Energy Use and Loss Analysis

U.S. Manufacturing and Mining

DRAFT April 2004

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1.0 Energy Use and Loss Analysis Overview

1.1 Introduction

The Role of Energy Efficiency

The U.S. manufacturing sector depends heavily on fuels and power for the conversion of raw materials into usable products, and also uses energy as a source of raw materials (feedstock energy) for chemicals and materials. How efficiently energy is used, as well as the cost and availability of energy, consequently have a substantial impact on the competitiveness and economic health of U.S. manufacturers. More efficient use of fuels and power lowers production costs, conserves limited energy resources, and increases productivity. Efficient use of energy also has positive impacts on the environment – reductions in fuel use translate directly into fewer emissions of criteria pollutants such as sulfur oxides, nitrogen oxides, and particulates, as well as greenhouse gases such as carbon dioxide. Improved efficiency can also reduce the use of feedstock energy through greater yields, which means more product can be manufactured for the same amount of energy. Reducing use of energy feedstocks directly impacts our dependence on imported oil, and alleviates pressure on increasingly scarce natural gas supplies.

Energy efficiency can essentially be defined as the effectiveness with which energy resources are converted into usable work. Thermal efficiency is commonly used to measure the efficiency of energy conversion systems such as process heaters, steam systems, engines, and power generators. While there are many ways to determine thermal efficiency, it is basically the measure of the efficiency and completeness of fuel combustion, or in more technical terms, the ratio of the net work supplied to the heat supplied by the combusted fuel. In a gas-fired heater, for example, thermal efficiency would be equal to the total heat absorbed divided by the total heat supplied; in an automotive engine, thermal efficiency would be the work done by the gases in the cylinder divided by the heat energy of the fuel supplied.

Energy efficiency varies dramatically across industries and manufacturing processes, and even between plants manufacturing the same products. Efficiency can be limited by mechanical, chemical, or other physical parameters, or by the age and design of equipment. In some cases, operating and maintenance practices contribute to lower than optimum efficiency. Regardless of the reason, less than optimum energy efficiency means that as equipment is used, not all of the energy is converted to useful work – some is released as lost energy. In the manufacturing sector, these energy losses amount to several quadrillion Btus (British Thermal Units) and billions of dollars in lost revenues every year.

Typical Thermal Efficiencies of Selected Energy Systems and Industrial Equipment	
Power Generation	25-44%
Steam Boilers (natural gas)	80%
Steam Boilers (coal and oil)	84-85%
Waste Heat Boilers	60-70%
Compressors	10-20%
Pumps and Fans	55-65%
Motors	90-95%

Given this resource and cost perspective, it is clear that increasing the efficiency of energy use could result in substantial benefits to both industry and the nation. Unfortunately, the sheer complexity of the thousands of processes used in the manufacturing sector makes this a daunting task. There are, however, significant opportunities to address energy efficiency in generic energy systems that are used across many different industries, such as steam generators, onsite power systems, fired heaters, heat exchangers, compressors, motors, pumps, and others. A first step in realizing these opportunities is to identify where and how industry is using energy – how much is used for various energy systems, how much is lost, how much goes directly to processes, and so forth. Answering these questions for the U.S. manufacturing and mining sectors is the focus of this report.

1.2 Energy Footprints

To assist in targeting energy-savings opportunities for energy systems, a series of *Energy Footprints* was developed to map the flow of energy supply and demand in U.S. manufacturing industries. Identifying the sources and end-uses of energy helps to pinpoint areas of energy-intensity and characterize the unique energy needs of individual industries. A generic energy footprint is shown in Figure 1-1, and a set of industry-specific energy footprints for major energy users is provided in Appendix A.

On the supply side, the footprints provide details on the energy purchased from utilities, the energy that is generated onsite (both electricity and byproduct fuels), and excess electricity that is transported to the local grid (energy export). On the demand side, the footprints illustrate where and how energy is used within a typical plant, from central boilers to process heaters and motors. Most important, the footprints identify where energy is lost due to inefficiencies in equipment and distribution systems, both inside and outside the plant boundary. Losses are critical, as they represent immediate opportunities to improve efficiency and lower energy consumption through best energy management practices and improved energy systems.

Figure 1-1. Generic Energy Footprint

As Figure 1-1 shows, the *energy supply* chain begins with the electricity, steam, natural gas, coal, and other fuels supplied to a plant from off-site power plants, gas companies, and fuel distributors. Many industries generate byproducts and fuels onsite, and these are also part of the energy supply. Notable examples are the use of black liquor and wood byproducts in pulp and paper mills, still gas from petroleum refining processes, and light gas mixes produced during chemicals manufacture. Byproduct energy is included in fossil energy supply totals. Renewable energy sources such as solar, geothermal, and wind power are shown separately.

Once energy reaches the plant (indicated by green area), it flows either to a *central energy generation utility* system (e.g., steam plant, power generation, cogeneration) or is *distributed* immediately for direct use. Central energy systems generate electricity and steam for process use, and sometimes create more energy than is needed at the plant site. When this occurs, the excess energy is exported off-site to the local grid or another plant within close proximity.

Fuels and power (see blue area) are often routed to *energy conversion* equipment that is generally integrated with specific processes. The converted energy goes to *processes* and unit operations, where it drives the conversion of raw materials or intermediates into final products.

Energy losses occur all along the energy supply and distribution system (red arrows in Figure 1-1). A simplified flow of losses from energy supply through industrial processing is shown in Figure 1-2. Energy is lost in power generation and steam systems, both off-site at the utility and on-site within the plant boundaries, due to equipment inefficiency and mechanical and thermal limitations. Energy is lost in distribution and transmission systems carrying energy to the plant and within the plant boundaries.

Losses also occur in energy conversion systems (e.g., heat exchangers, process heaters, pumps, motors) where efficiencies are thermally or mechanically limited by materials of construction and equipment design. In some cases, heat-generating processes are not optimally located near heat sinks, and it may be economically impractical to recover the excess energy. With some batch processes, energy is lost during off-peak times simply because it cannot be stored. Energy is lost from processes whenever waste heat is not recovered and when waste by-products with fuel value are not utilized.

The energy footprints represent an average picture of energy use and losses across an industry. Through them we can begin to assess the relative losses due to inefficiencies as well as sources of energy-intensity. They also provide a baseline from which to calculate the benefits of improving energy efficiency.
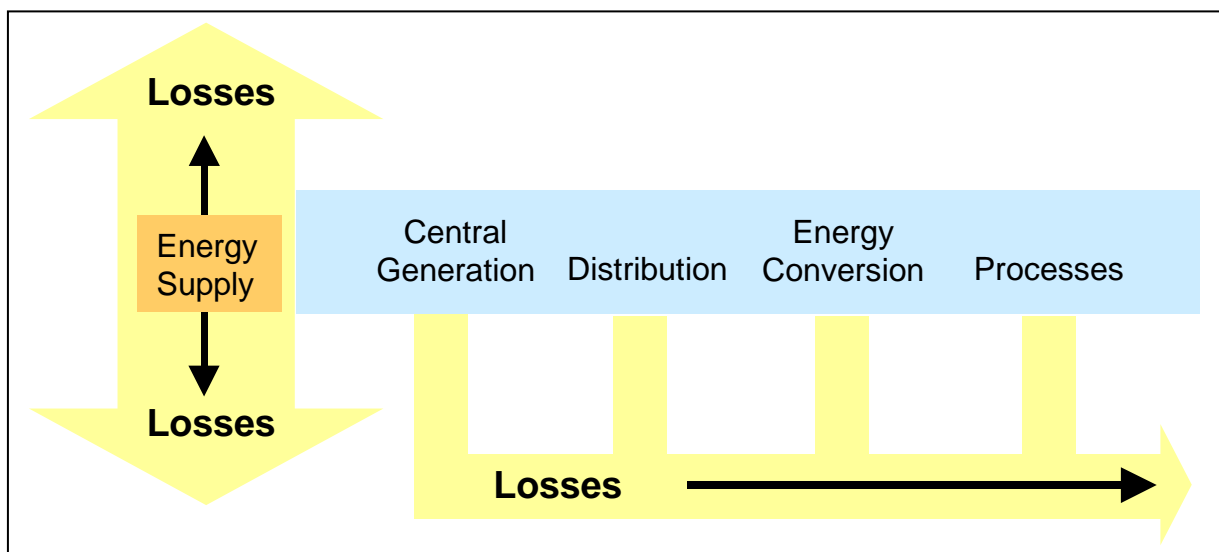

Figure 1-2 Simplified Flow of Energy Losses

1.3 Assumptions and Definitions

Throughout this report a number of parameters will be used to interpret the energy footprints. These are defined below, in the order they generally appear.

Primary energy use – the total processing energy consumption associated with an industrial sector. It is the sum of energy purchases (fuel and electricity), byproduct energy produced onsite, and the offsite losses associated with energy purchased from utilities and fuel suppliers (see offsite losses, below). Primary energy does not include feedstock energy, i.e., energy used as a raw material.

Offsite losses – the energy losses incurred during the generation and transmission of electricity at offsite utilities, plus the energy losses incurred during the transport of fuels to the plant boundary. The efficiency of utility power generation and transmission is assumed to be 10,500 Btu/kWh, which is equal to an overall efficiency of about 32.5%. This does not represent the state-of-the-art, but an average value for the national grid. Fuel transport energy losses are assumed to be about 3%.

Fuel and electricity use – direct use of fuels and electricity at the plant site, taken directly from the Manufacturing Energy Consumption Survey [MECS 1998] for the manufacturing sector, and estimated for mining based on a recent study [Mining 2002]. Electricity includes purchased electricity only, not electricity generated onsite (see electricity demand, below). Fuels used to generate on-site electricity as well as byproduct fuels are included in the fuels category. Offsite electricity losses are not included.

Feedstock energy – energy that is used as a raw material in the production of non-fuel products, such as chemicals, materials, tar, asphalt, wax, steel, and others. The most commonly used energy feedstocks are petroleum and petroleum derivatives and natural gas.

Energy export – excess energy (mostly electricity) that is generated onsite and exported offsite to the local grid or another facility.

Electricity demand – the net use of electricity at the plant site, including purchased electricity and electricity generated onsite, minus electricity exported offsite.

Energy distribution systems – pipes and transmission lines for delivering fuels, steam and electricity to processes and equipment.

Energy conversion systems – systems that convert energy into usable work for delivery to processes, such as heat exchangers, fired heaters, condensers, heat pumps, machine-drive and onsite transportation.

Process energy – energy used in industry-specific processes, such as chemical reactors, steel furnaces, glass melters, casting, welding or forging of parts, concentrators, distillation columns, and so forth.

Onsite losses – losses that are incurred in energy distribution and conversion systems, and in the central energy plant where steam and electricity are generated. Specific loss factors are shown in Table 1-1.

Boiler losses represent energy lost due to boiler inefficiency. In practice, boiler efficiency can be as low as 55-60%, or as high as 90%. The age of the boiler, maintenance practices, and fuel type are factors. Power generation losses vary depending on whether cogeneration is employed (systems producing both steam and electricity). It is assumed that the greater losses are in steam pipes (20%), with small losses incurred in other fuel transmission lines (3%) and electricity transmission lines (3%). Losses in steam

pipes and traps have been reported to be as high as from 20 to 40% [PNNL 1999]. For conservatism, a value of 20% was used for steam distribution losses.

As shown in Table 1-1, onsite power generation losses are assumed to be about 45%, which represents a relatively state-of-the-art gas turbine with heat recovery. Cogeneration raises the thermal efficiency of the power generating system by as much as 25-35%, significantly reducing power losses [ADL 2000].

Distribution losses represent steam heat lost in traps, valves, and steam pipes, and transmission losses in onsite fuel and electricity lines. In practice, these losses are very site-specific, and depend largely on plant size and configuration. The loss factors shown in Table 1-1 may underreport these losses, which have been reported to be as high as 10-40%. Sources are given in the Reference section. For simplicity, in this analysis distribution losses are distributed among the largest end-use categories.

Energy conversion losses occur in heat exchangers, preheat systems, or other equipment where the transfer of energy from steam or other direct heat or cooling takes place, prior to delivery of energy to the process. Losses also occur in electrolytic cells, and other energy systems such as onsite vehicles or other transport systems. In many cases energy conversion equipment is directly integrated with the process unit, making it difficult or impossible to estimate pre-process losses. As a result, the estimates for losses shown here may overlap with actual process losses, which are not estimated. Motor losses represent losses in motor windings as well as mechanical losses in the motor-driven systems (e.g., compressor) that occur during the conversion of energy to useful work.

Table 1-1 Loss Factors for Selected Equipment	
Energy System	**Percent Energy Lost**
Steam systems	Boilers – 20% Steam pipes and traps - 20% Steam delivery/heat exchangers – 15%
Power generation	Combined heat and power – 24% (4500 Btu/kWh) Conventional power – 45% (6200 Btu/kWh)
Energy distribution	Fuel and electricity distribution lines and pipes (not steam) – 3%
Energy conversion	Process heaters – 15% Cooling systems – 10% Onsite transport systems – 50% Electrolytic cells – 15% Other – 10%
Motor systems	Pumps – 40% Fans – 40% Compressed air – 80% Refrigeration – 5% Materials handling – 5% Materials processing (grinders) – 90% Motor windings – 5%

Combined heat and power (CHP) – energy system used for onsite cogeneration of steam and electricity.

Conventional power – gas or steam turbines generating onsite power, with heat recovery.

Steam systems – the complete steam system, including boilers, steam distribution lines, steam traps, and final delivery of steam to the process (e.g., heat exchangers).

Fired Heaters – direct and indirect-fired heaters such as furnaces, dryers, re-boilers, and evaporators.

Process heating – an aggregate of the energy used for process heating, including the use of steam, fired heaters, and all other heating devices.

Process cooling – energy used for cryogenic and other cooling systems. This category may have some overlap with motor-drive refrigeration.

Electrochemical or Electrolytic Cells – Energy used in systems that convert raw inputs to products through an electrochemical reaction

Motor systems – motor-driven systems, such as compressors, fans, pumps, materials handling and processing equipment, and refrigeration. Materials handling equipment typically includes conveyors and assembly processes that are motorized. Materials processing includes grinders, crushers, mixers, and other similar equipment of this nature. Motor energy is converted to external work (rotating, lifting, spinning, moving), and is sometimes called shaft work.

Onsite Transport – Energy used to fuel equipment (trucks, forklifts, etc.) that carry materials between locations at the plant site.

Facilities – energy used to provide heat, cooling, and lighting for building envelopes at the plant site.

2.0 U.S. Manufacturing and Mining

2.1 Overview of Manufacturing and Mining Industries

The U.S. manufacturing and mining sector is highly diverse, using thousands of processes to manufacture literally millions of different products. The mining and oil and gas extraction industries are the primary sources of raw materials for the manufacturing sector. Manufacturing is a complex composite of many industries – some convert raw materials into intermediate and final products, while others form, forge, fabricate, and assemble final products.

There are integral links between the raw material industries, heavy industries (e.g., chemicals, steel, pulp and paper) which convert raw materials, and the industries that create finished products. Mining, for example, provides the raw material for the production of intermediate steel products, which are then sent on to forging and fabricators, and finally to the transportation industry where they become automotive components. Similarly, changes in energy use patterns in the heavy industries can ripple through the industries they supply goods to, affecting not just product costs, but the life cycle energy embodied in the final product. Consequently, in examining energy use patterns, it is critical to understand the inter-dependencies of industries, as well as the unique energy needs of individual industries.

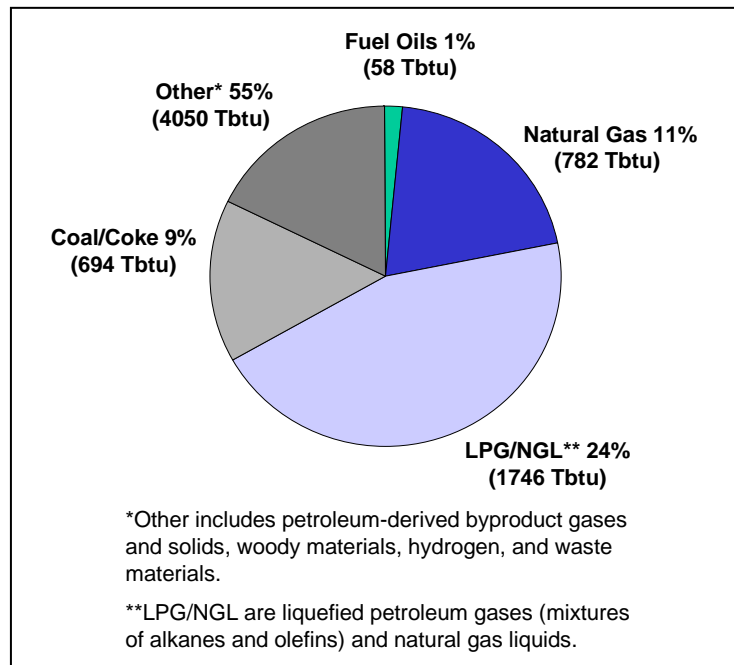| Table 2-1. Industry Sectors Selected for Study |
|---|
| **Coal, Metal Ore, and Nonmetallic Mineral Mining** NAICS 212 |
| **Food and Beverage**
 NAICS 311   Food
 NAICS 312   Beverage and Tobacco Products |
| **Textiles**
 NAICS 313   Textile Mills
 NAICS 314   Textile Product Mills
 NAICS 315   Apparel
 NAICS 316   Leather and Allied Products |
| **Forest Products**
 NAICS 321   Wood Products
 NAICS 322   Paper |
| **Petroleum Refining** NAICS 334110 |
| **Chemicals** NAICS 325 |
| **Plastics and Rubber Products**   NAICS 326 |
| **Glass and Glass Products**
 NAICS 3272   Glass and Glass Products
 NAICS 3296   Mineral Wool |
| **Cement** NAICS 327310 |
| **Iron and Steel Mills**   NAICS 333111 |
| **Alumina and Aluminum** NAICS 3313 |
| **Foundries** NAICS 3315 |
| **Fabricated Metals** NAICS 332 |
| **Heavy Machinery** NAICS 333 |
| **Computers, Electronics, Appliances, Electrical Equipment**
 NAICS 334   Computer and Electronic Products
 NAICS 335   Electrical Equipment, Appliances |
| **Transportation Equipment** NAICS 336 |

Source: North American Industrial Classification System, Office of Management and Budget, 1997.

This study looks at a large subset of the mining and manufacturing sector, with the objective of capturing the bulk share of energy consumption. Table 2-1 lists the industrial sectors covered and defines the sixteen groupings selected for energy footprint analysis. Groups are organized by their respective NAICS (North American Industrial Classification System) codes. Appendix B gives an overview of the specific products manufactured in the sectors shown in Table 2-1.

Industries were selected based on their relative energy-intensities, contribution to the economy, and relative importance to energy efficiency programs. Industries not selected for individual energy footprint analysis include oil and gas extraction, coal products, printing facilities, furniture, and miscellaneous unclassified manufacturing. However, with the exception of oil and gas extraction, energy consumption for these industries is included in the overall manufacturing energy footprint.

