnitude of difference in energy intensity between many basic manufacturing industries versus finished product manufacturing industries. For example, a ton of steel or cement has a much lower economic value than a ton of integrated circuits or finished consumer goods. Because steel or cement production have both a lower economic value and a higher energy input, the energy intensity of these basic manufacturing industries is higher than many industries producing finished goods.

MECS presents several ratios of manufacturing energy consumption to economic production; the most useful are energy consumption per dollar of value added and energy consumption per dollar value of shipments.[ee] "Dollar of value added" represents the net economic output, or gross economic output less the value of purchased inputs. This measure of manufacturing activity is derived by subtracting the cost of materials, supplies, containers, fuel, purchased electricity, and contract work from the value of shipments (products manufactured plus receipts for services rendered). "Dollar value of shipments" represents the gross economic value of product shipments, including the cost of inputs, and thus does not provide as refined a measurement of an industry's reliance on energy inputs for economic productivity. Value added is considered to be the best metric for comparing the relative economic importance of manufacturing among industries and geographic areas. However, as the key energy projections referenced in this report—EIA's *Annual Energy Outlook*, the *Clean Energy Future* report, and the American Gas Foundation's *Natural Gas Outlook to 2020*—all employ gross value of shipments as an economic metric, we primarily use value of shipments for the purposes of this analysis.

For each sector, Table 9 presents 2002 MECS data on energy consumption per economic output. As a benchmark, the energy consumption per economic output ratios are aggregated for all industrial sectors addressed in the MECS survey (listed as "All Industrial Codes with Figures").[ff] MECS calculates energy intensity based on energy consumed as a fuel, and the ratios do not include fuels consumed as feedstocks.

As MECS does not contain data for four of the sectors considered in this analysis (metal finishing, motor vehicle manufacturing, motor vehicle parts manufacturing, and shipbuilding and

[ee] In the 2002 MECS, EIA uses economic data from the U.S. Census Bureau's *2002 Economic Census, Manufacturing - Industry Series*.

[ff] EIA favors use of a MECS-weighted value of shipments in calculating ratios used in this table in order to minimize any sample peculiarities that may impact both consumption and value of shipments. This may result in deviations from intensities calculated using unweighted MECS energy consumption data.

ship repair), for all sectors we have included 2002 Census Bureau data from the *Annual Survey of Manufacturers* on costs of purchased energy per dollar of value added and per dollar of value of shipments as an approximation of energy intensity. For these metrics, the benchmark is the average for all manufacturing industries (NAICS 31-33).

Table 9: Sector energy intensity in 2002[25] [26]

NAICS	Sector	Energy Consumption per Dollar of Value Added (KBtu)	Energy Consumption per Dollar Value of Shipments (KBtu)	Energy Cost per Dollar of Value Added (share)	Energy Cost per Dollar Value of Shipments (share)
All Industrial Codes with Figures (benchmark)		**8.9**	**4.2**	**3.7%**	**1.8%**
	Higher than benchmark				
324110	Petroleum refining	116.3	16.1	21.0%	3.1%
327310	Cement	95.5	56.0	24.5%	15.1%
331111	Iron and steel[gg]	66.5	27.8	20.4%	8.0%
3313	Alumina and aluminum	34.3	12.2	21.0%	6.9%
322	Pulp and paper (within forest products)	31.1	15.2	8.8%	4.3%
325	Chemical manufacturing	15.3	8.5	5.4%	3.0%
321	Wood products (within forest products)	10.6	4.2	4.7%	1.9%
3315	Metal casting	10.3	5.6	8.0%	4.6%
332813	Metal finishing[hh]	NA	NA	6.7%	4.0%
	Lower than benchmark				
311	Food manufacturing	6.0	2.6	3.3%	1.5%
332	Fabricated metal products	3.0	1.7	2.7%	1.5%
3363	Motor vehicle parts manufacturing	NA	NA	2.1%	0.9%
336611	Shipbuilding and ship repair	NA	NA	1.2%	0.8%
33611	Motor vehicle manufacturing[ii]	NA	NA	1.1%	0.3%

It is important to note that the MECS energy intensity data are based on delivered energy consumption rather than primary energy consumption. Thus, it does not account for energy losses in the generation, transmission, and distribution of electric power (for additional detail, see the *Energy Losses in Purchased Electricity* sidebar in Section 2.2.5). This means that for a given energy requirement and a given dollar value of output, a sector that derives its process energy from direct combustion of natural gas onsite could have the same delivered energy intensity as one that receives process energy from purchased power. In reality, however, the electric power-dependent sector is more energy intensive from a system-wide perspective because of the losses associated with electric power generation, transmission, and distribution. To some degree the two energy cost columns in Table 9 (energy cost per dollar of value added and energy cost per dollar value of shipments) provide a closer approximation of primary energy intensity, since electric power is more costly on a Btu basis than energy produced from direct fuel inputs onsite.

---

gg Census Bureau data are for the larger NAICS category, iron and steel and ferroalloy manufacturing (NAICS 33111).

hh Census Bureau data are for the larger NAICS category, coating, engraving, heat treating, and allied activities (NAICS 33281).

ii Census Bureau data refer to NAICS 33611 as "automobile and light duty motor vehicle manufacturing."

Of the five sectors with the greatest annual energy requirements—chemical manufacturing, petroleum refining, pulp and paper, iron and steel, and food manufacturing—all but food manufacturing are more energy-intensive than the industrial manufacturing benchmark. However, comparing sector energy consumption with energy intensity highlights some important distinctions:

- Though the chemicals sector has the greatest energy consumption, it not the most energy intensive.
- The aluminum industry is highly energy intensive but uses far less energy than the five sectors with the highest energy consumption, in part due to the comparatively smaller size of the aluminum industry.
- The food manufacturing industry ranks fifth in terms of total energy usage (see Table 4), but it has a lower energy intensity than the industry benchmark.

These results indicate the importance of using multiple metrics to characterize sector energy usage. The energy intensity ratios shown in Table 9 are also important because they indicate an industry's expected sensitivity to fluctuations in fuel prices.