2.2 Energy Use and Loss Analysis for Manufacturing and Mining

Overview

Table 2-2 Snapshot of Energy Use and Losses in U.S. Manufacturing & Mining (Trillion Btu)			
Category	Manufacturing	Mining	TOTAL
Primary Energy Use	24658	1273	25931
Offsite Losses	6884	520	7404
Fuel & Electricity	17774	753	18527
Onsite Losses	5591	311	5902
Steam Generation	1233	1	1234
Power Generation	166	16	182
Energy Distribution	1330	13	1443
Energy Conversion	2862	281	3143
Facilities Energy	1405	neg	1405
Energy Exported	79	~0.01	79
Energy Delivered to Processes	10699	442	11141

Primary energy – A snapshot of primary energy use (fuels and power, plus offsite losses) for the manufacturing and mining sector is shown in Table 2-2. Energy losses are highlighted in red.   Primary energy use for manufacturing and mining is about 26 quads (quadrillion Btus), which represents 27% of the energy consumed in the United States [EIA 2001].

Fuel type – In manufacturing, natural gas accounts for the major portion of purchased fuel use, at about 38%, followed by smaller amounts of coal, petroleum and other fuels (13%), and purchased electricity (17%). A significant portion of energy is byproduct fuels, which account for about 32% [MECS 1998]. Byproduct fuels are comprised mostly of fossil-based fuel gases and liquid byproducts, and wood processing waste and byproducts. Significant users of byproduct fuels include petroleum refining, chemicals, forest products, iron and steel, and food and beverage. Mining relies heavily on transportation fuels and electricity [Mining 2002].

Feedstock energy – Energy is also used as a raw material for the production of non-fuel products such as petrochemicals, fertilizers, asphalt, wax, tar, steel and other consumer products. Since process energy use (fuels and power) is the focus of this report, feedstock energy is not included in the energy totals shown in Table 2-2 and is only mentioned in subsequent chapters

Fuel Oils 1% (58 Tbtu)
Other* 55% (4050 Tbtu)
Natural Gas 11% (782 Tbtu)
Coal/Coke 9% (694 Tbtu)
LPG/NGL** 24% (1746 Tbtu)

*Other includes petroleum-derived byproduct gases and solids, woody materials, hydrogen, and waste materials.

**LPG/NGL are liquefied petroleum gases (mixtures of alkanes and olefins) and natural gas liquids.

Figure 2-1 Use of Feedstock Energy in the Manufacturing and Mining Industries – 7.3 Quads
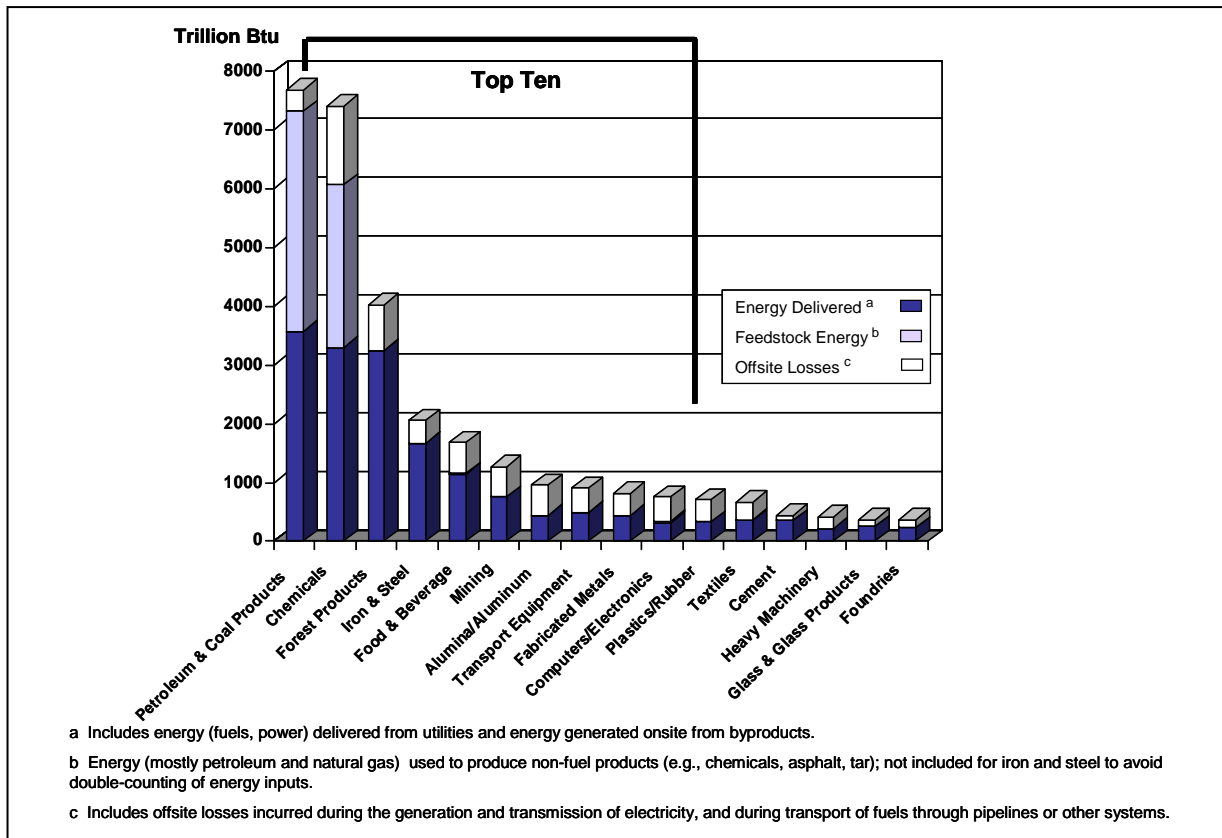
to provide context on overall energy use. However, the quantity of energy purchased for feedstocks is significant – 7.3 quads in 1998 (see Figure 2-1), and brings the annual energy use in manufacturing and mining to over 33 quads. Of this total, feedstocks account for a substantial 22%. The largest users of feedstock energy include chemicals, petroleum refining, iron and steel, and electrical equipment. Feedstock energy is used in small quantities in forest products, food and beverage, textiles, transportation equipment, and fabricated metals.
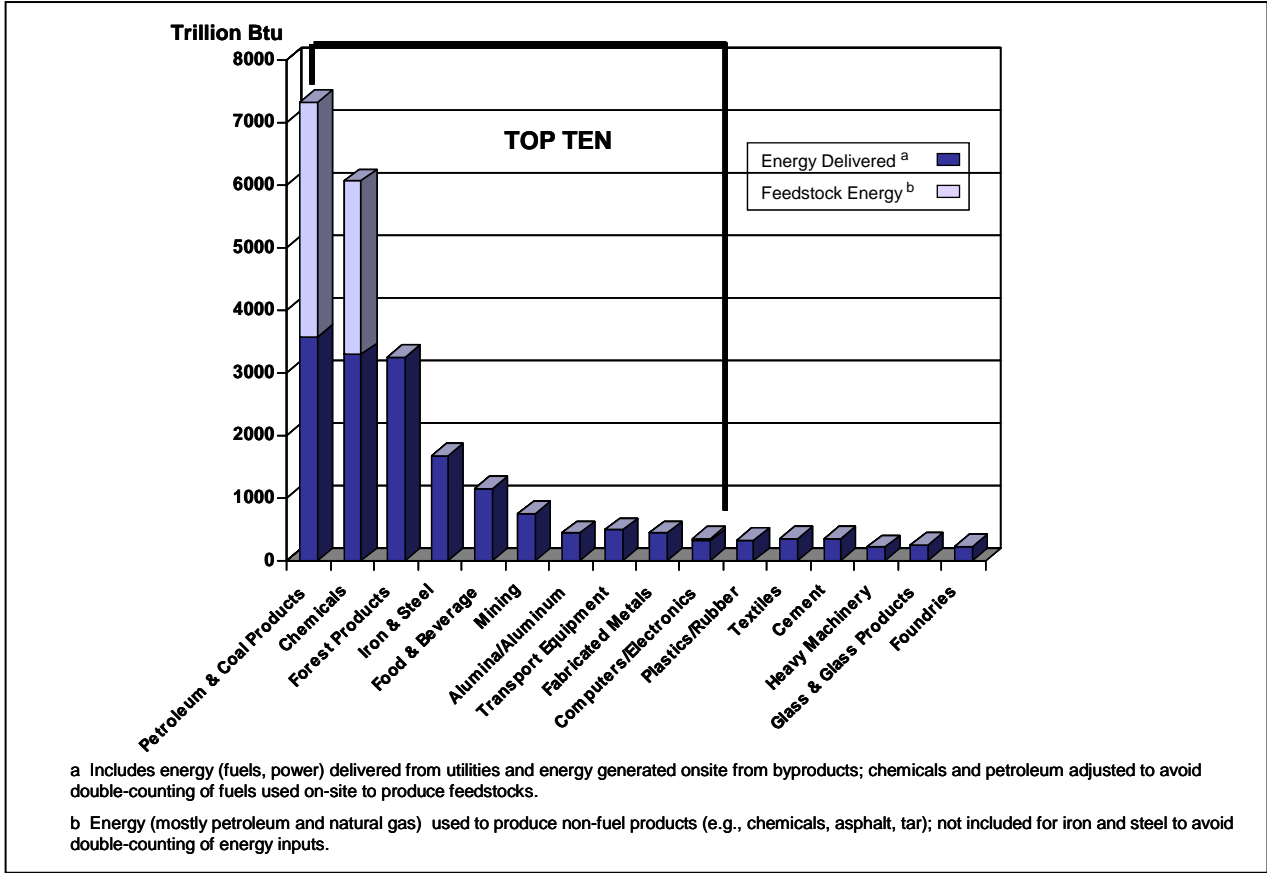
Figure 2-2 Total Energy Use in Manufacturing and Mining

There are several ways in which energy use can be reported for manufacturing and mining. The first, shown in Figure 2-2 illustrates what is termed 'total energy use'. Total energy use includes energy used for feedstocks, fuels and power, and the losses incurred offsite at utilities and in fuel transport. This is the most complete picture of all the energy associated with a particular industrial sector. Using this approach, petroleum and coal products ranks number one in energy use.

Energy consumption is also reported in the MECS as 'first use of energy', which includes net use of feedstocks and fuels and power (see Figure 2-3), and does not include offsite losses. To avoid double-counting of energy use, the fuel and power reported in first use of energy is adjusted to remove the fuels that are combusted and also produce some byproducts that are later used as feedstocks. This adjustment is only significant for the chemicals, petroleum refining, and iron and steel industries.

The 'first use of energy' provides an overall picture of all the energy sources that are purchased by an industry, as well as the fuels that are produced onsite. Because it includes feedstock energy, however, it does not illustrate the energy that is used strictly for heat, cooling, and powering processes or for other uses within the plant boundary, which is the primary object of this study. For this reason, two other energy categories are examined: Primary energy and fuels and power.

Trillion Btu

TOP TEN

Legend:
- Energy Delivered [a]
- Feedstock Energy [b]

Categories (x-axis): Petroleum & Coal Products, Chemicals, Forest Products, Iron & Steel, Food & Beverage, Mining, Alumina/Aluminum, Transport Equipment, Fabricated Metals, Computers/Electronics, Plastics/Rubber, Textiles, Cement, Heavy Machinery, Glass & Glass Products, Foundries

a Includes energy (fuels, power) delivered from utilities and energy generated onsite from byproducts; chemicals and petroleum adjusted to avoid double-counting of fuels used on-site to produce feedstocks.

b Energy (mostly petroleum and natural gas) used to produce non-fuel products (e.g., chemicals, asphalt, tar); not included for iron and steel to avoid double-counting of energy inputs.

Figure 2-3 First Use of Energy in Manufacturing and Mining

For the purposes of this report, energy use reported as 'primary energy use' and as 'fuels and power' are of the most interest. Primary energy includes fuels and power as well as offsite losses; it represents all the energy associated with industrial processes (process energy), *both external and internal to the plant boundary*. Fuels and power does not include offsite losses, and represents all the energy associated with industrial processes *inside the plant boundary*.

Differentiating between outside or inside the plant boundary is important to assessing the technology options for improving energy efficiency. Within the plant boundary, the industry has control over energy consumption. Outside the plant boundary, where energy is generated or provided by utilities, the industry has little or no control over technology efficiency and energy use. However, an industry can impact the losses associated with outside utilities by adopting technologies that allow them to generate more energy onsite, more efficiently than the utility (e.g., cogeneration).   Primary energy and fuel and power are covered in more detail in the following sections.

Primary Energy Use

Primary energy, which includes the energy losses associated with offsite utilities and fuel transport, presents an overall view of fuel and electricity use associated with manufacturing and mining (but excluding feedstock energy). Primary energy use and offsite energy losses are shown for each sector in Figure 2-4, ranked from left to right by magnitude of energy use.

The combined total primary energy use for manufacturing and mining is about 26 quads annually, or about 30% of all the energy used in the U.S. for any purpose. As Figure 2-4 illustrates, energy use varies widely across industrial sectors, with the heavy industries (chemicals, forest products, petroleum, iron and steel) emerging as some of the most energy-intensive.

Figure 2-4. U.S. Manufacturing & Mining Total Primary Energy
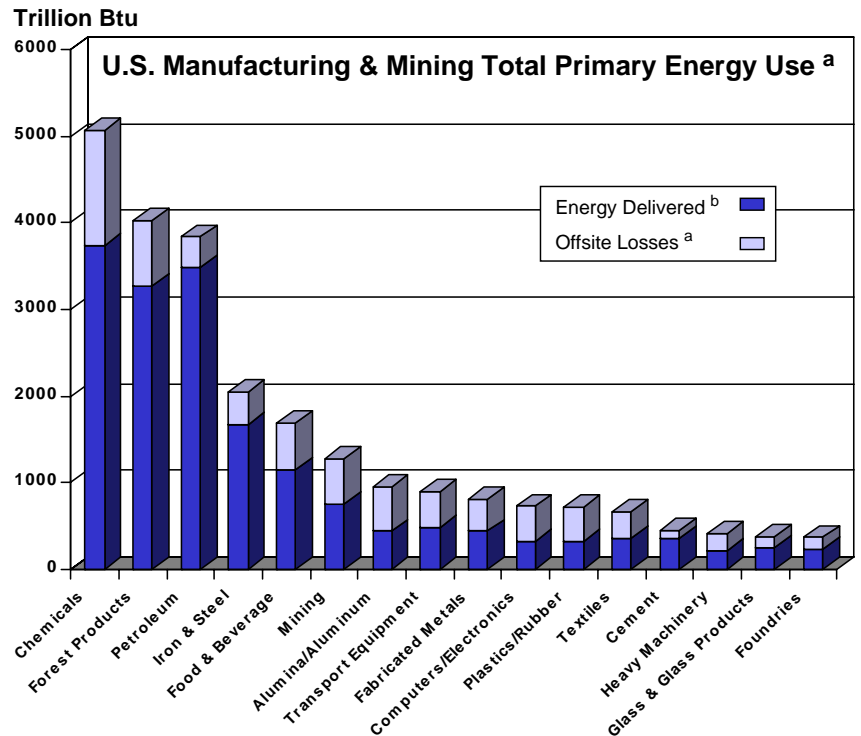
Includes offsite losses incurred during the generation and transmission of electricity, and during
e transport of fuels through pipelines or other systems.

ᴅ Includes energy delivered from utilities and energy generated onsite from byproducts and renewable resources. Does not include feedstock energy used to produce non-fuel products.

Table 2-3 ranks industry by primary energy use and identifies the large consumers. As Table 2-3 illustrates, the chemical industry is by far the largest consumer of primary energy, followed by forest products and petroleum refining. Other large consumers, with primary energy use of nearly a quad per year or more, include iron and steel mills, food and beverage, mining, aluminum, and transportation equipment manufacture.

The top three industries have several commonalities that contribute to their high energy consumption. First, the core processes used to convert raw materials in these industries are characterized by operation at high temperatures and pressures. Second, they are all large consumers of steam energy. Third, the energy efficiency of some core processes is below optimum, for a variety of reasons. In the chemical and petroleum refining industries, for example, over 40,000 energy-intensive distillation columns play a key role in producing chemicals and fuels. The energy efficiency of these energy-intensive columns is typically low (20-40%). To some degree, these same characteristics – high temperatures and pressures, steam intensity, and thermal efficiency – play a role in all other large energy-consuming industries.

Table 2-3. Industry Rank by Primary Energy Use		
Sector	**TBtu**	**Rank**
Chemicals	5074	1
Forest Products	4039	2
Petroleum Refining	3835	3
Iron & Steel Mills	2056	4
Food & Beverage	1685	5
Mining	1273	6
Alumina and Aluminum	958	7
Transportation Equipment	902	8
Fabricated Metals	815	9
Computers, Electronics	728	10
Plastics & Rubber	711	11
Textiles	659	12
Cement	446	13
Heavy Machinery	416	14
Glass & Glass Products	372	15
Foundries	369	16

Fuel and Electricity Use

Fuel and electricity use is shown in Figure 2-5, ranked by order of magnitude from left to right. This figure illustrates the direct use of purchased energy and byproduct fuels, and does not include losses incurred at offsite utilities. It provides a practical measure of the actual use of fuels and electricity at industrial facilities. The fuel category includes byproduct fuels generated at the plant site, as well as the onsite use of renewable sources such as solar energy. The top six energy consumers of fuel and electricity are chemicals, petroleum refining, forest products, iron and steel mills, food and beverage, and mining.

Trillion Btu
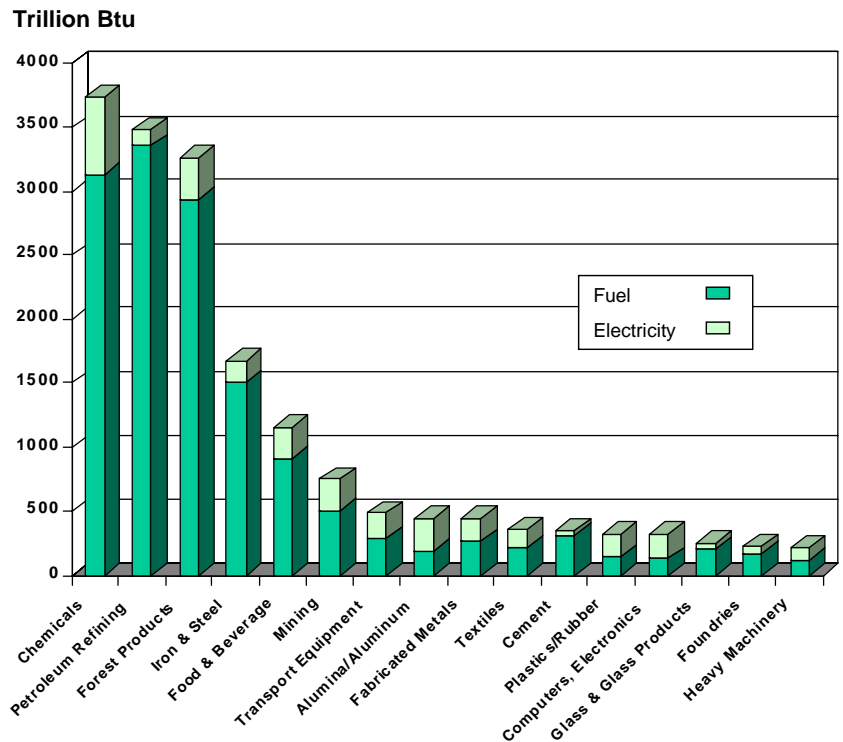
Figure 2-5 U.S. Manufacturing and Mining Direct Use of Fuel and Electricity

Table 2-4. Comparison of Fuel and Electrity Use by Industrial Sector					
	Total		**Fuel Use**		**Electricity**
Sector	**TBtu**	**Rank**	**TBtu**	**Rank**	**TBtu**	**Rank**
Chemicals	3729	1	3127	2	602	1
Petroleum Refining	3478	2	3355	1	123	12
Forest Products	3263	3	2936	3	327	2
Iron & Steel Mills	1672	4	1509	4	163	10
Food & Beverage	1156	5	915	5	241	5
Mining	753	6	510	6	243	4
Transportation Equipment	488	7	293	8	195	6
Alumina & Aluminum	441	8	195	12	246	3
Fabricated Metals	441	9	265	9	176	9
Textiles	359	10	218	10	141	11
Cement	355	11	316	7	39	16
Plastics & Rubber	327	12	144	14	183	8
Computers, Electronics	321	13	127	15	194	7
Glass & Glass Products	254	14	200	11	54	15
Foundries	233	15	170	13	63	14
Heavy Machinery	213	16	117	16	96	13

Note: Shading indicates ton ten ranking for total fuel and electricity use.