- Increasing energy costs are likely to have the greatest impact on industries with higher energy costs per dollar of value added and per dollar value of shipments than the manufacturing industry benchmark—particularly petroleum refining, cement, aluminum, and iron and steel.
- Despite the fact that the aggregated energy requirements of the food manufacturing industry are large, energy costs represent a relatively small fraction of economic output (lower than the manufacturing industry benchmark), which likely accounts for the fact that this sector has not historically engaged in energy efficiency efforts to the same degree as highly energy-intensive manufacturing industries.

When we discuss the economic context for energy usage in Section 2.4, the energy cost and energy intensity ratios are the metrics we use to rank the sectors in terms of sensitivity to energy costs (see Table 17).

2.2.5 The Manufacturing Energy System

For manufacturing industries, including the 12 sectors considered in this analysis, the major stages of energy use include the following:[27]

- ***Energy generation:***
  - Fossil fuels are the largest energy inputs in manufacturing and may be used in central plants to generate electricity, steam, or CHP, or used directly to power manufacturing process systems.[jj]
  - Purchased electric power is another important energy input that is generated offsite by electric utilities and transmitted to the facility.
  - Energy may also be supplied by renewable energy sources onsite. Though the renewable fraction is small for most sectors, in the forest products industry more than half of the sector's energy requirements are provided through onsite power generation using renewable biomass fuels.
  - Though a less commonly utilized energy source than purchased fuels or electricity, some industrial plants also purchase steam and/or chilled water.

> **Energy Losses in Purchased Electricity**
>
> Electric power generation is associated with substantial energy losses, particularly for fossil fuel-fired power plants. The magnitude of such losses varies greatly according to factors such as fuel inputs and age of equipment. Electric power transmission and distribution are associated with smaller energy losses.
>
> Aggregated across the national grid, the energy loss fraction is 67.5 percent of total electric energy, meaning that delivered electricity consumption represents just over 30 percent of total energy inputs for electric power generation.

- ***Energy transmission/distribution:*** Within the facility, energy transmission/distribution systems include piping for steam, hot water, chilled water, cooling water, compressed air, steam condensate return, and chilled water return piping, fuel piping, and wires for electric power transmission.
- ***Energy end uses:***
  - Facility-related energy requirements include lighting, heating, ventilating, and air conditioning (HVAC), and office equipment, and typically comprise a relatively small fraction of manufacturing energy use.
  - Equipment energy use includes direct energy inputs for process heating, cooling, and electrochemical transformation, as well as indirect energy inputs for machine drives that operate pumps, compressors, fans, blowers, conveyors, and mixers. Common processes used in industrial manufacturing applications include separation, melting, drying, mixing, grinding, forming, and waste handling.

Each stage of the manufacturing energy system—energy generation, transmission/distribution, and use—is associated with energy losses. Substantial offsite energy losses are associated with electric generation (see previous sidebar, *Energy Losses in Purchased Electricity*), and these losses are represented by the difference between primary and delivered energy consumption. In the manufacturing energy system, several categories of losses represent general areas of opportunity for increased energy efficiency:[28]

---

jj Fossil fuels are also used as manufacturing feedstocks (raw materials) by some sectors, but feedstock fuel use is not included in DOE's manufacturing energy footprint diagrams that are discussed in this section.

- ***Energy generation losses:***
  - *External generation losses* are most significant for electric power generation, transmission, and distribution, but for any given manufacturing facility the external loss fraction will vary according to the efficiency of local sources of electric power generation. (As an average for the entire national grid, DOE assumes the efficiency of utility power generation and transmission is 32.5 percent, meaning that associated energy losses are assumed to be 67.5 percent).[29] A small amount of loss also occurs with fuel transport (approximately 3 percent of total fuel energy). Facilities can reduce offsite energy losses through more efficient use of purchased electricity, and to some degree by replacing purchased electricity with onsite electricity generation, which is also associated with energy losses.
  - *Onsite generation losses* occur in central energy generation applications such as steam plants, power plants, and CHP plants. Losses from boilers vary widely due to equipment age, fuel type, and maintenance, and range from 10 to 45 percent.[30] More efficient generating processes such as CHP are associated with lower internal generation losses.
- ***Onsite energy transmission/distribution losses:*** Within the facility, energy is lost in fuel and electricity distribution lines, as well as steam pipes, traps, and valves. The magnitude of such losses ranges from 3 to 40 percent, but the largest losses are typically in steam pipes (20 percent) with smaller losses associated with fuel transmission lines and electric wires (3 percent).[31]
- ***Equipment energy losses:*** Energy is also lost due to inefficiencies in the wide range of equipment used for preprocess and manufacturing process activities: motors, mechanical drives, process heaters and coolers, etc. Again, there is a wide range in how much energy is typically lost from such equipment. Compressors typically lose as much as 80 percent of energy inputs, pumps and fans typically lose 35 to 45 percent, and motors lose 5 to 10 percent.[32]

DOE's Industrial Technologies Program (ITP) has compiled a set of energy use and loss footprints for many of the sectors considered in this analysis, as well as an aggregated footprint for U.S. manufacturing industries (energy consumption data used in this analysis were from the 1998 MECS).[33] In Table 10, we examine three energy loss categories as a fraction of each industry's primary energy requirements: (1) external losses (losses in energy generation, transmission, and distribution) associated with purchased electricity and fossil fuel inputs; (2) onsite generation, transmission, and distribution losses (generation losses from thermal and electric generating equipment, as well as losses from pipes, valves, steam traps, and electric and fuel transmission lines occurring within the facility); and (3) equipment losses (losses from preprocess energy conversion equipment such as heat exchangers, condensers, heat pumps, machine drives, pumps, and motors). We also examine two energy end use categories as a fraction of each industry's primary energy requirements: (1) process energy consumption (energy used in the manufacturing process) and (2) facilities energy use (energy used for lighting, HVAC, etc.).