Table 2-4 compares and ranks the total use of electricity and fuels among different industrial sectors. This comparison provides a means of identifying those industries that are highly electricity or fuel-intensive. It also helps to identify those industries that could benefit from the use (or increased use) of efficient onsite cogeneration technology.

As Table 2-4 illustrates, the top ten users of fuel and electricity are some of the most energy-intensive heavy industries (chemicals, forest products, iron and steel mills), metal fabricators, and end users who rely on these industries (transportation equipment, food and beverage). The petroleum refining industry, while a very large energy consumer, relies almost entirely on fuels, using only a comparatively small amount of electricity.

The rankings shown in Table 2-4 do not reflect the relative importance of electricity to an industry compared to fuels. This is an important factor when assessing the vulnerability of individual industries to energy price or supply volatility. Table 2-5 shows the relative percentages of energy and fuel use for all the industry sectors.

Table 2-5 identifies seven industries that may be particularly susceptible to the availability, quality, and price of electricity: alumina and aluminum, mining, computers and electronics, plastics and rubber, transportation equipment, fabricated metals, and heavy machinery. Electricity use accounts for 40% or more of energy requirements in all these industries.

From a fuel perspective, five industries would be most vulnerable to fuel availability: chemicals, forest products, iron and steel, petroleum refining, and cement. Fuel use accounts for about 90% or more of energy use in these industries. Natural gas is of particular concern, since it comprises the largest share of purchased fuel use. However, four of these five industries also relay heavily on by product fuels. Other relatively heavy fuel users include mining, food and beverage, fabricated metals, foundries, and glass making.

Onsite Generation and Electricity Demand

Electricity demand provides a more complete picture of electricity use in individual industries. Electricity demand is a composite of purchased electricity, plus electricity generated onsite by cogeneration or conventional power generation, minus the excess electricity that is exported offsite to other users.

Electricity demand for individual industries is shown in Table 2-6, along with the percent of electricity that is generated and used onsite. The only change in rank between Table 2-4 and Table 2-6 is that mining, food processing, and petroleum refining move up in rank due to their use of onsite generation.

Significant onsite power generators include chemicals, forest products, petroleum refining, iron and steel mills, food processors, and cement. Notably, some of the industries that are very dependent on electricity (40 to over 50% of energy use) rely almost entirely on purchased electricity (aluminum, computers and electronics, plastics and rubber, heavy machinery).

Table 2-5 Percent of Fuel and Electricity Use		
Sector	**%Fuel**	**%Electric**
Chemicals	84	16
Forest Products	90	10
Alumina/Aluminum	44	56
Mining	68	32
Food & Beverage	79	21
Transportation Equipment	60	40
Computers, Electronics	40	60
Plastics and Rubber	44	56
Fabricated Metals	60	40
Iron and Steel Mills	90	10
Textiles	61	39
Petroleum Refining	96	4
Heavy Machinery	55	45
Foundries	73	27
Glass and Glass Products	79	21
Cement	89	11

| Table 2-6 Industries Ranked by Electricity Demand			
	Electricity Demand		
Sector	**Tbtu**	**Rank**	**% Onsite**
Chemicals	733	1	18
Forest Products	491	2	33
Mining	262	3	7
Food & Beverage	258	4	7
Alumina & Aluminum	249	5	1
Transportation Equipment	198	6	2
Computers, Electronics	194	7	0
Plastics & Rubber	184	8	<1
Iron & Steel Mills	181	9	10
Fabricated Metals	176	10	0
Petroleum Refining	174	11	29
Textiles	142	12	1
Heavy Machinery	97	13	1
Foundries	63	14	0
Glass & Glass Products	54	15	0
Cement	41	16	5

Figure 2-6 illustrates the use of onsite power systems to meet demand for energy in manufacturing and mining. Overall, about 13% of electricity demand in manufacturing and mining is met through onsite power generation. Most electricity (over 95%) is generated using cogeneration systems, which also provide high temperature steam for process heating. Cogeneration is the optimum choice for onsite generation, as it provides power and steam with overall thermal efficiencies 20-30% higher than conventional power systems. Despite the advantages, cogenerated steam currently only accounts for about 8% of steam demand. In some industries, the adoption of onsite cogeneration is limited by the large capital investments for power systems, and the capacity to utilize additional steam onsite. As large steam and electricity users, chemicals, forest products, petroleum refining, and steel mills are logically large cogenerators (see Table 2-5).
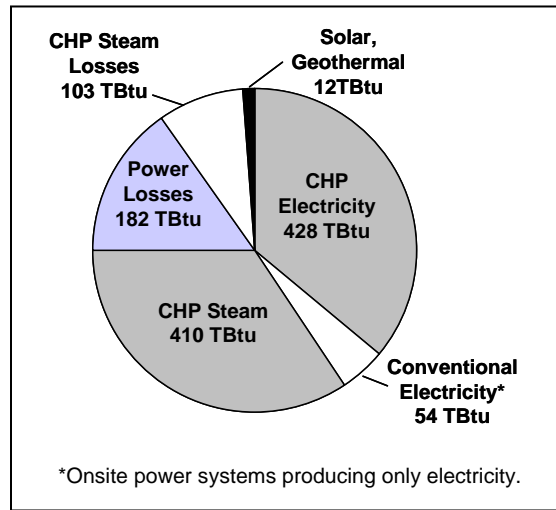
Figure 2-6 Onsite Power Generation and Loss Profile for Manufacturing and Mining

End Use Profile

Energy is consumed throughout industry to generate steam, for direct process heating and cooling, to power machine drives and electrolytic systems, to generate power, and to heat, cool and light facilities. A breakdown of energy end-use for the manufacturing and mining sector is shown in Figure 2-7.
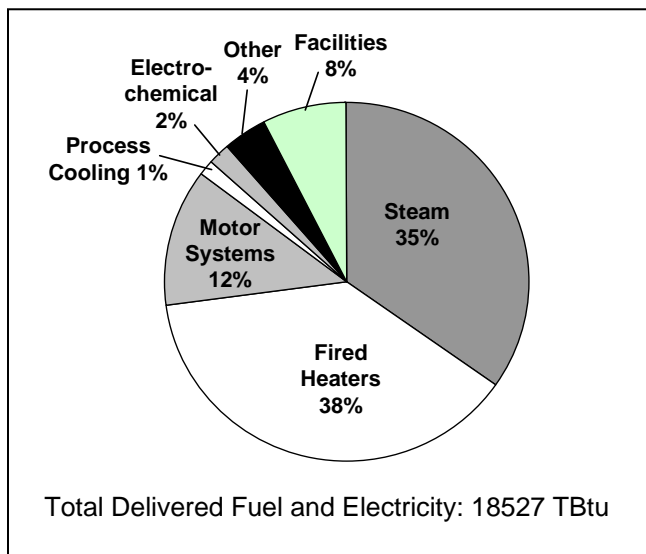
Figure 2-7. Energy End-Use in Manufacturing and Mining

Overall, process heating (steam, fired heaters) and cooling systems dominate the industrial use of energy, at 74% of the total. These include energy systems that are commonly used throughout many industries, such as boilers and steam-driven equipment, as well as direct or indirect-fired heaters such as furnaces, dryers, calciners, evaporators, condensers, and other direct-fueled heating systems. Motor-driven systems account for the next substantial share of energy use at 12%.

The distribution shown in Figure 2-7 represents an average across industry, and may vary significantly for an individual industry. Foundries, glass and cement, for example, use virtually no steam. In aluminum, electrolysis accounts for upwards of 40% of energy use. The energy end-uses unique to six major energy-using industries are covered in detail in separate sections of this study.

Table 2-7. Industry Ranked by Steam Use		
	Steam Use	
Sector	Tbtu	Rank
Forest Products	2442	1
Chemicals	1645	2
Petroleum Refining	1061	3
Food & Beverage	610	4
Textiles	132	5
Transportation Equipment	112	6
Iron & Steel Mills	96	7
Plastics & Rubber	81	8
Computers, Electronics	53	9
Alumina & Aluminum	41	10
Fabricated Metals	35	11
Heavy Machinery	25	12
Foundries	22	13
Glass & Glass Products	5	14
Mining	4	15
Cement	1	16

Note: Steam use includes small amount of electrically-generated steam (e.g., coils, rods).

Table 2-8 Industries Ranked by Use of Fired Heaters		
	Fired Heaters	
Sector	TBtu	Rank
Petroleum Refining	2156	1
Iron & Steel Mills	1372	2
Chemicals	1207	3
Food & Beverage	300	4
Cement	296	5
Mining	204	6
Glass & Glass Products	204	7
Forest Products	196	8
Heavy Machinery	182	9
Fabricated Metals	182	10
Alumina & Aluminum	164	11
Foundries	147	12
Transportation Equipment	94	13
Computers, Electronics	65	14
Textiles	62	15
Plastics & Rubber	60	16

Use of steam by industrial sector is shown in Table 2.7, ranked by order of magnitude. Four industries – forest products, chemicals, petroleum refining, and food and beverage – account for 87% of steam use in industry. Textiles, transportation equipment, iron and steel mills, and plastics and rubber products are also significant steam users.

The energy conversion component of steam systems (e.g., heat exchangers, injectors, mechanical drives) varies substantially among industries and is generally process- and site-specific. The chemical industry, for example, uses steam mostly for fluid heating (steam stripping, steam reforming). Other industries may use steam for direct heating of parts or components, for cleaning, or for other process heating (e.g., sterilization). The specific uses of steam within individual industries will be the subject of a future study.

Fired heaters account for a substantial share of energy use and losses. These systems are used for the direct and indirect heating of fluids and solids (e.g., metals), and widely used across all industries. As Table 2-8 illustrates, energy use attributed to fired heaters is substantial (more than a quad) in three industries (petroleum refining, iron and steel mills, and chemicals) and is significant (above 200 trillion Btus) in another five industries. The primary fuel used for fired heaters is natural gas, with smaller amounts of petroleum, propane, and coal.

The energy efficiency of fired heating systems varies widely depending upon the application and the material being heated. Evaluating the industry-specific efficiency for process heating equipment and potential areas for improvement will be the subject of a future study.

Loss Profile

As discussed in Sections 1.2 and 1.3, energy losses associated with industrial energy use take two forms: offsite and onsite losses. **Offsite losses** are comprised mostly of losses associated with electricity purchased from utilities, with a much smaller share attributed to losses in fuel pipes and other fuel transport systems. Electricity losses are the result of lower turbine and power system efficiencies (as low as 25% for older steam-based systems, and up to 40% or even better for state-of-the-art gas turbines). On average, this means every kilowatt hour of power generated by a utility requires three kilowatt hour equivalents of fuel. Even though the industrial facility does not incur these losses, including them in the loss analysis provides a total picture of the energy associated with an individual industry's use of electricity. When viewed in this context, *offsite losses account for over 57 percent* of the total energy losses associated with manufacturing and mining, and *nearly 30 percent* of energy inputs.

Industrial facilities have no control over the efficiency of power generation at utilities. However, reducing use of purchased electricity by improving energy efficiency or by switching to more efficient onsite power generation systems can make an impact on these offsite losses and improve the availability and reliability of energy supply to the plant. For this reason, offsite losses are an important aspect of this study.

Onsite losses are the losses incurred within a plant boundary, and take various forms (see Section 1.3). Overall, *about 32 percent of the energy input to plants is lost inside the plant boundary*, prior to use in the intended process. Many onsite losses are typical across industries, such as those incurred in steam systems, cogeneration and conventional power units, energy distribution lines, heat exchangers, motors, pumps, compressors, and other commonly used equipment. In other cases, onsite losses are very specific to the industrial processes employed. This study estimates the onsite prior-to-process energy losses that are common to many industries, using standard loss factors obtained from the literature and experts in the field. The reference section provides details on the sources used for loss analysis.

Figure 2-8 depicts total onsite and offsite losses for individual industries, ranked in order of magnitude from left to right. This table illustrates that offsite losses are substantial, and in most cases much larger than onsite losses.

Industries that are proportionately large users of electricity will also exhibit large offsite losses. This occurs because electricity generation and transmission losses comprise the largest share of offsite losses. The alternate is true for low users of electricity, and for industries that cogenerate large amounts of their electricity demand. Petroleum refining, for example, only relies on electricity for about 4% of energy use, and cogenerates a considerable amount onsite. This is reflected in a lower percent of total losses being offsite losses, as illustrated in Figure 2-6. The same is true, although to a lesser extent, for forest products, because they are large cogenerators.
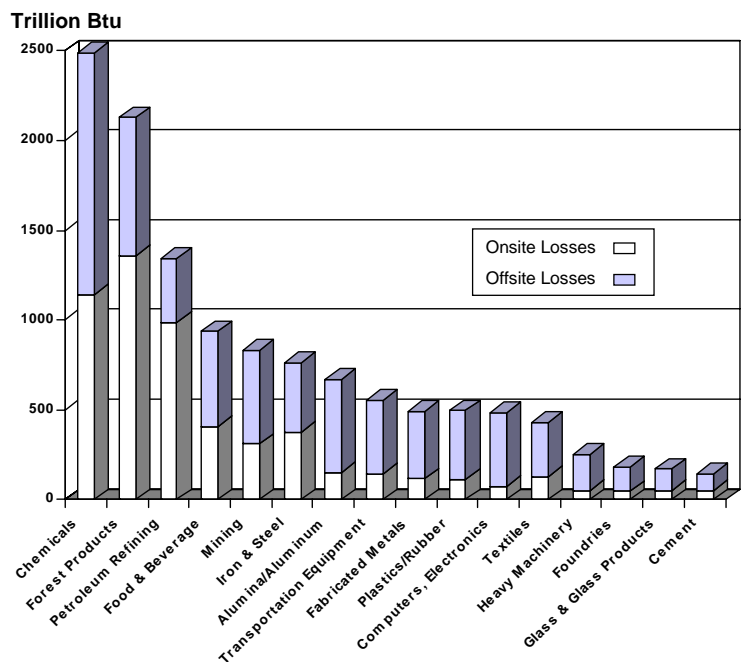
Figure 2-8. U.S. Manufacturing and Mining Offsite and Onsite Energy Losses

In targeting efficiency improvements for energy systems in industrial plants, it is important to preliminarily define the sources of onsite losses. This provides a first pass identification of energy-saving opportunities and energy sinks. An overall breakdown of onsite losses in the manufacturing and mining sectors is shown in Figure 2-9. These include only losses incurred prior to use in processes. In addition, another 20 to 50 percent or more of energy inputs is lost at the end of the process through exit gases, evaporative or radiative heat losses, and in waste steam and hot water. This study does not attempt to estimate these losses, but they can be considerable, as illustrated in Figure 2-9.
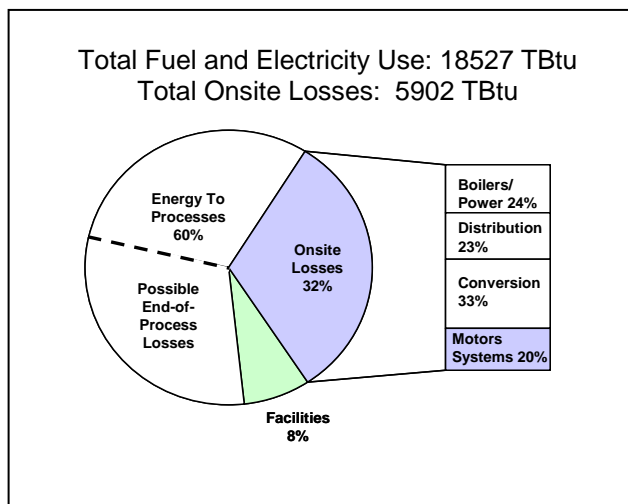
Figure 2-9. Onsite Energy Loss Profile for U.S. Manufacturing and Mining Sector

As noted previously, onsite losses account for a substantial 32% of energy inputs to industrial plants. Translated, that means about a third of energy is lost due to inefficiencies in plant energy systems prior to use in process-specific operations (e.g., chemical reactors, glass furnaces, wood pulping units). After considering the amount of energy that is exported, and energy used for heating and lighting facilities, only about 60% is actually used to drive industrial processes. To quantify, of the 17.8 quads that arrive at industrial facilities, about 5.7 is lost prior to process units and never recovered.

Energy conversion systems (heat exchangers, preheaters, heat pumps, reboilers, condensers, and others account for about a third of losses, and represent large targets for improvement. The remainder of losses is distributed relatively evenly among steam and power systems, energy distribution, and motor-drives.

Table 2-9 provides industry rank for onsite losses, and the percent of energy inputs these losses represent for each industry. Percents are calculated by dividing the onsite losses by the amount of fuel and electricity inputs to the industry (not primary energy, which includes offsite losses). In ten out of sixteen industries, offsite losses account for more than one-fourth of energy use, i.e., more than a fourth of energy entering the plant is lost due to equipment and distribution system inefficiencies. In seven of these industries, onsite losses are more than a third of fuel and electricity inputs.

Large users of high temperature and pressure processes will have large onsite losses due to limitations in equipment and thermal efficiency. In most industries, onsite losses are directly related to process equipment and plant configuration.

Table 2-9. Industry Rank by Onsite Losses and Percent of Energy Use (fuels, electricity)			
	Onsite Losses		
Sector	**TBtu**	**Rank**	**% Use**
Forest Products	1474	1	45
Chemicals	1363	2	37
Petroleum Refining	978	3	28
Food & Beverage	407	4	35
Iron & Steel Mills	378	5	23
Mining	311	6	41
Alumina & Aluminum	153	7	55
Transportation Equipment	142	8	29
Textiles	128	9	36
Fabricated Metals	117	10	27
Plastics & Rubber	113	11	35
Computers & Electronics	75	12	23
Glass & Glass Products	54	13	21
Cement	52	14	15
Heavy Machinery	52	15	24
Foundries	47	16	20

System-Specific Losses

Looking at the components of energy losses for specific energy end-uses helps to identify energy saving opportunities. The components of onsite energy losses are illustrated in Figure 2-10, and summarized in Table 2-10. The bulk of energy losses occur in process heating, which is comprised of steam systems, fired heaters and cooling systems. Steam system losses account for the largest share of losses in this category, at 2819 trillion Btu, or about 45% of total energy input to steam systems. Fired heating and cooling systems account for another 1296 trillion Btu, or about 18% of energy inputs. Motor system losses, which include losses in motor windings as well as mechanical components in pumps, compressors, and so forth, amount to 1289 trillion Btu, or 55% of energy inputs, which represents the largest proportional loss of any end-use category.

It is important to note that the losses shown in Figure 2-10 and Table 2-10 represent losses incurred *prior to use in the process*, and do not include the losses that occur at the end of the process. As discussed earlier, these losses, which include energy embodied in waste heat, exit gases (stack, flue, flare, etc), waste steam or hot water, and other sources, can be as much or more than those incurred prior to the process. Looking at fired systems, for example (fired heaters and cooling), if just the distribution and conversion losses are taken into consideration, the assumption could be made that these systems are roughly 80 percent efficient. When considered from when energy enters the plant gate to the end of the process, as much as 50 percent of the energy to fired systems could potentially be lost.

The important point is that the losses estimated prior to the process underestimate the total losses associated with a particular process overall, since they do not consider exhaust and other downstream waste heat sources. Estimation of end-of-process losses is outside the scope of this study.
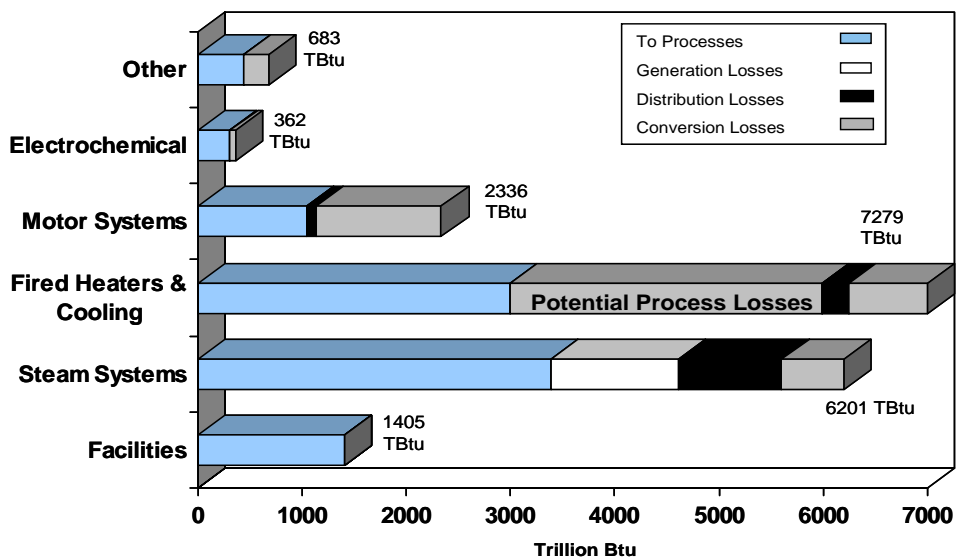

*Onsite generated power has been distributed among end-uses and is not included in the total.

Figure 2-10. Energy End-Use and Loss Distributions in Manufacturing and Mining

Table 2-10. Manufacturing & Mining Energy Use and Losses (Trillion Btus)						
	To Process/ End Use	Generation Losses	Distribution Losses	Conversion Losses	Total Onsite Losses	Total
Facilities	1405	na	na	na	na	1405
Steam Systems	3382	1234	987	598	2819	6201
Fired Heaters and Cooling Systems	5983	na	256	1040	1296	7279
Motor Systems	1047	na	85	1204	1289	2336
Electrochemical	295	na	15	52	67	362
Other Uses	434	na	na	249	249	683
Onsite Power	*(482)	182	na	na	182	182
Export of Power	79	na	na	na	na	79
TOTALS	12625	1416	1343	3143	5902	18527

*Onsite-generated power has been distributed among end-uses and is not included in the totals.

Figure 2-9 breaks out components of onsite losses for steam systems (excluding boiler fuel used for power generation, but including steam generated from cogenerators). According to Figure 2-11, boiler inefficiencies, which range from 50-85%, account for the largest share of losses. The remaining losses occur in distribution and conversion. Distribution losses (including pipes and valves) were estimated to be about 15% of energy inputs to steam systems.

Energy conversion systems are closely connected with process units, resulting in some overlap of steam conversion losses and losses that occur in process units and at the end of the process. These end-of-process losses are not calculated here, and the connection between energy conversion losses and process units will be the subject of a future study.
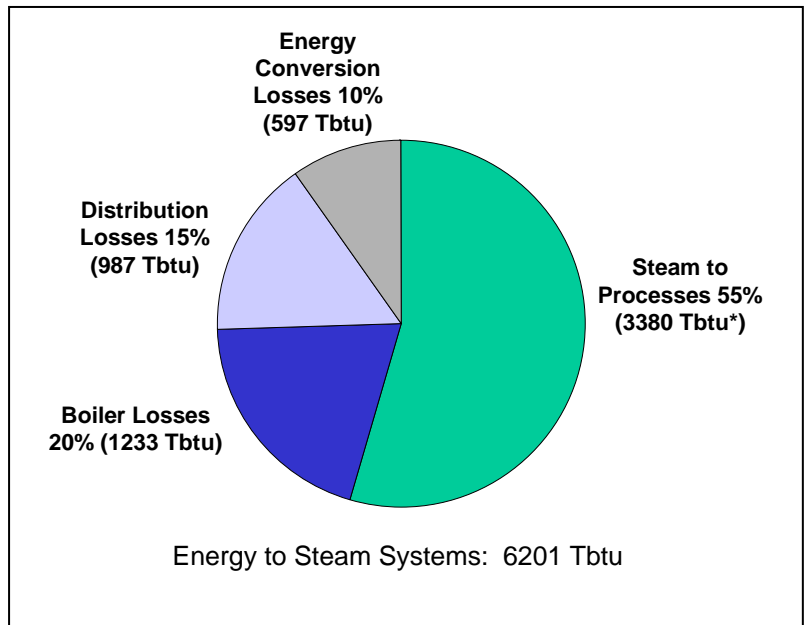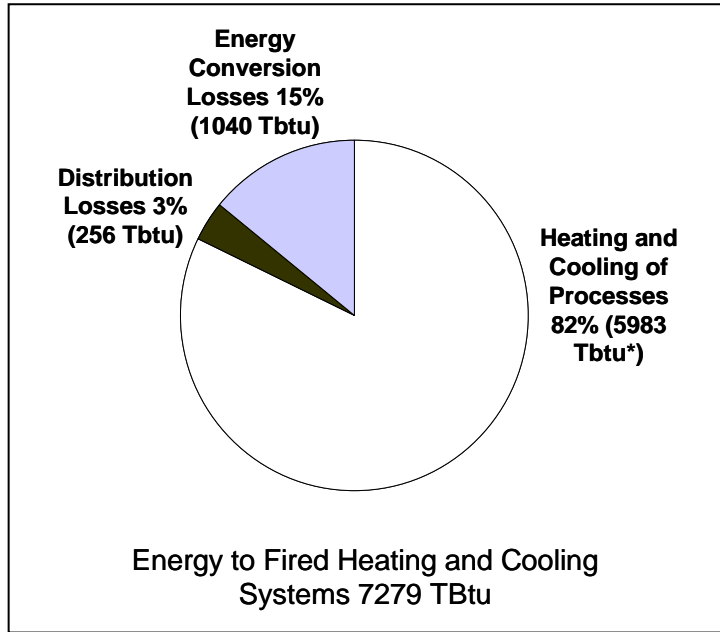

Energy to Steam Systems: 6201 Tbtu

Figure 2-11. Steam Use and Losses in Manufacturing and Mining

Energy to Fired Heating and Cooling
Systems 7279 TBtu

**Figure 2-12 Profile of Energy Use and Losses
in Fired Systems**

A profile of energy used for fired systems is shown in Figure 2-12. The bulk of energy losses occur in the conversion of fuels to useful work (i.e., energy conversion). Distribution losses in pipes and electricity transmission lines only account for about 3% of energy losses.

Again, these systems are often integrally connected with process units, and an attempt was made to separate pre-process losses. While significant energy losses may also occur in the actual process units, estimation of these losses is outside the scope of this study.

A profile of motor use and losses is shown in Figure 2-13. This figure illustrates the significant losses that are attributed to the low efficiency of some motor-driven equipment. While motor efficiency itself is relatively high (90-95%), system inefficiencies in the conversion of motor energy to usable work lead to substantial energy losses. In materials processing, for example, which includes motor-driven grinders, crushers, and mixers, as much as 80-90% of energy is not converted to useful work. Compressed air systems are also very inefficient, with typically only about 10-15% of energy converted to useful work. Total losses in motors and motor-driven systems amount to 1204 trillion Btus.
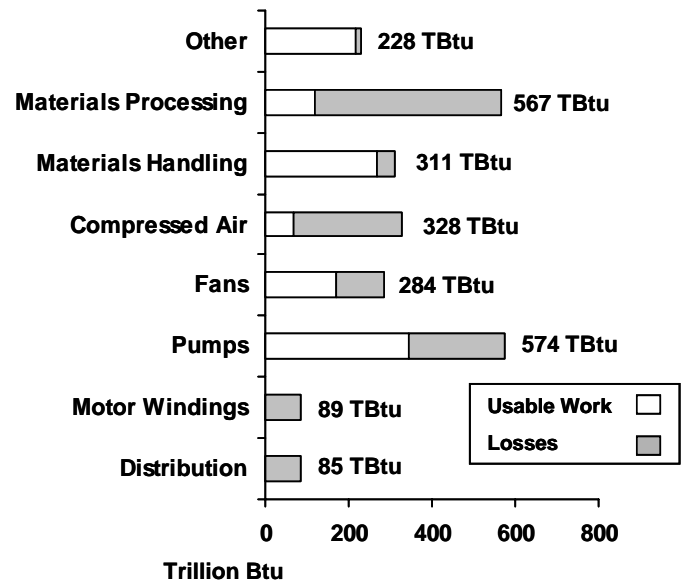
**Figure 2-13 Motor System Energy Use and Loss
Profile for Manufacturing and Mining**

3.0 Chemicals Industry (NAICS 325)

3.1 Overview of the Chemicals Industry

The chemical industry is an integral component of the U.S. economy, converting various raw materials (e.g, petroleum, natural gas, minerals, coal, air and water) into more than 70,000 diverse products. Very few goods can be manufactured without some input from the chemical industry, and the industry's products are also critical to construction, transportation and other industries.

Chemical Industry Sectors
Organic Chemicals
Petrochemicals
Cyclic Crudes and Intermediates
Other Basic Organic Chemicals
Inorganics
Industrial Gases
Alkalies and Chlorine
Other Basic Inorganic Chemicals
Plastics, Fibers and Resins
Plastics Materials and Resins
Synthetic Rubber
Noncellulosic Fibers
Fertilizers
Nitrogenous Fertilizers
Phosphatic Fertilizers

The industry creates its diverse product slate using materials in two forms: organic (oil, natural gas) and inorganic (minerals, ores or elements taken from the earth, air). The industry is divided into industrial sectors that reflect these raw material lines.

The chemical industry is the largest consumer of fuels and power in the U.S. industrial sector. The manufacture of chemicals is complex and energy-intensive, often requiring large quantities of thermal energy to convert raw materials to useful products. The efficiency of the processes and equipment used to produce chemicals is also constrained by thermodynamic, kinetic, or transport limitations, and operating conditions may be severe (high temperatures, pressures, corrosive environments). All these factors contribute to proportionally high energy use per pound of product.
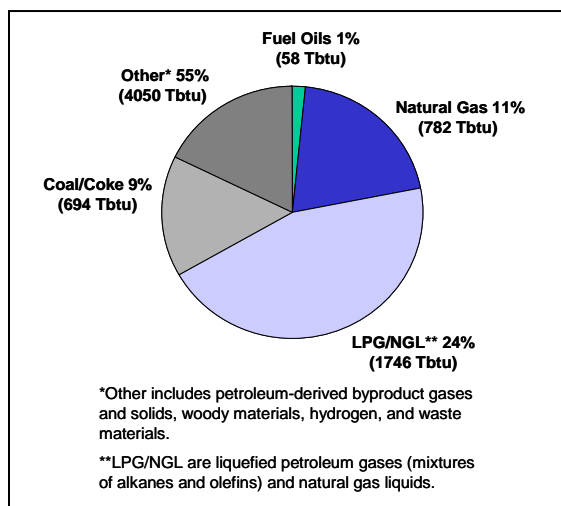
3.2 Energy Use and Loss Analysis for Chemicals

Table 3-1 Snapshot of the Chemical Industry: Energy Use and Rank Within U.S. Manufacturing and Mining		
Category	**Rank**	**Energy (TBtu)**
Primary Energy Use	1	5074
Offsite Losses	1	1345
Fuel and Electricity	1	3729
Onsite Losses	2	1363
Steam Generation	2	328
Power Generation	2	54
Energy Distribution	2	322
Energy Conversion	1	659
Facilities	2	123
Energy Export	1	25
Energy Delivered to Processes	2	2218

Overview

A snapshot of how the chemical industry ranks in terms of energy use and losses within manufacturing and mining is shown in Table 3-1. The chemical industry ranks among the top three in U.S. manufacturing and mining in every energy end-use category. The industry is a large user of steam and fired heaters, and ranks number one in energy used for motor-driven systems.

Natural gas is the primary fuel used by the chemical industry (63%), followed by byproduct fuels produced onsite (24%). Small amounts of coal, petroleum products, natural gas liquids (NGL), and liquefied petroleum gases (LPG) make up the remainder.
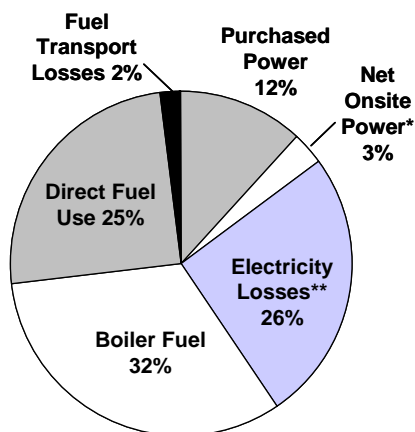
Figure 3-1 Feedstock Energy Use in the Chemicals Industry – 2.8 Quads

* Excludes losses; includes 25 TBtu electricity export.
** Includes both offsite and onsite electricity generation

Figure 3-2 Primary Energy Use in the U.S. Chemical Industry - 5074 Trillion Btu

Although not the focus of this report, the chemical industry also uses a significant amount of feedstock energy (petroleum derivatives and natural gas) as a raw material primarily for the production of organic chemicals and ammonia. As shown in Figure 3-1, the total feedstock energy consumed by the industry is 2.8 quads [MECS 1998]. When feedstock is combined with fuels and electricity, total energy use amounts to about 6.2 quads. Energy feedstocks represent about 45% of total energy use.

Improvements in the efficiency of energy systems directly impacts the use of energy feedstocks, much of which are petroleum-based and contribute to our use of imported oil. More efficient heat transfer in an ethylene furnace, for example, can increase the yield of product obtained per Btu of energy used, which reduces the amount of petroleum feedstock required.

Primary Energy Use

Primary energy, which includes purchased fuels and electricity, byproduct fuels, and the energy losses associated with offsite power generation and energy supply systems, provides a perspective on the total energy use associated with chemicals manufacture. Primary energy inputs to the industry are shown in Figure 3-2. Fuels for boilers and direct-fired systems comprise nearly 60% of total primary energy; power demand (purchased plus self-generated electricity) is about 15%.

A considerable 28% of the primary energy associated with chemicals manufacture is lost during energy generation and transport. The bulk of these energy losses occur during the generation of electricity at offsite utilities, where the efficiency of generating systems can be as low as 28-30%. Losses also occur in onsite power generating systems, but thermal efficiency is greatly improved through the use of cogeneration. About 20% of chemical industry electricity demand is currently met by onsite power systems. The chemicals industry is in fact the second largest cogenerating industry, topped only by pulp and paper mills.

Fuel and Electricity Use

About 3.7 quads of fuels and electricity were consumed by the chemical industry in 1998. On average, about 84% of energy use is fuels, and the remainder is purchased electricity (16%).

The chemical industry makes over 70,000 different products and uses hundreds of different chemical processes. As a result, energy use patterns vary dramatically across sectors. Processes used to produce petrochemicals, for example, are very steam-intensive, while chlorine production depends heavily on electricity and electrolytic cells.

Figure 3-3 illustrates the energy consumption patterns across major sectors of the industry. Overall, the production of organic chemicals, which are derived from petroleum or natural gas, is responsible for nearly 50% of fuel and electricity consumption in the industry. Inorganic chemicals production is the most electricity-intensive.
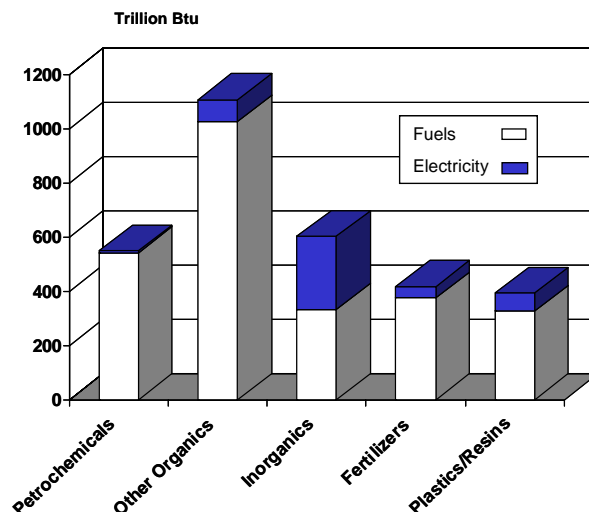

Figure 3-3 Fuel and Electricity Use in Selected Chemical Industry Sectors

Onsite Generation and Electricity Demand

The chemical industry is ranked first in demand for electricity, at 733 TBtu per year. Electricity demand is equal to purchases of electricity, plus electricity generated onsite, minus electricity exported offsite. It provides the most complete picture of actual electricity use. On average, electricity use only accounts for about 16% of energy consumption across the industry. However, several sectors are very electricity-intensive, such as alkali's and chlorine (34% of energy), industrial gases (61% of energy), and other inorganic chemicals (39% of energy)[MECS 1998].