Table 10: Sector energy use and loss footprint in 1998[34]

NAICS	Sector	External Generation/ Transmission Losses	Onsite Generation/ Transmission Losses	Energy Conversion Equipment Losses[kk]	Process Energy Consumption	Facilities Energy Use
3313	Alumina and aluminum	54%	3%	13%	28%	1%
327310	Cement	20%	3%	14%	63%	0.5%
325	Chemical manufacturing	27%	14%	13%	44%	2%
332	Fabricated metal products[ll]	46%	3%	11%	28%	12%
311, 312	Food & beverage manufacturing	31%	14%	10%	39%	5%
321, 322	Forest products[mm]	19%	25%	12%	42%	2%
33111	Iron, steel, and ferroalloy[nn]	19%	4%	14%	60%	3%
3315	Metal casting[oo]	37%	3%	9%	41%	10%
324110	Petroleum refining	9%	12%	13%	64%	1%
336	Transportation equipment[pp]	46%	6%	10%	22%	16%

The energy use and loss footprints illustrate important differences in the way these sectors use energy:

- Due to the magnitude of energy losses associated with electricity generation, transmission, and distribution, electricity-dependent sectors such as aluminum, fabricated metal products (the larger NAICS category that includes metal finishing), and transportation equipment have high external generation/transmission losses.
- The magnitude of onsite generation and transmission losses in the chemical manufacturing, food manufacturing, forest products, and petroleum refining industries is attributable to the fact that these sectors meet a larger fraction of their energy needs with onsite generation. Given the magnitude of associate energy losses, boilers and other onsite energy generating equipment represent a key area for energy efficiency improvement.
- The relatively small process energy fraction for less energy-intensive sectors like fabricated metal products and transportation equipment suggests that energy efficiency opportunities are likely to lie in a number of areas, in addition to process-related improvements.

---

kk DOE addresses energy use and losses by energy conversion equipment (preprocess) and process equipment separately but does not attempt to quantify process energy losses, primarily because energy conversion equipment and process equipment are frequently integrated, making it difficult to distinguish preprocess from process energy losses.

ll Metal finishing (NAICS 332183) is included in the larger NAICS category, fabricated metal products (NAICS 332).

mm Forest products includes the wood products (NAICS 321) and pulp and paper (NAICS 322) sectors.

nn Iron and steel mills (NAICS 331111) is included in the larger category for iron, steel, and ferroalloy manufacturing (NAICS 33111).

oo DOE refers to NAICS 3315 as "foundries."

pp Motor vehicle assembly (NAICS 33611), motor vehicle parts manufacturing (NAICS 3363), and shipbuilding and ship repair (NAICS 336611) are included in the larger NAICS category, transportation equipment (NAICS 336).

2.2.6 Energy Efficiency and Clean Energy Opportunities

In the sector summaries contained in Chapter 3, we focus on five primary opportunities for reducing the environmental impact of energy use—primarily air emissions of GHGs and CAPs. These opportunities promote environmentally preferable energy outcomes by reducing energy-related air emissions through increased energy efficiency (which reduces fuel consumption and associated emissions) and/or transitioning to less emissions-intensive energy sources.

- ***Cleaner fuels.*** These opportunities involve replacing fuel inputs with alternate fuel inputs that produce lower GHG and/or CAP emissions for the same amount of energy in terms of Btus (e.g., natural gas in place of coal). This category also includes onsite renewable electricity generation using biomass, wind, solar, or geothermal power. Two clarifying points need to be made. First, in general there is no perfect hierarchy of what constitutes a "cleaner" fuel across all applications, as emissions will vary according to plant-specific factors such as equipment age and pollution control mechanisms. Second, also note that "alternate fuels," such as waste fuels used in cement kilns, may or may not be cleaner than what they are replacing depending on unit-specific characteristics.
- ***Increased CHP.*** Combined heat and power applications increase energy efficiency by producing heat (typically steam) and power (electricity) from a single fuel source—a form of cogeneration. Some CHP systems are engineered to provide electricity, hot water, and chilled water as well, depending on the needs of the particular industry. Common fuel inputs for CHP include coal, natural gas, biomass, and fuel oil. CHP is a form of distributed generation, as electricity is generated at the facility level rather than by an electric utility, and thus is associated with lower levels of transmission and distribution losses than purchased electricity. Conventional generation of electric power also wastes much of the heat generated in electricity production (which CHP uses), and conventional thermal energy generation often misses an easy opportunity to generate electric power. As a result, CHP systems have efficiencies exceeding 70 percent. CHP systems achieving efficiencies exceeding 80 percent are frequent, and some highly integrated systems have been shown to reach levels in excess of 90 percent. CHP represents a substantial efficiency improvement compared with a state-of-the-art central plant that offers maximum system fuel efficiency for delivered power in the range of 55 to 60 percent.[35]
- ***Equipment retrofit/replacement.*** Energy efficiency can be increased by retrofitting or replacing existing equipment used for onsite heat or power generation and distribution, manufacturing processes, or to meet facility requirements such as lighting or HVAC. Many of the sectors considered in this report have substantial onsite capacity for generating electric and thermal energy, and upgrades to such equipment can reduce energy losses. Given the magnitude of industrial process energy requirements, retrofitting or replacing existing process equipment offers the potential for substantial increases in energy efficiency, and thus a reduction in energy-related emissions per unit of manufacturing output. Equipment is most likely to be replaced at the end of its full service life, because new highly capital-intensive equipment purchases usually cannot be justified on the basis of energy savings alone. Also, equipment replacement often entails substantial time requirements for design, engineering, building, installing, and commissioning. Installing new process equipment typically involves building a new process line rather than shutting down operating equipment, and this constraint requires that the facility have sufficient space available to support the new line. As full equipment replacement often faces these types of hurdles, retrofitting may be a more viable opportunity in many cases. Retrofitting

or replacing facility equipment such as lighting and HVAC system components may also be easier to achieve from an operational and capital standpoint.