As noted earlier, the chemical industry meets a significant amount of electricity demand through onsite generation. A profile of onsite produced energy is shown in Figure 3-4. About 358 trillion Btu of energy use is associated with the production of onsite electricity. About 95% of electricity produced onsite in the chemicals industry comes from cogenerating units, which also generate about 150 trillion Btu in steam. A small amount of electricity is produced in conventional steam and gas turbines or other systems that are not producing steam for process use.
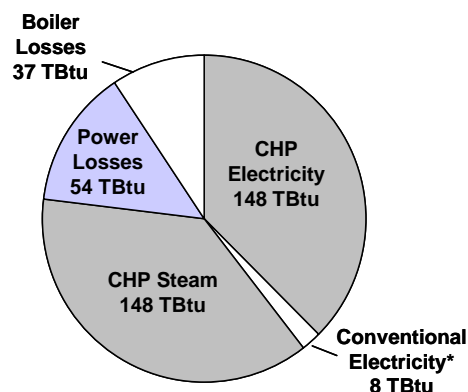

Figure 3-4 Onsite Power Generation Profile for Chemicals

* Steam or gas turbines not producing steam for process use

End Use Profile

Energy is consumed in chemicals manufacture for process heating and cooling, to power motor-driven systems and electrochemical reactors, and for various other purposes. A breakdown of energy end-use is shown in Figure 3-5. It should be noted that the energy trends shown here are an average for the industry and may not reflect sector differences.
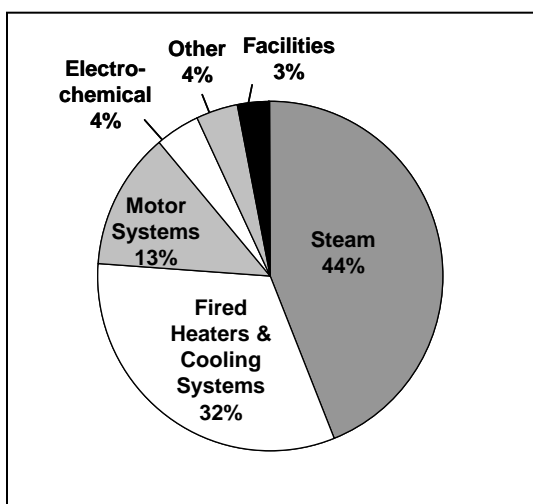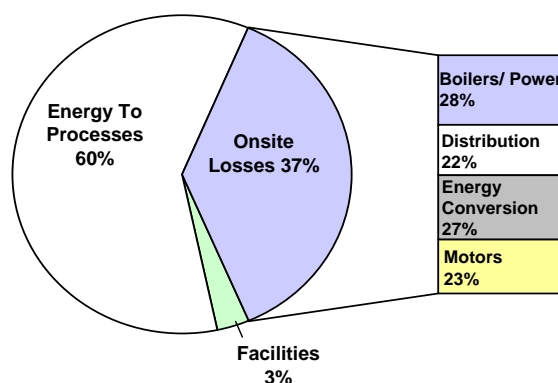

Figure 3-5 Energy End-Use in the Chemicals Industry: Total Delivered Fuel and Electricity - 3729 Trillion Btu

Figure 3-6 Onsite Energy Loss Profile for the Chemical Industry (NAICS 325) Total Onsite Losses – 1363 Trillion Btu

Process heating and cooling systems, particularly those used for fluid heating, represent the bulk of energy use in chemicals manufacture (76%). These include steam systems, fired heaters such as furnaces and reboilers, and cryogenic or other cooling units. Motor systems, which include motor-driven units such as pumps, conveyors, compressors, fans, mixers, grinders, and other materials handling or processing equipment, rank second with 13% of energy use. Heating, cooling and lighting of facilities only accounts for about 3% of energy use.

The industry ranks second in steam use within manufacturing and mining, and third in the use of fired heaters. Chemicals manufacture is also the largest user of motor-driven systems in the industrial sector**.**

Loss Profile

The energy footprint for the chemical industry (see Appendix A) evaluates end-use and loss patterns to better understand the opportunities for energy efficiency improvements. Figure 3-6, which is based on the energy footprint, illustrates the general flow of energy and losses within the average chemical plant. As Figure 3-6 shows, a substantial 37% of the energy that enters the plant is lost prior to use in process units. These losses occur in equipment and distribution systems that are supplying energy to process operations or converting energy to usable work (see Section 1.0 for an explanation of loss categories). Onsite losses are nearly evenly distributed among boilers and power generation, energy distribution, and energy conversion systems.

As noted earlier, the energy to processes includes a significant amount of energy that is lost at the end of the process in exhaust gases, waste steam and hot water, and other waste heat sources. These losses have not been estimated.

System-Specific Losses

Detailed energy use and losses for component systems are summarized in Figure 3-7 and Table 3-2. These provide more insight into the source of energy losses and identify targets for energy-saving opportunities.

As shown in Figure 3-7, the bulk of energy losses occur in process heating and cooling, which includes steam systems as well as fired heaters and cooling or refrigeration units. In terms of trillion Btus, steam system losses are the highest of all energy systems, about 748 trillion Btu, which represents about 45% of the total energy input to steam systems. Proportionally, however, motor system losses are the greatest. About 66% of the energy input to motor-driven systems is lost due to system inefficiencies.
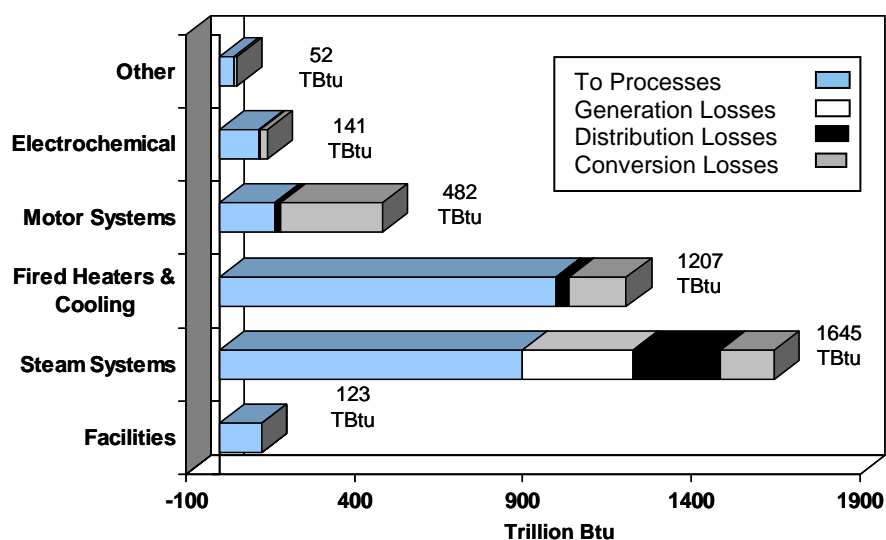
Figure 3-7 Energy End-Use and Loss Distributions in Chemicals (NAICS 325)

Table 3-2 Chemicals Energy Use and Losses (Trillion Btus)						
	To Process/ End Use	Generation Losses	Distribution Losses	Conversion Losses	TOTAL Onsite Losses	Total
Facilities	123	na	na	na		123
Steam Systems	897	328	262	158	748	1645
Fired Heaters & Cooling	997	na	38	172	210	1207
Motor Systems	163	na	18	301	319	482
Electrochemical	117	na	4	20	24	141
Other Uses	44	na	na	28	28	52
Onsite Power	(156)*	54	na	na	54	54
Export of Power	25	na	na	na		25
TOTALS	**2366**	**382**	**322**	**659**	**1363**	**3729**

*Onsite-generated power has been distributed among end-uses and is not included in the totals.
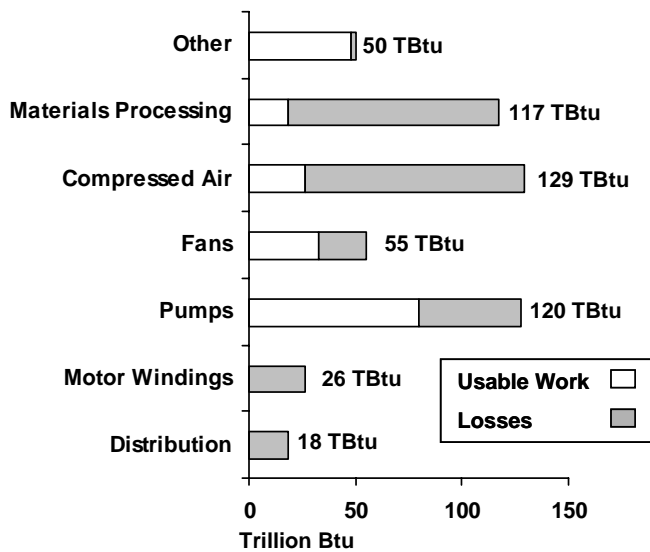
Figure 3-8 Chemical Industry Motor System Energy Use and Loss Profile

Energy to Steam Systems 1645 TBtu

Overall Steam System Losses ~45%
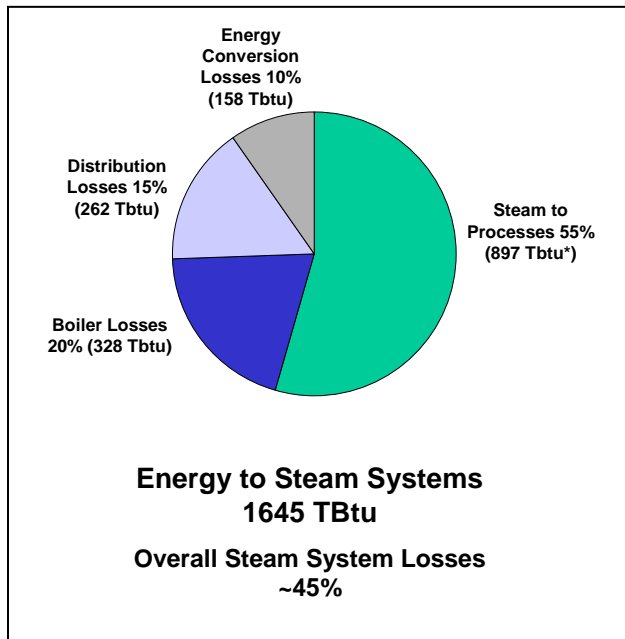
Figure 3-9 Steam Use and Loss Profile for the Chemical Industry

A motor use profile for chemicals is shown in Figure 3-8. The losses, indicated in gray, illustrate the substantial amounts of energy that are wasted due to the inefficiency of some motor-driven equipment. Compressed air and materials processing (e.g., grinding, mixing, crushing) exhibit the greatest proportion of losses. Some of these systems have efficiencies as low as 10-20%.

Motor system energy conversion losses total 275 trillion Btu; conversion losses in motor windings comprise another 26 trillion Btu. The associated energy distribution losses are 18 trillion Btu. Combined losses attributed to motor systems (excluding distribution) are about 301 trillion Btu. Most of the energy used for motor systems is electricity (over 90%), although small amounts of fuel are also employed.

A profile of chemical industry steam use and associated losses is shown in Figure 3-9. About 45% of energy inputs are lost due to system inefficiencies. The bulk of these occur in the boiler, where thermal efficiencies range from as low as 55% to as high as 85%, depending upon the age of the boiler and fuel burned. Waste heat boilers, for example, will have much lower overall thermal efficiency than natural gas-fired boilers.

Distribution losses are also significant. These occur in steam traps, valves, and pipes carrying steam to processes and energy conversion units. These losses can vary widely between facilities, and are very dependent on plant configurations, how effectively heat sources and sinks are integrated, and operating and maintenance practices.

4.0 Petroleum Refining Industry (NAICS 324110)

4.1 Overview of the Petroleum Refining Industry

Petroleum is the largest energy source used in the United States. Petroleum consumption is four times higher than nuclear power or renewable energy and even two times higher than coal or natural gas. In the U.S. alone there are 155 refinery facilities that transform petroleum into usable products, such as fuels, gasoline, liquefied petroleum gas (LPG), residual oil, coke, and kerosene. Refineries also produce raw materials for the petrochemical industry, such as plastics, agrochemicals, and pharmaceuticals. The U.S. is the largest producer of petroleum products, with almost 30 percent of the global market and an annual production of 6 billion barrels of refined products.

Table 4-1 Petroleum and Coal Products Manufacturing Sub-sectors
Petroleum Refineries
Asphalt Paving, Roofing, and Saturated Materials Manufacturing
Asphalt Paving Mixture and Block Manufacturing
Other Petroleum and Coal Products Manufacturing
Petroleum Lubricating Oil and Grease Manufacturing
All Other Petroleum and Coal Products Manufacturing
Crude Petroleum and Natural Gas Extraction
Natural Gas Liquid Extraction

Petroleum refineries are the second largest energy consumers in the manufacturing sector. Today's refineries are highly sophisticated facilities, consisting of a complex configuration of energy intensive distillation columns, cracking and coking units, chemical reactors, and blending and upgrading equipment. The industry spends between $5 and $6 billion in pollution abatement practices annually, and must also manufacture its products to meet strict environmental regulations.

The petroleum and coal products manufacturing sector (NAICS 324), includes various sub-sectors other than petroleum refining products. The following sections refer only to the petroleum refining sub-sector's (NAICS 324110) energy use and losses. The petroleum refining sector accounts for 90% of the petroleum and coal products industry shipments.

4.2 Energy Use and Loss Analysis for Petroleum Refining

Table 4-2 Snapshot of the Petroleum Refining Industry: Energy Use and Rank Within U.S. Manufacturing and Mining		
Category	Rank	Energy (TBtu)
Primary Energy Use	3	3835
Offsite Losses	11	357
Fuel and Electricity	2	3478
Onsite Losses	3	985
Steam Generation	3	212
Power Generation	3	17
Energy Distribution	3	242
Energy Conversion	2	514
Facilities	11	50
Energy Export	4	1
Energy Delivered to Processes	1	2442

Overview

A snapshot of how the petroleum refining industry ranks in terms of energy use and losses within manufacturing and mining is shown in Table 4-1. The petroleum refining ranks third in a large number of energy end-use categories. The industry is the largest user of fired heaters and ranks first in use of fuels.

The industry's main source of fuels consists of byproducts from petroleum refineries (66%) which are comprised mostly of still gas. The industry also uses significant amounts of natural gas (27%) and small amounts of liquefied petroleum gas (LPG), coal and coke.

The industry also consumes energy to produce non-energy products such as ethane, propane, naphtha, ethylene, butane, butylene, propylene, toluene, and xylene. The petroleum refining industry uses more than 95 percent of the manufacturing sector's LPG, mostly for feedstocks. Approximately one fourth of the industry's natural gas consumption is also used for feedstocks. The total petroleum refining industry feedstock use is 3.7 quads [MECS 1998].

The use of energy feedstocks is directly impacted by system efficiencies as these affect yield and throughput. Feedstocks are mainly petroleum-based and contribute directly to our use of imported oil.

Primary Energy Use
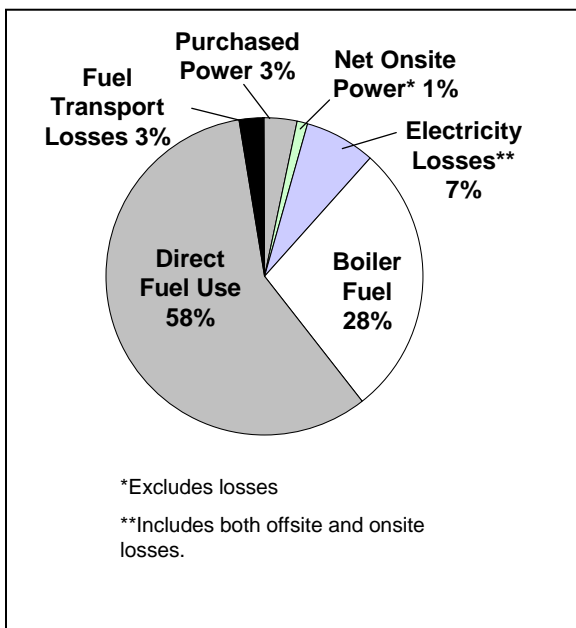
Figure 4-1 shows the primary energy inputs for the petroleum refining industry. Fuels for boilers and direct-fired systems comprise 86% of total primary energy; power demand is only 4%. Primary energy includes purchased fuels, electricity, byproduct fuels, and the energy losses associated with offsite power generation, providing a perspective on the total energy use associated with the industry.

Approximately 10% of the primary energy associated with petroleum refining is lost during energy generation and transport. The main portion of these energy losses (7%) occurs during the generation of electricity at offsite utilities, where the efficiency of generating systems can be as low as 28-30%. Even though fuels represent the main source of energy for the industry, fuel transport losses are only 3% of the total primary energy use.

*Excludes losses

**Includes both offsite and onsite losses.

Figure 4.1 Primary Energy Use in the U.S. Petroleum Refining Industry – 3,838 Trillion Btu

Fuel and Electricity Use

In 1998, the petroleum refining industry's total electricity and fuel consumption was almost 3.5 quads. On average, about 96% of energy use is fuels.

Petroleum refineries supply both fuel and non-fuel products, and unit operations vary considerably in energy use patterns depending on product slate. Figure 4.2 shows the energy consumption patterns across the petroleum and coal products industry.

Fuels such as gasoline, jet fuel, and fuel oils represent 90% of the products from petroleum refineries. The remaining 10% of the products include road oil, asphalt, lubricants, non-fuel coke, waxes, and petrochemicals. By volume, 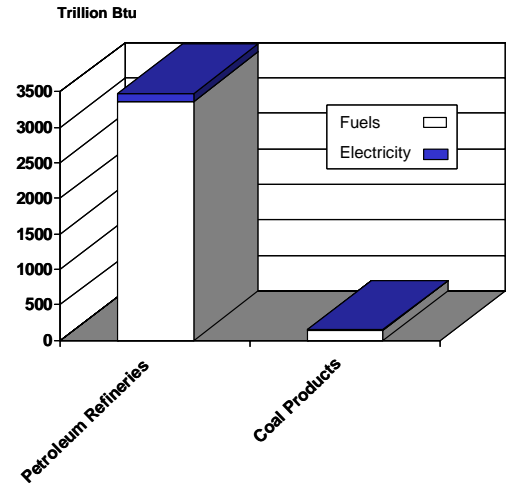refineries produce more gasoline than any other product. In 2000, refineries supplied an average of 17 million barrels of refined products per day. Figure 4.2 shows the energy consumption patterns across the petroleum and coal products industry.

Figure 4-2 Fuel and Electricity Use in the Petroleum and Coal Products Industry (NAICS 324)

Onsite Generation and Electricity Demand

The petroleum refining industry is ranked eleventh in demand for electricity, at 174 TBtu per year. Electricity use only accounts for about 4% of the total energy consumption in refineries.

The petroleum refining industry is the third largest cogenerator in the manufacturing sector. Although electricity represents a small portion of the industry's energy use, 30% of its electricity demand is met through onsite generation, primarily through cogeneration. The industry has substantial demand for steam, making cogeneration an attractive and economic option. Since 1985, cogeneration in the industry has more than tripled. About 118 trillion Btu of energy use is associated with the production of onsite electricity. Figure 4-3 shows a profile of the energy produced onsite.
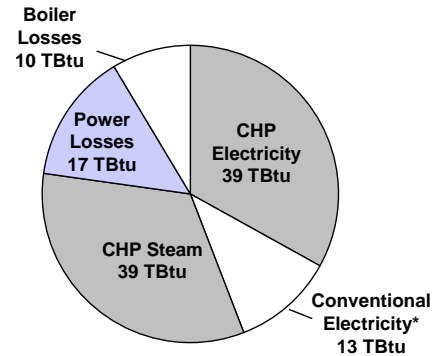
Figure 4-3 Onsite Power Generation Profile for Petroleum Refining

*Onsite power systems producing only electricity.