- ***Process improvement.*** This term encompasses a broad range of opportunities for increasing energy efficiency and reducing energy-related emissions, some of which are major capital-intensive changes and some of which are relatively minor low-cost improvements. Capital-intensive opportunities entail wholesale process changes such as the transition from wet to dry kilns in cement manufacturing, or from the blast furnace and coke plant to direct iron ore reduction in steelmaking. (Note that in cases where process changes require installation of new equipment, such opportunities could also be classified as "equipment replacement," but we have made an effort to differentiate these wholesale process-related changes from other types of equipment upgrades). Less capital-intensive opportunities are primarily geared towards implementing energy management best practices or adjusting existing processes to improve energy efficiency and/or achieve other environmental benefits such as waste minimization. Examples include reducing waste treatment energy requirements through increased recycling of process materials and scheduling production activities to reduce equipment idling time.
- ***Research and development (R&D).*** As noted earlier, a number of sectors participate in DOE's ITP and/or other R&D efforts in order to develop and commercialize higher-efficiency technologies and processes. These projects represent typically longer-term energy efficiency opportunities.

In some cases, exploiting one or more of these opportunities may produce an environmental quality improvement in some respects, and an environmental quality reduction in other areas. For example, reducing inputs of purchased electricity in favor of natural gas may reduce energy-related emissions at the electric generation level and improve the overall efficiency of energy use (because direct natural gas inputs at the facility level are associated with lower energy losses than purchased electricity), but may lead to an increase in energy-related emissions at the facility level. In the *Environmental Implications* section of each sector summary (see Chapter 3), we seek to identify such tradeoffs to the extent possible.

2.2.7 Transportation Energy Consumption

This analysis focuses on energy use and energy efficiency opportunities at manufacturing facilities and does not address in detail transportation energy requirements, which are substantial for many sectors with respect to freight shipping. Though it was not possible to obtain annual data on product shipments for all sectors, Table 11 summarizes commodity shipping data for some of the sectors covered in this analysis. The commodities shown in the table represent more than half of all U.S. commodity shipments in 2002. The food manufacturing sector is particularly intensive in terms of transportation energy requirements.

Table 11: Commodity shipments by sector in 2002[36]

Commodity	Ton miles (millions)[qq]	% of Total
All commodities	**3,137,898**	**100.0%**
Food	678,263	21.6%
Petroleum and coal products	265,684	8.5%
Chemicals	268,560	8.6%
Wood products	127,941	4.1%
Paper	118,557	3.8%
Iron and steel	93,934	3.0%
Fabricated metal products[rr]	42,680	1.4%
Transportation equipment	69,678	2.2%
Remaining commodity shipments	1,472,601	46.9%

qq A ton mile is a unit of freight transportation that is derived by multiplying the distance the freight is hauled in miles by the weight of the shipment in tons. (See DOE's *Energy Efficiency Glossary* at http://www.eia.doe.gov/emeu/efficiency/ee_gloss.htm.)

rr Metal finishing (NAICS 332183) is included in the larger NAICS category, fabricated metal products (NAICS 332).

2.3 Environmental Context

Insights

National Emissions Inventory (NEI) data on energy-related emissions of criteria air pollutants by the sectors considered in this analysis show that sulfur dioxide and nitrogen oxides comprise the largest fraction of energy-related emissions.[ss] Though not represented in NEI emissions data, energy use also contributes to emissions of the GHG carbon dioxide (CO_2), which is an important contributor to global climate change. Key opportunities for reducing energy-related emissions lie with energy efficiency upgrades to external combustion boilers and process equipment.

2.3.1 Sources and Impacts of Energy-Related Air Emissions

Our assessment of the environmental effects of sector energy use focuses on air emissions. Energy-related air emissions sources include the following:

- Stationary source emissions, for the purposes of this analysis, include those that occur at the manufacturing facility from fuels consumed onsite to generate electric or thermal energy, as well as fuels required to power manufacturing process equipment, and offsite emissions from electric power generation that meets the purchased electricity fraction of manufacturing energy requirements.
- Mobile source emissions are primarily associated with freight shipping. We do not seek to quantify sector-related mobile source emissions for the purposes of this analysis.

Table 12 summarizes the health and environmental impacts associated with the primary energy-related air pollutants considered in this analysis.

Table 12: Health and environmental impacts of energy-related air pollutants[37]

Pollutant	Health Impact	Environmental Impact
Carbon dioxide (CO_2)	None	Greenhouse gas that contributes to global warming
Carbon monoxide (CO)	Reduces blood's capacity for carrying oxygen to body cells and tissues; is particularly damaging for people with impaired cardiovascular and lung function	A greenhouse gas precursor that contributes to the formation of methane and carbon dioxide in the atmosphere[38]
Nitrogen oxides (NOx)	Causes lung damage and respiratory illness	Contributes to acid rain that degrades soil and water quality; forms acid aerosols that reduce visibility; contributes to fine particulates and ozone
Particulate matter (PM)	Causes respiratory system irritation and illness; causes lung damage	Forms haze that reduces visibility
Sulfur dioxide (SO_2)	Causes respiratory illness and may lead to lung damage	Contributes to acid rain that degrades soil and water quality; forms acid aerosols that reduce visibility; contributes to fine particulates
Volatile organic compounds (VOCs)	Causes respiratory illnesses including asthma; irritates eyes and respiratory system; some VOCs may cause cancer	Reacts with nitrogen oxides to form ozone; some VOCs damage vegetation
Ozone (ground-level)[tt]	Causes respiratory illnesses including asthma; irritates eyes and respiratory system	Forms smog that reduces visibility; damages vegetation

ss NEI data also show substantial energy-related carbon monoxide (CO) emissions, but as CO does not typically represent a large component of combustion-related emissions from stationary sources, NEI data may overstate such emissions and thus we devote minimal discussion to emissions of CO.

tt This analysis is not able to quantify ground-level ozone resulting from sector energy consumption, though VOC and NOx emissions that contribute to ozone formation are reported in Section 2.3.2 and at the sector level in Chapter 3.

In manufacturing industries, the majority of energy-related emissions of CAPs are attributable to combustion processes. Sulfur dioxide emissions mostly result from combustion of sulfur-containing fuels, primarily coal. Nitrogen oxides are also products of combustion, but emissions do not vary as much by fuel type as SO_2 emissions. Particulate matter can be ash and dust resulting from the combustion of coal or heavy oil, or very fine particulates ($PM_{2.5}$), which are largely composed of aerosols formed by nitrogen oxide and sulfur dioxide emissions. Carbon monoxide is a product of incomplete combustion, but the largest source is vehicles, with stationary sources typically contributing a smaller part of the inventory. Volatile organic compounds (VOCs) can also result from incomplete combustion, but the largest energy-related components are fugitive emissions from fuel storage tanks and pipelines, and combustion-related vehicle emissions. The largest components of energy-related CAP emissions from the industrial sector are SO_2, NOx, and larger particulates from combustion of coal. Excepting emissions from off-road vehicles, VOCs and CO emissions from combustion are a much smaller fraction of total energy-related emissions.

More than half of the U.S. population lives in counties that are in non-attainment for ozone and/or particulate matter National Ambient Air Quality Standards (NAAQS).[39] Energy-related emissions of NOx and VOCs contribute to ground-level ozone formation, and SO_2 emissions contribute to PM formation. Thus, reducing energy-related CAP emissions by industrial sources is an important component of ongoing efforts to achieve NAAQS.

Another critical environmental impact of energy use is emissions of the GHG carbon dioxide, which also results from fuel combustion processes and is an important contributor to global climate change. (Other GHGs, such as methane, also contribute to global climate change, but as energy-related sources of these GHGs are not substantial, we focus primarily on CO_2 emissions in this analysis.) Such emissions do not impact regional air quality, but CO_2 is persistent in the upper atmosphere, trapping infrared radiation from the earth's surface and contributing to increases in the earth's temperature.

Though this analysis focuses primarily on CAP and GHG emissions, energy consumption also contributes to emissions of other hazardous air pollutants (HAPs), including mercury. In addition, this analysis does not attempt to quantify energy-related impacts on soil and water quality.

2.3.2 Approach Used to Assess Energy-Related Air Emissions

In our assessment of environmental impacts resulting from sector energy consumption, this analysis focuses on CAP emissions, as well as two pollutants that contribute to the formation of CAPs: VOCs and ammonia (NH_3). (Ammonia is a very minor component of energy-related emissions, but is included in this analysis as it is one of the pollutants represented in the NEI data set.) We collectively refer to emissions of these pollutants as CAPs. In addition to the overview of energy-related CAP emissions across all sectors contained in Section 2.3.3, the sector summaries in Chapter 3 present a more detailed description of energy-related CAP emissions for each sector, using data from NEI.

EPA's NEI is a national database of CAP and HAP emissions based on data from numerous state, tribal, and local air pollution control agencies; industry-submitted data; data from other EPA databases; as well as emissions estimates. State and local emissions inventories are submitted to EPA once every three years for most point sources contained in NEI. This analysis uses the *Draft 2002* NEI data, as the *Final 2002* data are not currently available at the level of detail required for this analysis.

In the NEI database, point source emissions are associated with industry classification codes (NAICS or Standard Industrial Classification (SIC) codes) as are the 12 sectors addressed in this analysis. It is important to note that emissions stemming from the generation of purchased energy (primarily electricity, but also other non-fuel sources of energy such as steam that may be purchased by industrial manufacturing sectors) are attributed to the generating source, not the purchasing entity. Therefore, emissions for any given sector will not include emissions from purchased energy. Recognizing this omission will be particularly important for electricity-dependent sectors, as noted in the sector summaries in Chapter 3.

- CAP emissions in NEI are associated with several levels of source classification codes (SCC) that indicate the detailed source of each CAP emission data point. SCCs are associated with emissions from all source categories (point, area, and mobile). For the purposes of this analysis, more than 1,000 SCCs were identified as being “energy-related” from the list of 9,865 SCCs. Energy-related CAP emissions include emissions from combustion processes, such as those SCCs listed in the following general source categories:
  - External combustion boilers
  - Internal combustion engines
  - Stationary source fuel combustion
- *Energy-related CAP emissions* also include emissions from the use of fuels for energy in industrial processes (such as process heaters) and emissions from the storage of fuels.
- *All other CAP emissions* include process-related CAP emissions not related to fuel combustion, emissions where it was unclear from the SCC whether they are energy-related (such as SCC descriptions “Not Specified,” “Not Defined,” “Not Classified,” “Miscellaneous,” “General,” or “All Processes”), and sector emissions that are not associated with an SCC.
- In Chapter 3, the figures showing NEI data on energy-related CAP emissions include the following:
  - *Energy-related CAP emissions:* Compares energy-related CAP emissions with all other CAP emissions.
  - *Emissions by criteria air pollutant:* Shows the fraction of total energy-related CAP emissions represented by each CAP.
  - *Emissions by source category:* Shows energy-related CAP emissions by the most general available source category (e.g., external combustion boilers, internal combustion engines, and industrial processes).
  - *Emissions by fuel type:* Shows energy-related CAP emissions that source from the use of a fuel (e.g., distillate oil or natural gas). It also aggregates emissions of combustion byproducts (e.g., exothermic) or handling fuels (e.g., coal handling and storage) as “Unknown.”

As NEI data do not capture CO_2 emissions, we include CO_2 emissions estimates and projections from EIA’s 2006 *Annual Energy Outlook* and the *Clean Energy Future* report, which address eight of the sectors included in this analysis. We address projected CO_2 emissions under our “base case” and “best case” energy scenarios in Chapter 3.

2.3.3 Stationary Source Emissions

Table 13 presents NEI data on annual energy-related CAP emissions by sector (units are tons per year (TPY)).