End Use Profile

The petroleum refining industry consumes energy for process heating and cooling, to power motor-driven systems, and for other purposes. A breakdown of energy end-use is shown in Figure 4-4.
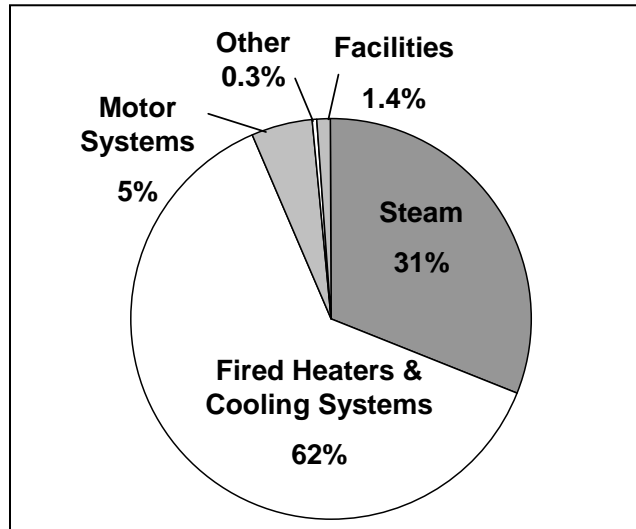
Figure 4-4 Energy Use in the Petroleum Refining Industry: Total Delivered Fuel and Electricity – 3478 Trillion Btu

The petroleum refining industry's largest use of energy is for process heating and cooling, which includes fired heaters, cooling, and steam systems. In 1998, 93% of the industry's energy end use was consumed for this purpose. Motor systems (motor-driven units such as pumps, conveyors, compressors, fans, mixers, grinders, and other materials handling or processing equipment) rank second with 5% of the industry's energy end use. Heating, cooling and lighting of facilities accounts for less than 2% of energy use.

The petroleum refining industry ranks first in fired heater energy use, accounting for 30% of the total energy use for fired heaters by the manufacturing and mining sectors. The industry is also the third largest steam user.

Loss Profile

The energy footprint for the petroleum refining industry (see Appendix A) evaluates end-use and loss patterns to better understand the opportunities for energy efficiency improvements. The general flow of energy and losses within the average petroleum refinery is illustrated in Figure 4-5, which is based on the energy footprint. As shown in Figure 4-5, as much as 28% of the energy that enters the plant is lost prior to use in process units. These losses occur in equipment and distribution systems that are converting energy into work or supplying energy to process operations (see Section 1.0 for an explanation of loss categories). Energy conversion systems account for 42% of the total onsite losses. The remaining onsite losses are evenly distributed among boilers and power generation, distribution, and motor systems.

Figure 4-5 Onsite Energy Loss Profile for the Petroleum Refining Industry (NAICS 324110) Total Onsite Losses – 958 Trillion Btu

Energy losses that occur at the end of the process are not included. These can be substantial, or from 10-50 percent of the energy shown in Figure 4-5 that is delivered to processes.

System-Specific Losses

Figure 4-6 and Table 4-2 shows in detail the energy use and losses for component systems. These provide more insight into the source of energy losses and identify targets for energy-saving opportunities.

As shown in Figure 4-6, the largest energy losses occur in process heating and cooling systems (including fired heaters, steam, and cooling systems). Motor system inefficiencies represent the largest proportional source of system losses. About 52% of the energy input to motor-driven systems is lost in energy generation, distribution and conversion. In terms of Btus, steam system losses are the highest of all individual energy systems (484 trillion Btu). Approximately 45% of the total energy input to steam systems is lost.
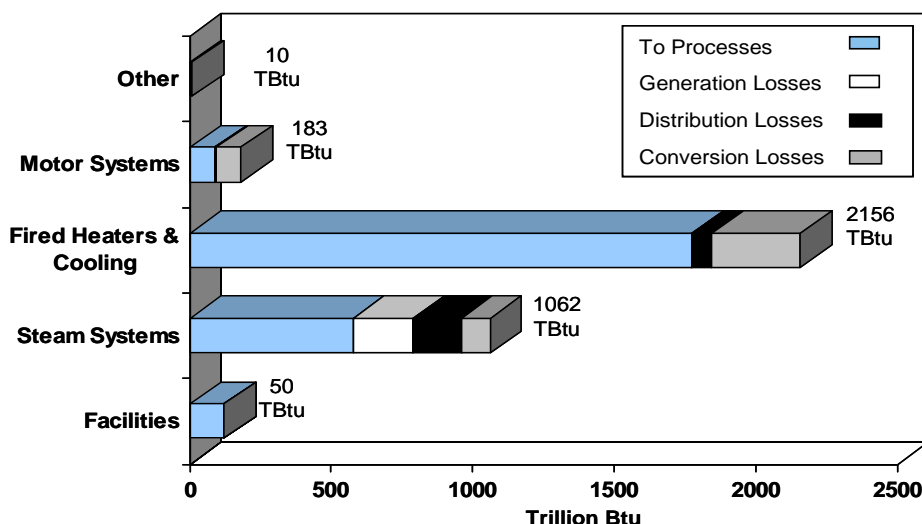
Figure 4-6 Energy End Use and Loss Distributions in Petroleum Refining (NAICS 324110)

Table 4-2 Petroleum Refining Energy Use and Losses (Trillion Btus)						
	To Process/ End Use	Generation Losses	Distribution Losses	Conversion Losses	TOTAL Onsite Losses	Total
Facilities	50	na	na	na		50
Steam Systems	578	212	170	102	484	1062
Fired Heaters & Cooling	1776	na	68	312	380	2156
Motor Systems	89	na	5	89	94	183
Electrochemical					0	0
Other Uses	7	na	na	3	3	10
Onsite Power	(52)*	17	na	na	17	17
Export of Power	1	na	na	na		1
TOTALS	**2501**	**229**	**243**	**506**	**978**	**3479**

*Onsite generated power has been distributed among end-uses and is not included in the totals.
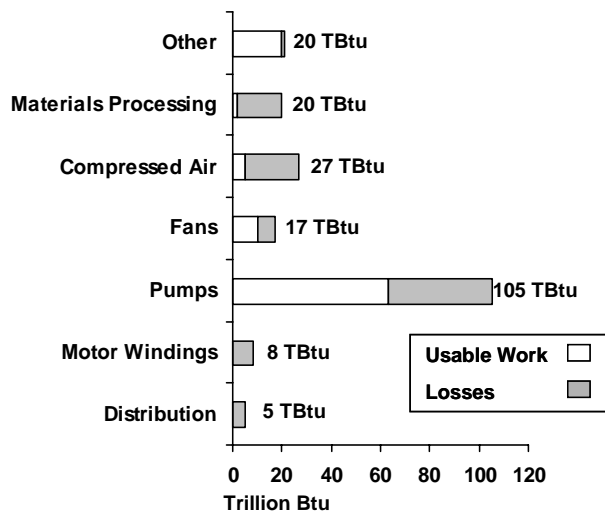
Figure 4-7 Petroleum Refining Motor System Energy Use and Loss Profile

Energy to Steam Systems 1062 TBTU

Overall Steam System Losses ~45%

Figure 4-8 Steam System Use and Loss Profile for the Petroleum Refining Industry

A breakdown of energy use (white) and losses (gray) in motor systems for the petroleum refining industry is shown in Figure 4-7. More than 50% of the energy input for motor systems is lost due to subcomponent inefficiencies. In Btus, the greatest losses are exhibited by pump systems, but the greatest inefficiencies are experienced by compressed air systems and materials processing (e.g., grinding, mixing, crushing). The losses for some for some of these systems are as high as 80-90% of the energy inputs.

The highest motor system losses occur during energy conversion, and these total 89 trillion Btu for the industry. Additional conversion losses take place in motor windings (8 trillion Btu). Distribution energy losses (occurring during transport of electricity to motor systems) are the smallest source of losses (5 trillion Btu). Over 92% of the energy used for motor systems consists of electricity (146 trillion Btu). Fuels only represent 18% of the total energy used for motor systems (32 trillion Btu).

A breakdown of steam use and associated losses for the petroleum refining industry is shown in Figure 4-8. About 45% of energy inputs are lost due to system inefficiencies. Boiler inefficiencies account for the largest losses (20%), followed by distribution losses (16%). Throughout industry, boiler efficiencies range from 55% to 85%, with newer boiler systems at the higher end of the range. The type of fuel used also affects boiler system efficiency. For example, waste heat boilers have much lower overall thermal efficiencies than natural gas-fired boilers.

Steam system distribution losses are also large, and occur in steam traps, valves, and pipes carrying steam to processes and energy conversion units. These losses can vary widely between facilities, and are very dependent on plant configurations, how effectively heat sources and sinks are integrated, and operating and maintenance practices.

5.0 Forest Products Industry (NAICS 321 & 322)

5.1 Overview of the Forest Products Industry

The forest products industry produces thousands of products from renewable raw materials (wood) that are essential for every-day needs in communication, education, packaging, construction, shelter, sanitation, and protection.

Forest Products Industry Sectors

NAICS 321 = Wood Products
 Wood Product Sectors
  Sawmills
  Wood Preservation
  Veneer, Plywood, and Engineered Woods
  Other Wood Products

NAICS 322 = Paper
 Paper Sectors
  Pulp Mills
  Paper Mills
  Newsprint Mills
  Paperboard Mills

The industry is divided into two major categories: Wood Product Manufacturing (NAICS 321) and Paper Manufacturing (NAICS 322). These industries are often grouped together because both rely on the nation's vast forest resources for raw material. In addition, many companies that produce pulp and paper also produce lumber and wood products in integrated operations.

The forest products industry is the third largest consumer of fuels and power in the U.S. industrial sector. The manufacture of wood and paper products is highly energy-intensive, requiring large quantities of thermal energy to convert raw materials to useful products. In addition to fossil fuels, the industry uses wood residues and byproducts (black liquor) to self-generate over 50% of its energy needs.

5.2 Energy Use and Loss Analysis for Forest Products

Overview

Table 5-1 Snapshot of the Forest Products Industry: Energy Use and Rank Within U.S. Manufacturing and Mining		
Category	**Rank**	**Energy (TBtu)**
Primary Energy Use	2	4039
Offsite Losses	2	767
Fuel and Electricity	3	3272
Onsite Losses	1	1473
Steam Generation	1	535
Power Generation	1	67
Energy Distribution	1	401
Energy Conversion	3	470
Facilities	7	76
Energy Export	3	24
Energy Delivered to Processes	3	1699

A snapshot of how the forest products industry ranks in terms of energy use and losses within manufacturing and mining is shown in Table 5-1. The forest products industry ranks among the top three in U.S. manufacturing and mining in nearly every energy end-use category. The industry ranks first in steam use and cogeneration, and second to chemicals in primary energy use.

Figure 5-1 shows the fuel use in the forest products industry. Biomass (black liquor and wood residues) is the primary fuel used by the forest products industry (52%), followed by natural gas (22%). Coal, fuel oils, and other petroleum-based fuels make up the remainder of the industry's fuel use.
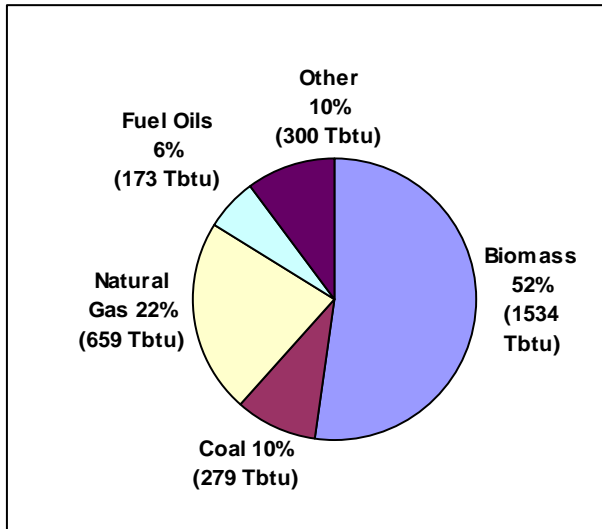
Figure 5-1 Fuel Use in the Forest Products Industry – 2936 Trillion Btu
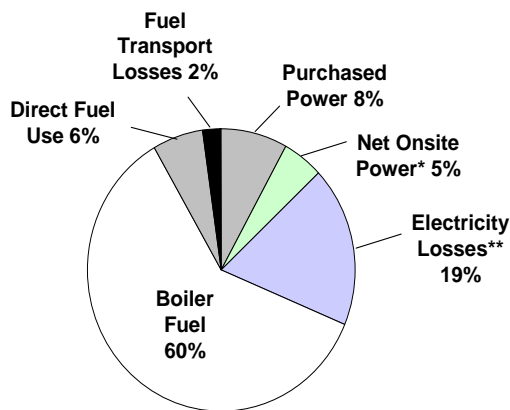
*Excludes losses; includes 24 Tbtu electricity transported offsite.

**Includes both offsite and onsite losses.

Figure 5-2 Primary Energy Use in the U.S. Forest Products Industry – 4039 Trillion Btu

The industry is the largest industrial user of biomass. Biomass used by the forest products industry includes black liquor produced by kraft pulping processes and wood residues collected from wood handling and manufacturing processes. These wood byproducts are burned by the forest products industry to generate steam and electricity.

Improvements in the efficiency of energy systems directly impacts the fuel use distribution. The forest products industry is steam-intensive. Reducing boiler fuel use by increasing boiler and process heat transfer efficiencies can have significant impacts on the industry's fuel use. As steam systems become more efficient, the forest products industry can rely more on biomass fuel, reducing its dependence on fossil fuels.

Primary Energy Use

Primary energy, which includes purchased fuels and electricity, byproduct fuels, and the energy losses associated with offsite power generation and energy supply systems, provides a perspective on the total energy use associated with forest products manufacture. Primary energy inputs to the industry are shown in Figure 5-2. Fuels for boilers comprise 60% and power demand only 13% of the industry's primary energy use.

Electricity generation and fuel transport losses represent 21% of the primary energy consumed by the forest products industry. The bulk of these energy losses occur during the generation of electricity at offsite utilities, where the efficiency of generating systems can be as low as 28-30%. Losses also occur in onsite power generating systems, but thermal efficiency is greatly improved through the use of cogeneration. The forest products industry is the largest cogenerating industry. Over 39% of the forest products industry's electricity demand is currently met by onsite power systems.

Fuel and Electricity Use

Over 3.2 quads of fuel and electricity was consumed by the forest products industry in 1998. On average, about 90% of the industry's primary energy use is fuels, and the remaining 10% is electricity.

The forest products industry produces a wide variety of products. Each forest products sector uses different production processes which results in a variety of energy use patterns across the sectors. Figure 5-3 illustrates the energy consumption patterns across the major sectors of the forest products industry [MECS 1998].

Within the same product sector such as with the pulp mill sector, production processes can also vary depending upon the technology used. For example, pulp can be made by chemical pulping, mechanical pulping, or a combination of the two pulping processes. In addition, the type of chemical pulping process (i.e. kraft, sulfite, etc.) can vary from mill to mill. As a result, energy use patterns can vary dramatically within each forest products sector.

Although sector energy use patterns are difficult to determine it is clear that pulp and paper accounts for a majority (84%) of energy use. The paper industry's largest use of energy is for boiler fuel to provide process steam and onsite electricity generation. In the wood products industry fuel to make steam for lumber drying and curing and electricity to drive equipment such as saws and conveyors consumes the majority of the industry's energy use.

Trillion Btu

Figure 5-3 Fuel and Electricity Use in Selected Forest Products Sectors

Onsite Generation and Electricity Demand

The forest products industry is ranked second in demand for electricity, at 500 TBtu per year. Electricity demand is equal to purchases of electricity, plus electricity generated onsite, minus electricity exported offsite. It provides the most complete picture of actual electricity use. On average, electricity demand accounts for only 15% of energy consumption across the forest products industry.

*Steam or gas turbines not producing steam for process use

Figure 5-4 Onsite Power Generation Profile for Forest

As noted earlier, the forest products industry meets a significant amount of electricity demand through onsite generation. A profile of onsite produced energy is shown in Figure 5-4. About 428 trillion Btu of energy use is associated with the production of onsite electricity. About 88% of electricity produced onsite in the forest products industry comes from cogenerating units, which also generate about 173 trillion Btu in steam. 9 trillion Btu of electricity is produced by renewable solar, wind, hydro, or geothermal power systems and 15 trillion Btu of electricity is generated in conventional steam and gas turbines or other systems that are not producing steam for process use.

End Use Profile

Energy is consumed in forest products manufacturing for process heating and cooling, to power motor-driven systems, and for various other purposes. A breakdown of energy end-use is shown in Figure 5-5. It should be noted that the energy trends shown here are an average for the industry and may not reflect the mill and sector differences discussed earlier.
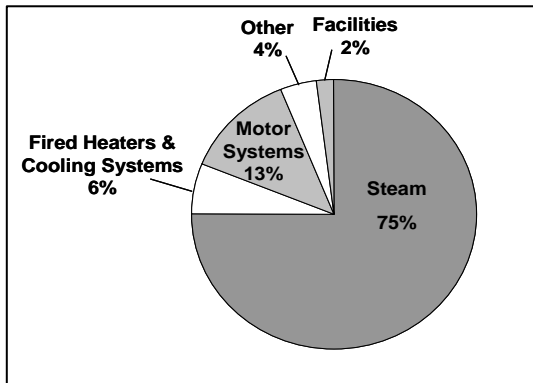
Figure 5-5 Energy End-Use in the Forest Products Industry: Total Delivered Fuel and Electricity – 3272 Trillion Btu

Process heating and cooling systems, particularly those used for drying or evaporation, represent the bulk of energy use in forest products manufacture (81%). These systems include steam systems, fired heaters such as furnaces and reboilers, as well as cooling units. Motor systems, which include motor-driven units such as pumps, conveyors, compressors, fans, mixers, grinders, and other materials handling or processing equipment, rank second with 13% of the forest products energy end use. Heating, cooling and lighting of facilities only accounts for about 2% of energy use.

The forest products industry ranks first in steam and second in motor-driven systems energy end use within the U.S. industrial sector.

Loss Profile

The energy footprint for the forest products industry (see Appendix A) evaluates end-use and loss patterns to better understand the opportunities for energy efficiency improvements. Figure 5-6, which is based on the energy footprint, illustrates the general flow of energy and losses within the average forest products mill. As Figure 5-6 shows, a substantial 45% of the energy that enters the mill is lost prior to use in process units. These losses occur in equipment and distribution systems that are supplying energy to process operations or converting energy to usable work (see Section 1.0 for an explanation of loss categories). The majority of the onsite losses, 41%, are boiler and electricity generation losses. Boiler losses represent 36% or 535 trillion Btu of the total onsite losses. Energy distribution and conversion systems account for the remaining offsite energy losses.

Figure 5-6 Onsite Energy Loss Profile for the Forest products Industry (NAICS 325) Total Onsite Losses – 1474 TBtu

Figure 5-7 Energy End-Use and Loss Distributions in Forest Products NAICS 321 & 322)

System-Specific Losses

Detailed energy use and losses for component systems are summarized in Figure 5-7 and Table 5-2. These provide more insight into the source of energy losses and identify targets for energy-saving opportunities.

As shown in Figure 5-7, the bulk of energy losses occur in steam systems. In terms of trillion Btus, steam system losses are the highest of all energy systems, about 1143 trillion Btu, which represents 47% of the total energy input to steam systems. Proportionally, however, motor system losses are the greatest. About 51% of the energy input to motor-driven systems is lost due to system inefficiencies.

Table 5-2 Forest Products Energy Use and Losses (Trillion Btus)						
	To Process/ End Use	**Generation Losses**	**Distribution Losses**	**Conversion Losses**	**TOTAL Onsite Losses**	**Total**
Facilities	76	na	na	na		76
Steam Systems	1299	535	379	229	1143	2442
Fired Heaters & Cooling	174	na	7	30	37	211
Motor Systems	211	na	16	202	218	429
Electrochemical	2	na	0	0	0	2
Other Uses	12	na	na	9	9	21
Onsite Power	(197)*	67	na	na	67	67
Export of Power	24	na	na	na		24
TOTALS	**1798**	**602**	**402**	**470**	**1474**	**3272**

*Onsite generated power is distributed among end-uses and is not included in the totals.