Table 13: Energy-related CAP emissions by sector in 2002[40]

NAICS	Sector	CO (TPY)[uu]	NOx (TPY)	PM_{10} (TPY)	SO_2 (TPY)	NH_3 (TPY)	VOC (TPY)	All Energy-Related CAP (TPY)	All CAP Emissions (TPY)
3313	Alumina and aluminum	6,776	13,036	474	51,176	40	1,234	**72,736**	**538,841**
327310	Cement	15,674	11,636	668	12,943	3	553	**41,477**	**544,501**
325	Chemical manufacturing	213,176	220,183	10,510	279,403	4,474	11,377	**739,123**	**1,536,183**
311	Food manufacturing	70,848	73,073	7,218	90,203	860	5,522	**247,724**	**395,289**
331111	Iron and steel	125,574	45,779	6,858	43,589	1,543	4,465	**227,808**	**850,644**
332813	Metal finishing	11	28	1	70	0	1	**111**	**374**
3315	Metal casting	1,790	2,295	150	759	24	207	**5,225**	**72,645**
33611	Motor vehicle manufacturing	2,456	3,720	167	2,235	27	196	**8,801**	**48,761**
3363	Motor vehicle parts manufacturing	201	492	26	9	8	131	**867**	**7,778**
324110	Petroleum refining	46,942	117,470	8,738	108,189	1,366	16,133	**298,838**	**788,985**
322	Pulp and paper (within forest products)	195,218	184,514	17,617	303,285	1,215	19,099	**720,948**	**1,173,568**
321	Wood products (within forest products)	101,106	26,369	17,271	3,658	90	34,791	**183,285**	**289,727**
336611	Shipbuilding and ship repair	186	866	90	1,150	6	121	**2,419**	**5,520**
Total		**779,958**	**699,461**	**69,788**	**896,669**	**9,656**	**93,830**	**2,549,362**	**6,252,816**

As noted in Section 2.3.2, the NEI data presented in Table 13 represent energy-related emissions that occur at the facility level but do not capture emissions associated with the generation and transmission of purchased electricity. For electricity-dependent sectors such as aluminum, the magnitude of such emissions is likely to be substantial but also vary depending upon the energy inputs used to generate electricity at the utility level (for example, hydroelectric generation is considerably less emissions-intensive than coal-powered generation, and many aluminum manufacturing facilities are located in the Pacific Northwest, which has extensive hydropower resources).

Data presented in the table above raise the following points regarding energy-related CAP emissions:

- Sulfur dioxide (35 percent) and nitrogen oxides (27 percent) represent the largest fraction of energy-related CAP emissions. Increasing energy efficiency or promoting a cleaner fuel mix in these sectors is likely to have the greatest impact on emissions of these pollutants. (According to NEI data, carbon monoxide, a product of incomplete combustion, also represents a substantial fraction (31 percent) of energy-related CAP emissions, but NEI data errors may contribute to an overstatement of CO emissions, as they are not typically

uu As CO does not typically represent a large component of combustion-related emissions from stationary sources, NEI data may overstate such emissions and thus we devote minimal discussion to emissions of CO.

a very large component of combustion-related emissions from stationary sources. Therefore, we devote minimal discussion to CO emissions.)

- Energy-related CAP emissions are a function of total energy consumption, fuel mix, process energy requirements, and equipment type. Thus, there are many factors that determine whether a sector's energy-related CAP emissions are higher or lower than any other sector.
- Between sectors there is wide variation in the fraction of total CAP emissions that is classified as energy-related—from 8 percent to 63 percent of total CAP emissions. Total CAP emissions also range widely due to industry-specific factors inherent to the manufacturing process, such as the magnitude of process heating requirements. Thus, it is not necessarily meaningful to compare the energy-related CAP fractions across sectors, especially since NEI data do not include indirect emissions from offsite electricity generation, which is a substantial component of energy use in sectors such as aluminum, metal finishing, motor vehicle manufacturing, etc.
- The fraction of energy-related CAP emissions also depends on unique characteristics of sector energy use. For example, in food manufacturing, pulp and paper, and wood products, energy-related CAP emissions comprise more than 60 percent of total CAP emissions. This result is in large part due to the magnitude of onsite power generation in these sectors, which in itself may represent an environmentally preferable energy strategy. For example, in the forest products industry (pulp and paper and wood products), a large fraction of the sector's energy requirements are met with onsite generation of electric and thermal energy using biomass fuels that are byproducts of the manufacturing process. Increased use of such renewable biomass fuels would reduce energy losses associated with offsite electricity generation, transmission, and distribution (see Section 3.5).
- Energy efficiency and clean energy improvement in the sectors with the greatest energy-related CAP emissions (chemical manufacturing, food manufacturing, forest products, iron and steel, and petroleum refining) offer the greatest potential for reducing the environmental impact of sector energy use.

Table 14 presents NEI data on the sources of energy-related CAP emissions presented in Table 13. External combustion boilers have multiple applications in industrial manufacturing facilities, including central power generation, steam generation, process heating, and space heating. Industrial process emissions include emissions from direct fuel combustion in the manufacturing process, such as from fuel-fired equipment. The internal combustion engine category includes central power generation applications such as turbines and reciprocating engines. The petroleum and solvent evaporation category includes emissions from equipment like heaters used in coating operations. The "other" category includes all miscellaneous sources that are associated with energy-related CAP emissions, such as emissions from other combustion processes (e.g., fires).

Table 14: Energy-related CAP emissions by source category in 2002[41]

NAICS	Sector	External Combustion Boilers	Industrial Processes	Internal Combustion Engines	Petroleum and Solvent Evaporation	Other	TOTAL[vv]
3313	Alumina and aluminum	82%	18%	0%	0%	0%	**100%**
327310	Cement	16%	82%	2%	0%	0%	**100%**
325	Chemical manufacturing	60%	33%	6%	0%	0.3%	**99%**
311	Food manufacturing	94%	3%	3%	0%	0.2%	**100%**
331111	Iron and steel	59%	41%	0%	0%	0%	**100%**
332813	Metal finishing	90%	8%	2%	0%	0%	**100%**
3315	Metal casting	49%	39%	11%	1%	0%	**100%**
33611	Motor vehicle manufacturing	74%	8%	9%	0%	8.9%	**100%**
3363	Motor vehicle parts manufacturing[ww]	17%	6%	77%	0%	1%	**101%**
324110	Petroleum refining	51%	37%	10%	0%	2%	**100%**
322	Pulp and paper (within forest products)	95%	4%	1%	0%	0%	**100%**
321	Wood products (within forest products)	88%	12%	0%	0%	0.5%	**101%**
336611	Shipbuilding and ship repair	71%	1%	27%	0%	1%	**100%**
Total		**75%**	**21%**	**3%**	**0%**	**0.4%**	**100%**

Several points are important to note regarding the data contained in Table 14:

- It may not be possible to make definitive distinctions between some of these source categories, particularly the industrial processes category and the boiler and engine categories. NEI data are based on facility reporting, modeling, and estimates, where there may be inconsistencies in how sources of energy-related emissions are categorized. For example, fuel combustion related to process heating could be categorized as an industrial process energy use or defined under the external combustion boiler category.
- For a given sector, the primary source of energy-related CAP emissions depends primarily on industry-specific factors inherent to the manufacturing process.
- In general, the primary opportunities for reducing energy-related CAP emissions lie with external combustion boilers and process equipment, with boilers comprising the largest source of emissions in most industries. Process equipment dominates energy-related CAP emissions in a few key industries including cement kilns, fluid process heaters in the chemical and petroleum refining industries, and fired systems such as furnaces, metal melters, and heaters in iron and steel.

Additional detail on energy-related emissions of carbon and CAPs is provided in the sector summaries in Chapter 3.

vv Rows may not sum to 100% due to independent rounding.

ww The high fraction of energy-related CAP emissions from internal combustion engines is the result of an NEI data reporting error, as noted in Section 3.10.

2.3.4 Comparison of Energy Consumption Characteristics

To continue our characterization of sector energy consumption from Section 2.2 and gain insight into how energy consumption and energy intensity relate to CAP emissions, Table 15 ranks the sectors on the basis of three metrics: total energy-related CAP emissions, total energy consumption, and energy intensity.

Table 15: Comparison of 2002 data on energy-related CAP emissions, total energy consumption, and energy intensity by sector[42 43 44]

		Emissions		Energy Consumption		Energy Intensity	
NAICS Code	Sector	Total Energy-Related CAP Emissions (TPY)	Rank	Total Energy Consumption (TBtu)	Rank	Energy Consumption per Dollar Value of Shipments (KBtu)	Rank
325	Chemical manufacturing	739,123	1	6,465	1	8.5	6
322	Pulp and paper	720,948	2	2,363	3	15.2	4
324110	Petroleum refining	298,838	3	6,391	2	16.1	3
311	Food manufacturing	247,724	4	1,123	5	2.6	9
331111	Iron and steel	227,808	5	1,308	4	27.8	2
321	Wood products	183,285	6	377	9	4.2	8
3313	Alumina and aluminum	72,736	7	473	6	12.2	5
327310	Cement	41,477	8	409	8	56.0	1
33611	Motor vehicle manufacturing[xx]	8,801	9	429	7	0.7	10
3315	Metal casting	5,225	10	165	10	5.6	7
336611	Shipbuilding and ship repair	2,419	11	429	7	0.7	10
3363	Motor vehicle parts manufacturing	867	12	429	7	0.7	10
332813	Metal finishing	111	13	NA	NA	NA	NA

The following points are evident from the comparison of sector rankings in terms of energy-related CAP emissions, total energy consumption, and energy intensity as shown in Table 14:

- There is a good degree of correlation between energy-related CAP emissions and total energy consumption for most sectors, with the important caveat that for sectors with substantial purchased electricity requirements (e.g., aluminum, metal casting, metal finishing, motor vehicle manufacturing, motor vehicle parts manufacturing, and shipbuilding and ship repair), NEI data underestimate energy-related CAP emissions by attributing emissions associated with electric power generation to the generating sources rather than to the purchasing entity.
- There is less consistent correlation between energy intensity (energy consumption per value of economic output) and energy-related CAP emissions. For most sectors, the emissions ranking is either equivalent (within one point) to the energy intensity ranking or

[xx] As MECS does not contain sector-level data for motor vehicle manufacturing (NAICS 33611), motor vehicle parts manufacturing (NAICS 3363), or shipbuilding and ship repair (NAICS 336611), energy consumption and energy intensity data for these three sectors are for the larger NAICS category, transportation equipment (NAICS 336).

at least two points higher. For three sectors—aluminum, cement,[yy] and iron and steel—the energy intensity ranking is two or more points higher than the energy-related emissions ranking. In the case of aluminum, this result may be partly attributable to the fact that NEI data do not include emissions associated with purchased electricity. Still, the lack of correlation between energy intensity and energy-related CAP emissions suggests that in terms of reducing the environmental impacts of sector energy use, focusing on the most energy-intensive sectors may not produce the environmentally preferable outcome.

[yy] For the cement industry, the majority of the sector's energy requirements and associated emissions result from the thermo-reduction of limestone, clay, and sand. Given the high energy requirements of this process, and the fact that NEI data for the cement industry only classify 8% of the sector's total CAP emissions as "energy-related," it appears likely that NEI data misclassify some energy-related CAP emissions as non-energy-related.

2.4 Economic Context

Insights

Sector-based strategies for promoting energy efficiency and clean energy investment may be required due to varying economic trends (i.e., declining or increasing production and profitability), as well as characteristics such as the industry's sensitivity to energy cost fluctuations, average firm size, the homo- or heterogeneity of manufacturing processes within the sector, and the sector's geographic distribution.

2.4.1 Economic Production

A sector's economic production trends have important implications for energy management strategies. For example, industries undergoing growth in production may be less capital-restricted than sectors with declining production and may also be receptive to efforts to improve their competitive edge through increased management of energy costs. Moreover, growing sectors are adding capacity, which provides the most cost-effective opportunity to install more efficient equipment. Targeting energy efficiency efforts on industries with high energy intensity, high total energy use, and high economic growth is one obvious strategy for improving environmental performance. Table 16 presents recent economic trends for sectors considered in this analysis in terms of the annual change in value added and value of shipments from 1997 to 2004. To distinguish more recent from longer-term trends, the table also presents the annual rate of change in these metrics from 2000 to 2004.[zz]

Table 16: Annual growth in value added and value of shipments 1997-2004[45]