Figure 5-8 data:

Category	TBtu
Other	44 TBtu
Materials Processing	88 TBtu
Materials Handling	30 TBtu
Refrigeration	20 TBtu
Compressed Air	19 TBtu
Fans	82 TBtu
Pumps	130 TBtu
Motor Windings	18 TBtu
Distribution	16 TBtu

Legend: Usable Work □ Losses ▨

X-axis: 0   50   100   150
Trillion Btu
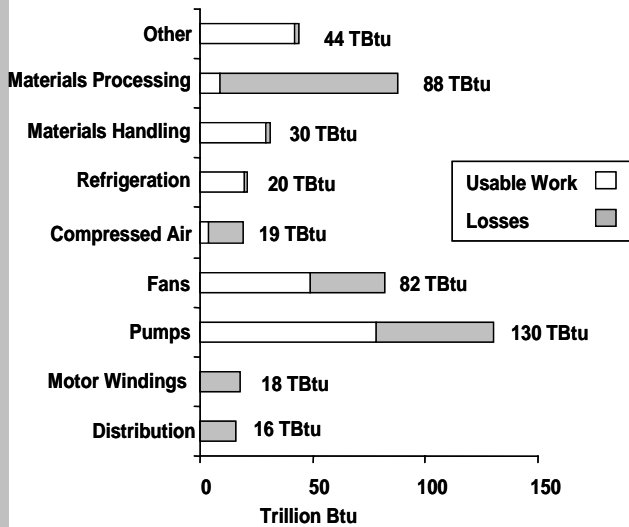
**Figure 5-8 Forest Products Industry
Motor System Energy Use and Loss**

Energy Conversion Losses 9% (229 Tbtu)
Distribution Losses 16% (379 Tbtu)
Boiler Losses 22% (535 Tbtu)
Steam to Processes 53% (1299 Tbtu*)

**Energy to Steam Systems
2442 TBTU**

**Overall Steam System Losses
~47%**

**Figure 5-9 Steam Use and Loss Profile
for the Forest Products Industry**

A motor use profile for forest products is shown in Figure 5-8. The losses, indicated in gray, illustrate the substantial amounts of energy that are wasted due to the inefficiencies of motor-driven equipment. Compressed air and materials processing (e.g., grinding, mixing, crushing) exhibit the greatest proportion of losses. Some of these systems have efficiencies as low as 10-20%.

Motor system energy conversion losses total 184 trillion Btu; conversion losses in motor windings comprise another 18 trillion Btu. The associated energy distribution losses are 16 trillion Btu. Combined losses attributed to motor systems (excluding distribution) are about 202 trillion Btu. Most of the energy used for motor systems is electricity (over 95%), although small amounts of fuel are also employed.

A profile of forest products industry steam use and associated losses is shown in Figure 5-9. About 47% of energy inputs are lost due to system inefficiencies. The bulk of these occur in the boiler, where thermal efficiencies range from as low as 55% to as high as 85%, depending upon the age of the boiler and fuel burned. Wood byproduct or hog fuel boilers, for example, will have much lower overall thermal efficiencies than natural gas-fired boilers.

Distribution losses are also significant. These occur in steam traps, valves, and pipes carrying steam to processes and energy conversion units. These losses can vary widely between facilities, and are very dependent on plant configurations, how effectively heat sources and sinks are integrated, and operating and maintenance practices.

6.0 Iron and Steel Industry (NAICS 333111)

6.1   Overview of the Iron and Steel Industry

Steel is an integral part of the U.S. infrastructure, providing the foundation for construction (bridges, buildings), transportation systems (railroads, cars, trucks), and utility systems (municipal water systems, power systems). It is also the material of choice for such diverse applications as military equipment, food storage, appliances, and tools. Traditionally valued for its strength, steel has also become the most recycled material, with two-thirds of U.S. steel now produced from scrap.

Steel is made by two different routes, both of which are energy-intensive. An integrated steel mill produces molten iron in blast furnaces using a form of coal known as coke, which is either produced on site or purchased. This iron is used as a charge to produce steel in a basic oxygen furnace (BOF). An electric arc furnace steel producer, also known as a mini-mill, uses electric arc furnaces (EAFs) to produce steel from steel scrap and other iron-bearing materials.

Steel is one of the most energy-intensive industries in the United States and is the fourth largest consumer of fuels and power in manufacturing. The manufacture of iron is energy-intensive, particularly the reduction of iron ore to pig iron in the blast furnace. The efficiency of the processes and equipment used to produce iron and steel is also constrained by thermodynamic, kinetic, or transport limitations, and operating conditions may be severe (high temperatures, corrosive environments). All these factors contribute to proportionally high energy use per ton of product.

6.2   Energy Use and Loss Analysis for Iron and Steel

Table 6-1 Snapshot of the Iron and Steel Industry: Energy Use and Rank Within U.S. Manufacturing and Mining		
Category	Rank	Energy (TBtu)
Primary Energy Use	4	2056
Offsite Losses	8	384
Fuel and Electricity	4	1672
Onsite Losses	5	378
Steam Generation	6	19
Power Generation	6	6
Energy Distribution	5	62
Energy Conversion	4	291
Facilities	9	56
Energy Export	*	~0
Energy Delivered to Processes	4	1238

* Not available

Overview

A snapshot of how the iron and steel industry ranks in terms of energy use and losses within manufacturing and mining is shown in Table 6-1. The industry ranks among the top five in U.S. manufacturing and mining in a number of energy end-use categories. The industry is a large user of fired heaters and ranks sixth in energy used for motor-driven systems.

Coke and coal are the primary fuels used by the iron and steel industry (38%), followed by natural gas (27%), byproduct fuels produced onsite (23%), and electricity (9% excluding losses). Small amounts of fuel oil and other fuels make up the remainder. The main by-product fuels are coke oven gas and blast furnace gas (coal-based in origin).
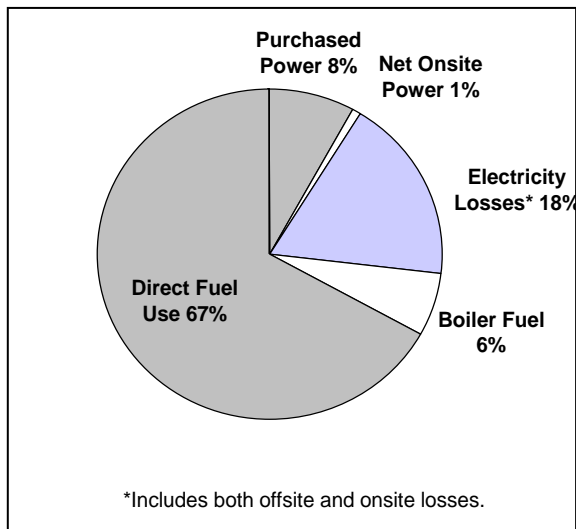
**Figure 6-1 Primary Energy Use in the
U.S. Iron and Steel Industry -
2056 Trillion Btu**

Primary Energy Use

Primary energy, which includes purchased fuels and electricity, byproduct fuels, and the energy losses associated with offsite power generation and energy supply systems, provides a perspective on the total energy use associated with the manufacture of iron and steel. Primary energy inputs to the industry are shown in Figure 6-1. Fuels for boilers and direct-fired systems comprise two-thirds of total primary energy; power demand is about 9%.

A considerable 18% of the primary energy associated with the manufacture of iron and steel is lost during energy generation and transport. Almost all of these energy losses occur during the generation of electricity at offsite utilities, where the efficiency of generating systems can be as low as 28-30%. Losses also occur in onsite power generating systems, but thermal efficiency is greatly improved through the use of cogeneration. Only about 1% of iron and steel industry electricity demand is currently met by onsite power systems.

Fuel and Electricity Use

About 1.7 quads of fuels and electricity were consumed by the iron and steel industry in 1998. On average, about 90% of energy use is fuels, and the remainder is electricity (10%).

As discussed earlier, the industry has two main routes for making steel. Figure 6-2 illustrates the energy consumption patterns across the two major sectors of the industry (electric losses are excluded). Overall, the production of steel via the integrated route is responsible for 75% of fuel and 36% of electricity consumption in the industry. EAF steelmaking accounts for the remainder – 25% of total industry fuel consumption and 64% of industry electricity consumption.
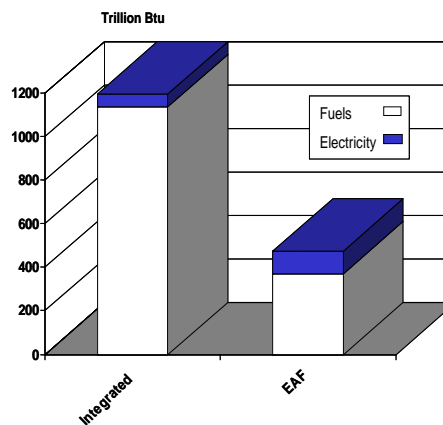
**Figure 6-2 Fuel and Electricity Use in the
Integrated and EAF Sub-sectors**

Onsite Generation and Electricity Demand

The iron and steel industry is ranked ninth in demand for electricity, at 181 TBtu per year. Electricity demand is equal to purchases of electricity, plus electricity generated onsite, minus electricity exported offsite. It provides the most complete picture of actual electricity use. On average, electricity use only accounts for about 10% of energy consumption across the industry. However, EAF steelmaking is very electricity-intensive and accounts for almost 30% of total electricity consumption in the steel industry.

As noted earlier, the steel industry meets some amount of electricity demand through onsite generation. About 18 trillion Btu of energy use is associated with the production of onsite electricity. Most of the electricity produced onsite in the steel industry comes from cogenerating units.

End Use Profile

Energy is consumed in the manufacture of iron and steel for process heating (reduction of FeO, melting, reheating), to power motor-driven systems such as rolling mills, and for various other purposes. A breakdown of energy end-use is shown in Figure 6-3.

Figure 6-3 Energy End-Use in the Iron and Steel Industry: Total Delivered Fuel and Electricity - 1672 Trillion Btu
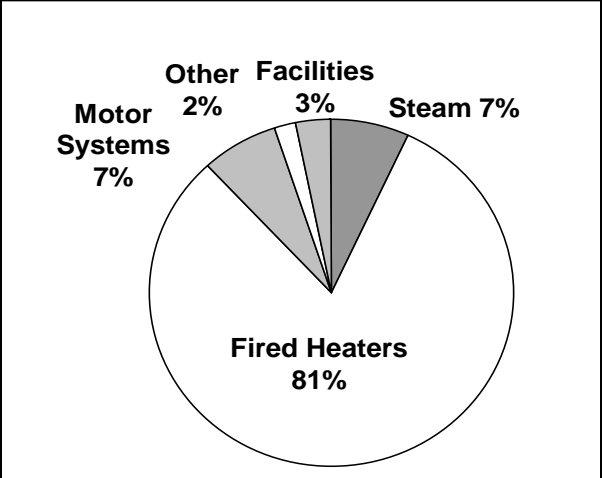
Fired heaters (excluding boilers), particularly ironmaking blast furnaces and other furnaces, represent the bulk of energy use in the industry (81%). Boilers contribute another 7% to total energy use for process heating. Motor systems, which include motor-driven units such as rolling mills, pumps, conveyors, fans, and materials handling equipment, represent another 7% of energy use. Heating, cooling and lighting of facilities only accounts for about 3% of energy use.

The industry ranks seventh in steam use within manufacturing and mining and sixth in the use of motor-driven systems in the industrial sector.

**Figure 6-4 Onsite Energy Loss Profile
for the Iron and Steel Industry:
Total Onsite Losses - 378 Trillion Btu**

Loss Profile

The energy footprints for the iron and steel industry (see Appendix A for footprints for the integrated sector, the EAF sector, and the industry overall) evaluate end-use and loss patterns to better understand the opportunities for energy efficiency improvements. Figure 6-4, which is based on the overall industry energy footprints, illustrates the general flow of energy and losses within the average steel mill. As Figure 6-4 shows, a substantial 23% of the energy that enters the plant is lost prior to use in process units. These losses occur in equipment and distribution systems that are supplying energy to process operations or converting energy to usable. The majority of onsite losses in the iron and steel industry occur in energy conversion systems.

System-Specific Losses

Detailed energy use and losses for component systems are summarized in Table 6-2 and Figure 6-5. The figure and table provide more insight into the source of energy losses and identify targets for energy-saving opportunities.

As shown in Figure 6-5, the bulk of energy losses occur in fired heaters and cooling systems, which includes furnaces and other heaters. In terms of trillion Btus, these heating and cooling losses total about 241 trillion Btu, which represents about 18% of the total energy input to these systems. Proportionally, however, motor system losses are the greatest. Nearly 70% of the energy input to motor-driven systems is lost due to system inefficiencies.

Table 6-2 Iron and Steel Industry Energy Use and Losses (Trillion Btus)						
	To Process/ End Use	Generation Losses	Distribution Losses	Conversion Losses	TOTAL Onsite Losses	Total
Facilities	56	na	na	na	na	56
Steam Systems	56	19	15	10	44	100
Fired Heaters & Cooling	1131	na	42	199	241	1372
Motor Systems	36	na	5	80	85	121
Electrochemical	4	na	na	1	1	5
Other Uses	11	na	na	1	1	12
Onsite Power	(18)*	6	na	na	6	6
Export of Power	0	na	na	na	na	0
TOTALS	**1294**	**25**	**62**	**291**	**378**	**1672**

*Onsite generated power is distributed among end-uses and is not included in the totals.
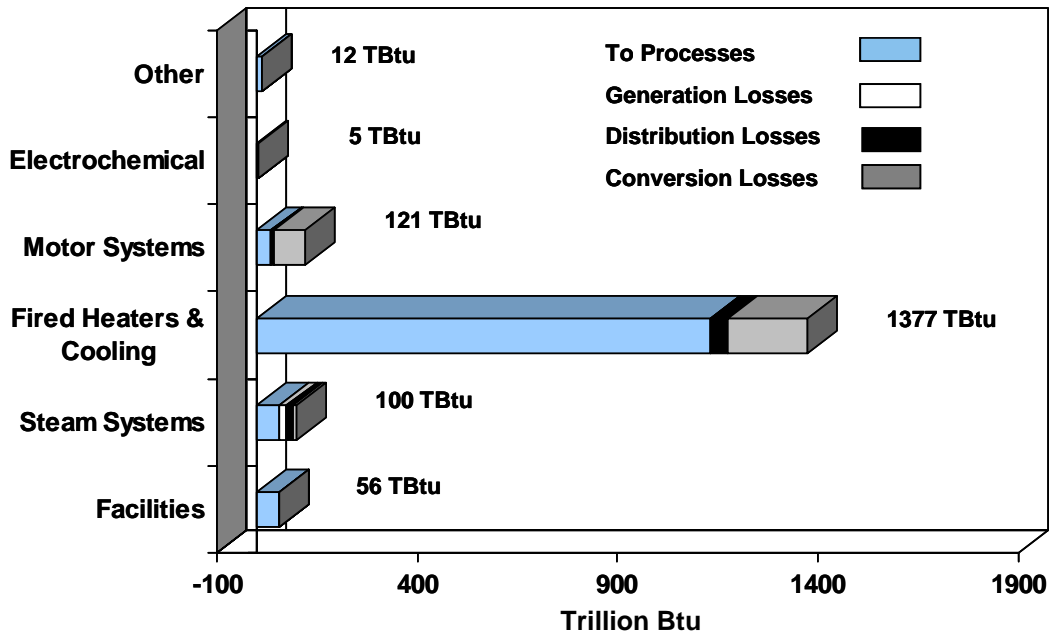
**Figure 6-5 Energy End-Use and Loss Distributions in the
Iron and Steel Industry**
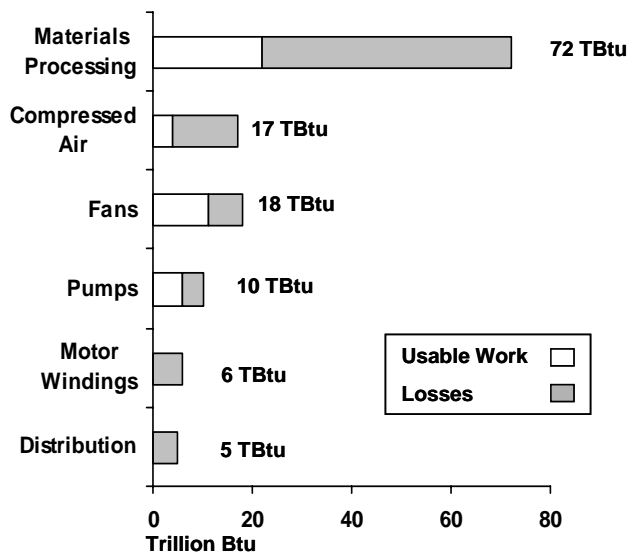
**Figure 6-6 Iron and Steel Industry Motor
System Use and Loss Profile**

A motor use profile for the iron and steel industry is shown in Figure 6-6. The losses, indicated in gray, illustrate the substantial amounts of energy that are wasted due to the inefficiency of some motor-driven equipment. Compressed air and materials processing (e.g., grinding, mixing, crushing) exhibit the greatest proportion of losses; some of these systems have efficiencies as low as 10-20%.

Motor system energy conversion losses total 74 trillion Btu; conversion losses in motor windings comprise another 6 trillion Btu. The associated energy distribution losses are 5 trillion Btu. Combined losses attributed to motor systems (excluding distribution) are about 80 trillion Btu. Most of the energy used for motor systems is electricity (over 90%).

**Energy to Steam Systems
1645 TBTU**

**Overall Steam System Losses
~44%**

**Figure 6-7 Steam Use and Loss Profile
for the Iron and Steel Industry**
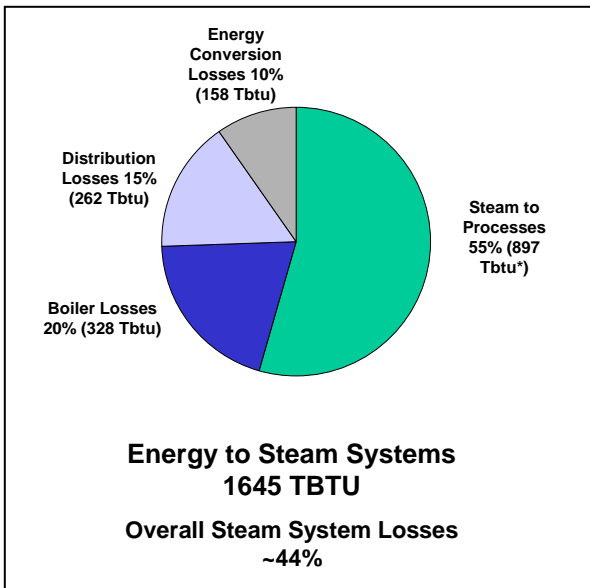
A profile of the iron and steel industry's steam use and associated losses is shown in Figure 6-7. About 44% of energy inputs are lost due to system inefficiencies. The bulk of these occur in the boiler, where thermal efficiencies range from as low as 55% to as high as 85%, depending upon the age of the boiler and fuel burned. Waste heat boilers, for example, will have much lower overall thermal efficiency than natural gas-fired boilers.