NAICS	Sector	Annual Change in Value Added		Annual Change in Value of Shipments	
		1997 - 2004	2000 - 2004	1997 - 2004	2000 - 2004
324110	Petroleum refining	5.4%	6.3%	6.6%	5.0%
3366	Shipbuilding and ship repair	2.7%	5.4%	1.8%	2.4%
311	Food manufacturing	2.5%	2.5%	0.8%	1.8%
327310	Cement	2.2%	1.2%	1.5%	1.6%
325	Chemical manufacturing	1.9%	3.7%	1.5%	1.8%
321	Wood products (within forest products)	1.8%	2.5%	0.3%	0.2%
331111	Iron and steel[aaa]	1.1%	8.3%	1.7%	6.1%
332813	Metal finishing[bbb]	0.1%	-1.2%	-0.3%	-2.0%
3363	Motor vehicle parts manufacturing	0.0%	-2.2%	-0.1%	-2.3%
322	Pulp and paper (within forest products)	-1.2%	-3.6%	-1.6%	-4.0%
33611	Motor vehicle manufacturing	-2.2%	1.9%	0.3%	0.1%
3313	Alumina and aluminum	-2.9%	-2.3%	-2.4%	-2.2%
3315	Metal casting	-3.2%	-5.4%	-2.4%	-3.7%

zz Census Bureau data were converted to inflation-adjusted 2000 dollars before annual growth rates were calculated.

aaa Economic data are for the larger NAICS category of iron, steel, and ferroalloy manufacturing (NAICS 33111).

bbb Economic data are for the larger NAICS category of coating, engraving, and heat treating (NAICS 33281).

Though presenting annual rates of change is the simplest way to capture long-term trends, this approach masks interannual variation, which is particularly worth noting for certain sectors:

- Though iron and steel and ferroalloy manufacturing shows growth in value added and value of shipments over the period, both metrics actually declined from 1997 to 2003 during a period of industry restructuring. From 2003 to 2004 value added jumped by more than 70 percent and value of shipments jumped by more than 45 percent. This turnaround was primarily due to a dramatic increase in the price of steel prices driven by surging demand for raw materials in Asian countries like China, India, South Korea, and Thailand,[46] and by the strengthened financial position of the industry post-restructuring.
- For shipbuilding and ship repair, value added and value of shipments grew relatively slowly from 1997 to 2001, then value added increased by almost 30 percent and value of shipments jumped by 6 percent from 2001 to 2002.
- Motor vehicle manufacturing, motor vehicle parts manufacturing, and metal finishing show relatively larger degrees of interannual variation.

Sectors showing economic growth trends include the following:

- Chemical manufacturing, cement, and petroleum refining are energy-intensive industries with consistent growth in economic output. Petroleum refining shows more interannual variation than the other two sectors but also shows the strongest growth trend over the time period. The sector's strong economic position is in part due to an industry turnaround after considerable consolidation occurred in the 1990s.
- Food manufacturing is a less energy-intensive sector that shows consistent economic growth. Wood products also shows growth over the timeframes considered but had greater interannual variation than food manufacturing due primarily to changes in demand for construction materials.

Sectors with declining economic trends include the following:

- Aluminum, metal casting, and pulp and paper are energy-intensive industries with declining economic trends, and thus are likely to face substantial capital constraints that affect decision-making about energy efficiency and clean energy investments.

2.4.2 Sector Composition

Other economic factors may be considered in developing sector-based strategies for promoting investment in energy efficiency and clean energy opportunities, including whether a sector consists of many small firms or a few large ones; whether a sector is geographically concentrated or dispersed across the country; and as discussed previously, whether energy costs comprise a relatively larger or smaller fraction of production costs. Designing policies aimed at increasing energy efficiency within a sector may be relatively simpler when a sector consists of a small number of large players with similar manufacturing processes, or is concentrated in a limited number of geographic regions. Communicating to a large number of small firms is more labor-intensive, and such industries may be less influenced by the best practices of industry leaders. In addition, sectors that encompass a broad range of manufacturing processes (the chemicals industry is one example) might not be well served by a homogeneous policy approach to promoting energy efficiency and clean energy investment.

We characterize each sector in terms of the relative number of firms in the industry, the average size of firms comprising the industry, and whether the sector is geographically dispersed across the country or concentrated in specific regions. Table 17 summarizes these attributes for the sectors included in this analysis; sector-specific write-ups in Chapter 3 provide additional information to support these characterizations.

Table 17: Overview of key economic characteristics by sector

NAICS	Sector	Economic Production Trend	Relative Firm Number	Relative Firm Size	Geographic Distribution	Energy Cost Sensitivity[ccc]
3313	Alumina and aluminum	Declining	Few	Large	Concentrated	High
327310	Cement	Increasing	Few	Large	Concentrated	High
325	Chemical manufacturing	Increasing	Many	Small/Large[ddd]	Dispersed	High
311	Food manufacturing	Increasing	Many	Large	Dispersed	Low
331111	Iron and steel[eee]	Increasing	Few	Large	Concentrated	High
3315	Metal casting	Declining	Many	Small	Concentrated	High
332811	Metal finishing[fff]	Mixed	Many	Small	Concentrated	High
33611	Motor vehicle manufacturing	Mixed	Few	Large	Concentrated	Low
3363	Motor vehicle parts manufacturing	Mixed	Many	Small/Medium	Dispersed	Low
324110	Petroleum refining	Increasing	Few	Large	Concentrated	High
322	Pulp and paper (within forest products)	Declining	Few	Large	Concentrated	High[ggg]
3366	Shipbuilding and ship repair	Increasing	Few	Large	Concentrated	High
321	Wood products (within forest products)	Increasing	Few	Large	Concentrated	High

ccc The energy cost sensitivity rating is primarily based on whether the industry rated higher or lower than the manufacturing industries' benchmark for energy cost per dollar of value added shown in Table 9.

ddd Certain segments of the chemical manufacturing industry, such as specialty-batch chemicals, are dominated by smaller firms, while others, such as commodity chemicals, are dominated by larger firms.

eee The economic trend assessment for the iron and steel sector is based on Census Bureau data for a larger NAICS category: Iron and steel and ferroalloy manufacturing (NAICS 33111).

fff The economic trend assessment for the metal finishing sector is based on Census Bureau data for a larger NAICS category: Coating, engraving, heat treating, and allied activities (NAICS 33281).

ggg Though the forest products industry (pulp and paper and wood products) is energy intensive, it is important to note that more than half of its energy requirements are met by manufacturing byproducts (biomass). The industry has increased utilization of its biomass resources, reducing the impact of rising costs for purchased energy.