Distribution losses are also significant. These occur in steam traps, valves, and pipes carrying steam to processes and energy conversion units. These losses can vary widely between facilities, and are very dependent on plant configurations, how effectively heat sources and sinks are integrated, and operating and maintenance practices.

7.0 Mining Industry (NAICS 212)

7.1 Overview of the Mining Industry

The mining industry plays an important role in the U.S. energy supply and economy. In 2000, mined materials such as uranium and coal represented 72% of energy inputs for electric power production, and process materials of mineral origin accounted for 5% of the nation's GDP. On average, 47,000 pounds of material have to be mined per person each year, making the industry indispensable to our quality of life. In 2000, 35% of the 1.07 billion tons of coal produced had to be mined from underground, and the remainder was obtained from the surface. That same year, mining of crude industrial ore and crude metal ore totaled 3.1 billion pounds and 1.3 billion pounds respectively. The U.S. mining industry directly employs more than 320,000 people.

Mining Industry Sub-sectors
Oil and Gas Extraction
Mining Except Oil and Gas   • Coal Mining   • Metal Ore Mining   • Nonmetallic mineral mining & quarrying
Support Activities for Mining

Some mining operations are very energy intensive. For example, rock crushing, drilling, and grinding require very large mechanical forces, hence large amounts of energy.

The mining industry (NAICS 21) includes various sub-sectors. The metal and mineral mining sector accounts for a large portion (50%) of the whole mining industry shipments. The following analysis refers only to mining activities which exclude oil and gas extraction energy use and losses.

7.2 Energy Use and Loss Analysis for the Mining Industry

Overview

A snapshot of how the mining industry ranks in terms of energy use and losses within manufacturing and mining is shown in Table 7-1. The mining industry energy use ranking is diverse with most falling in the moderate category. The industry ranks sixth in primary energy use, fuel and electricity use, and onsite losses. The mining sector ranks fourth in offsite losses and fifth in energy conversion losses.

Table 7-1 Snapshot of the Mining Industry: Energy Use and Rank Within U.S. Manufacturing and Mining		
Category	**Rank**	**Energy (TBtu)**
Primary Energy Use	6	1273
Offsite Losses	4	520
Fuel and Electricity	6	753
Onsite Losses	6	311
Steam Generation	12	0.8
Power Generation	4	16
Energy Distribution	12	13
Energy Conversion	5	281
Facilities	*	*
Energy Export	5	0.01
Energy Delivered to Processes	6	442

* Not available

Trillion Btu

Figure 7-1 Mining Industry Energy Supply By Energy Source (NAICS 212) – 753 Trillion Btu

Fuel oil represents the largest portion of the mining industry's total energy supply (35%) followed by electricity (32%). The remaining energy needs are satisfied by natural gas (22%), coal (10%) and gasoline (2%). Figure 7-1 shows the breakdown of the mining industry's energy supply by energy source. The mining industry is very fuel-intensive, and uses large quantities of diesel fuel for service trucks and other hauling equipment. Electricity is used for fans, drills, crushers and conveyors, all of which are relatively energy-inefficient.

Primary Energy Use

Figure 7-2 shows the primary energy inputs to the mining industry. Fuels for boilers and direct-fired systems comprise 37% of total primary energy; power demand is 20%. Primary energy includes purchased fuels, electricity, byproduct fuels, and the energy losses associated with offsite power generation, providing a perspective on the total energy use associated with the industry.

As much as 43% of the primary energy associated with the mining industry is lost during energy generation and transport. Offsite utilities, responsible for electricity generation, are accountable for the main portion of these energy losses (42%). The efficiency of generating systems at these offsite utilities can be as low as 28-30%. Even though fuels represent the main source of energy for the mining industry, fuel transport losses are only 1% of the total primary energy use.

*Excludes losses

**Includes both offsite and onsite losses.
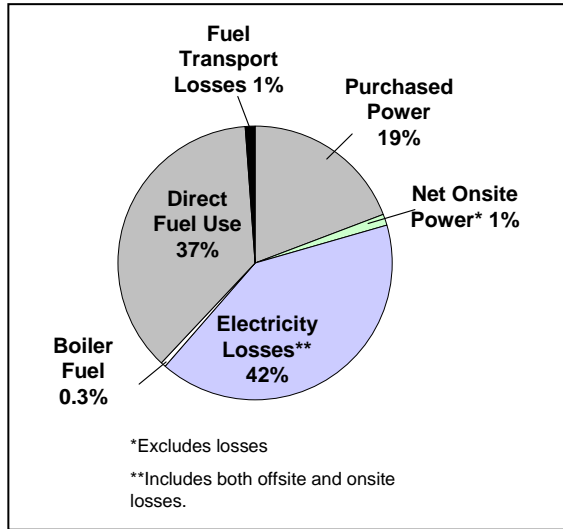
Figure 7-2 Primary Energy Use in the U.S. Mining Industry – 1273 Trillion Btu

Fuel and Electricity Use

The total energy supply for the mining industry is in excess of 0.75 quads of energy. Fuels account for almost 68 % of the industry's purchased energy. Energy patterns across the mining industry vary primarily due to differences in mining methods (underground or surface mining), nature and location of ore or mineral deposits, and the size, depth and grade of minerals. Coal, for example, is mined using both surface and underground methods. On the other hand, 96% of industrial ores come from surface mines.

Figure 7-3 illustrates the percent energy use across mining industry sectors. Due to the large volume of production, coal mining accounts for the most energy use. However, mineral mining is much more energy intensive (Btu/ton).
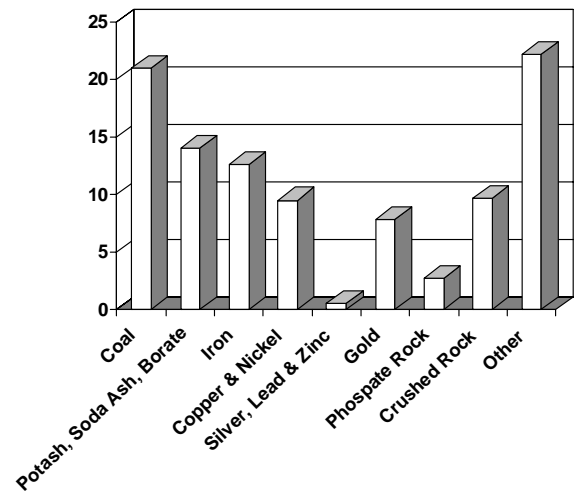
Figure 7-3 Fuel and Electricity Use in Selected Mining Sectors

Onsite Generation and Electricity Demand

The mining industry ranks third in electricity demand, only topped by the chemical and forest product industries.

Data is not available on cogeneration of electricity in the mining sector, although it is most likely small. Conventional electricity generating systems are used to supply about 19 trillion Btu per year. Power losses from onsite generation are as much as 16 trillion Btu, while boiler losses only amount to 1 trillion Btu. Figure 7-4 shows a profile of the energy produced onsite for the mining industry.
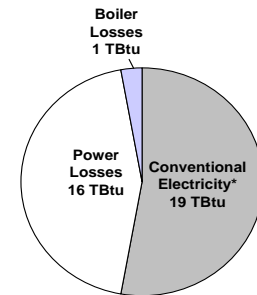
Figure 7-4 Onsite Power Generation Profile for the Mining Industry (NAICS 212)
*Onsite power systems producing only electricity.

End Use Profile

The mining industry consumes energy for direct heating, to power motor-driven machinery, and for other purposes. A breakdown of energy end-use is shown in Figure 7-5.

The mining industry's largest use of energy for heat and power is classified under "other" uses. This includes crushing, grinding, and drilling equipment, and transport of materials, which are all energy intensive. Very little data is available on the exact breakdown of energy use among these processes, as the mining industry is not part of the MECS done by the U.S. Department of Energy. Over 61% of the industry's energy end use is reflected in the "other" category. Motor systems (pumps and material handling equipment) rank second with 25% of the total energy end use. Direct heating represents 13% of the industry's energy end use.
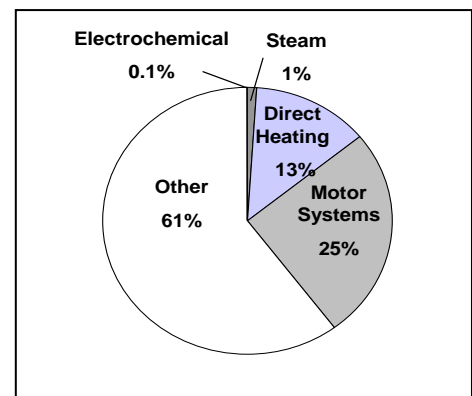
Figure 7-5 Onsite Energy Loss Profile for the Mining Industry (NAICS 312) Total Onsite Losses – 311 Trillion Btu

Loss Profile

Appendix A includes an energy footprint for the mining industry which evaluates end-use and loss patterns to better understand the opportunities for energy efficiency improvements. Based on the energy footprint, Figure 7-6 shows a breakdown of the mining industry's onsite losses and general flow of energy. As shown in the figure, as much as 42% of the energy that enters the plant is lost prior to use in process units. These losses occur in equipment and distribution systems that are converting energy into work or supplying energy to process operations (see Section 1.0 for an explanation of loss categories). Energy conversion systems account for the bulk of the total onsite losses (62%). Motors represent 31% of the mining industry's onsite losses, and the remaining losses occur in boiler systems and energy distribution.
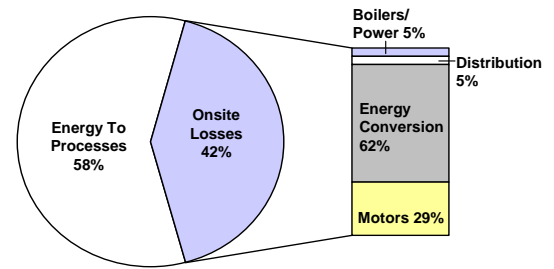
Figure 7-6 Energy End Use and Loss Distributions in Mining (NAICS 212)

System-Specific Losses

Figure 7-7 and Table 7-2 show in detail the energy use and losses for component systems, providing more insight into the source of energy losses and identifying targets for energy-saving opportunities.

As shown in the figure, the largest energy losses occur in the category shown as 'other". Because the mining sector is not part of the DOE MECS, little solid data is available on the exact end-uses and losses within the 'other' category. They are assumed to be mostly due to low efficiency of crushing, grinding, drilling and transport equipment. Motor system inefficiencies represent the largest proportional source of system losses. About 48% of the energy input to motor-driven systems is lost in energy distribution and conversion. Steam use for mining operations is small, but approximately 36% of the total energy input to steam systems is lost.
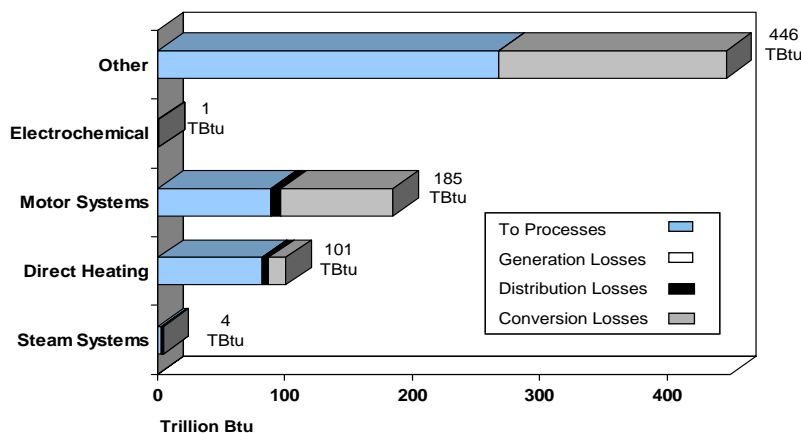
Figure 7-7 Energy End Use and Loss Distribution in Mining (NAICS 212)

	To Process/ End Use	Generation Losses	Distribution Losses	Conversion Losses	TOTAL Onsite Losses	Total
Facilities	0	na	na	na		0
Steam Systems	3	1	0.3	0.3	1.6	4
Direct Heating	82	na	5	14	19	101
Motor Systems	89	na	8	88	96	185
Electrochemical	1	na	na	na	0	1
Other Uses	268	na	na	178	178	446
Onsite Power	(19)*	16	na	na	16	16
Export of Power	0.01	na	na	na		0.01
TOTALS	**442**	**17**	**13**	**281**	**311**	**753**

Table 7-2 Mining Energy Use and Losses (Trillion Btus)

*Onsite generated power is distributed among end-uses and is not included in the totals.
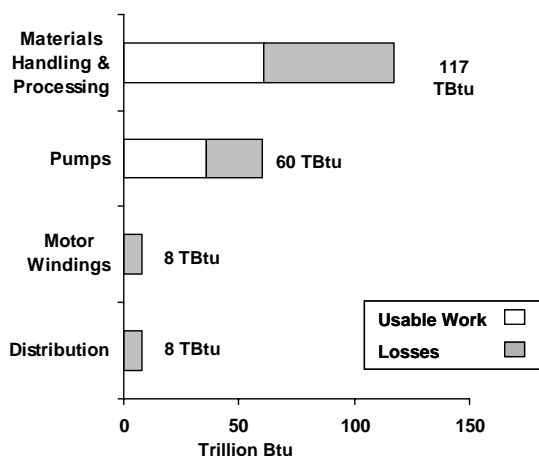
Figure 7-8 Mining Industry Motor System Energy Use and Loss Profile

Figure 7-8 shows a breakdown of energy use (white) and losses (gray) in motor systems for the mining industry. Almost 50% of the energy input for motor systems is lost through subcomponent inefficiencies. In Btus, The greatest losses are exhibited by materials processing systems, with inefficiencies as high as 90%. Pump system inefficiencies are also considerable, and are about 40%.

The highest motor system losses occur during energy conversion, and total 89 trillion Btu for the industry. Additional conversion losses take place in motor windings (8 trillion Btu), and distribution losses total an additional 8 trillion Btu. The fuel-mix for motor systems in the industry consists of 82% electricity and 18% fuel.

**Energy to Steam Systems
4 TBtu**

**Overall Steam System Losses
~36%**

**Figure 7-9 Steam System Use and Loss Profile
for the Mining Industry**
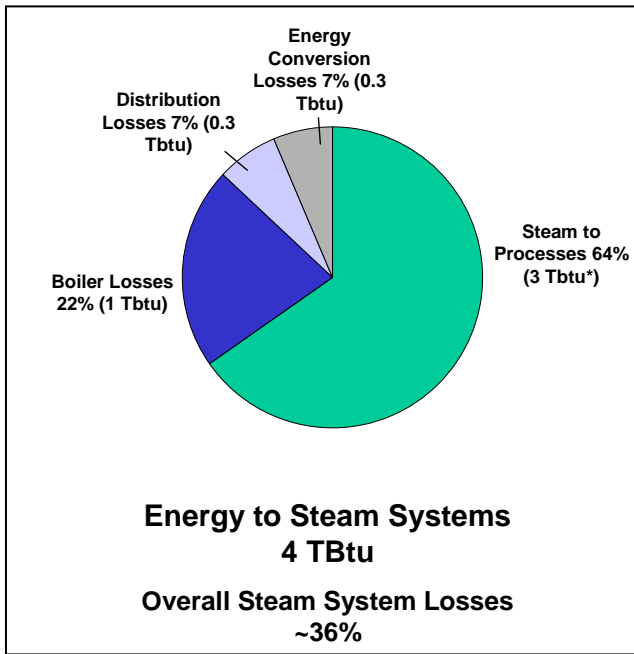
A breakdown of steam use and associated losses for the mining industry is shown in Figure 7-9. About 36% of energy inputs are lost due to system inefficiencies. Boiler inefficiencies account for the largest losses (22%), and the remaining losses are evenly distributed between distribution and energy conversion (0.3% each). However, steam represents a very small portion of the industry's overall end-use (as previously shown in Figure 7-5).

Steam system distribution losses occur in steam traps, valves, and pipes carrying steam to processes and energy conversion units. These losses vary based on site configuration, how effectively heat sources and sinks are integrated and operating and maintenance practices.

8.0 Food and Beverage Industry (NAICS 311 and 312)

8.1 Overview of the Food and Beverage Industry

The food and beverage industry is an integral component of the U.S. economy, transforming livestock and agricultural products into intermediate and final food and beverage products. The food and beverage industry is one of the largest manufacturing sectors, accounting for $570 billion in shipments, or about 14 percent of total manufacturing shipments. Increasing globalization of agriculture markets and companies has led to increased trade for food and beverage products. Exports in 2002 reached approximately $29 billion, with imports of $31 billion.

Food and Beverage Industry Sectors
Animal Food
Grain and Oilseed Milling
Sugar and Confectionery Products
Fruit and Vegetable Preserving and Specialty Food
Dairy Products
Meat Products
Seafood Product Preparation and Packaging
Bakeries and Tortillas
Other Foods
Beverages
Tobacco Products

The food and beverage industry is highly diversified, and produces thousands of different products. Processing facilities range from small plants to large industrial units, and most plants produce more than one product. The industry is divided into sectors that reflect major product categories.

The food and beverage industry is one of the largest consumers of fuels and power in the U.S. industrial sector. The manufacture of foods and beverages often requires significant quantities of thermal energy to convert raw materials to useful products. The efficiency of the processes and equipment used to produce foods and beverages is often constrained by thermodynamic, kinetic, or transport limitations, and operating conditions may be harsh. All these factors contribute to high energy use per pound of product.

8.2 Energy Use and Loss Analysis for Food and Beverage

Overview

A snapshot of how the food and beverage industry ranks in terms of energy use and losses within manufacturing and mining is shown in Table 8-1. The food and beverage industry ranks among the top six in U.S. manufacturing and mining in nearly every energy end-use category. The industry is a large user of steam and fired heaters.

Natural gas is the primary fuel used by the food and beverage industry (67%), followed by coal (17%). Lesser amounts of petroleum products, natural gas liquids (NGL), liquefied petroleum gases (LPG), and other fuels make up the remainder.

Table 8-1 Snapshot of the Food and Beverage Industry: Energy Use and Rank Within U.S. Manufacturing and Mining		
Category	**Rank**	**Energy (TBtu)**
Primary Energy Use	5	1685
Offsite Losses	3	529
Fuel and Electricity	5	1156
Onsite Losses	4	407
Steam Generation	4	121
Power Generation	5	7
Energy Distribution	4	113
Energy Conversion	6	166
Facilities	6	87
Energy Export	3	4
Energy Delivered to Processes	5	658

*Excludes losses; includes 4 Tbtu electricity export.

**Includes both offsite and onsite electricity generation.

Figure 8-1 Primary Energy Use in the U.S. Food and Beverage Industry - 1685 Trillion Btu

Primary Energy Use

Primary energy, which includes purchased fuels and electricity, byproduct fuels, and the energy losses associated with offsite power generation and energy supply systems, provides a perspective on the total energy use associated with food and beverage manufacture. Primary energy inputs to the industry are shown in Figure 8-1. Fuels for boilers and direct-fired systems comprise about 53% of total primary energy; power demand is about 15%.

A considerable 32% of the primary energy associated with food and beverage manufacture is lost during energy generation and transport. The bulk of these energy losses occur during the generation of electricity at offsite utilities, where the efficiency of generating systems can be as low as 28-30%. Losses also occur in onsite power generating systems, but thermal efficiency is greatly improved through the use of cogeneration. About 9% of food and beverage industry electricity demand is currently met by onsite power systems. The food and beverage industry is the fifth largest cogenerating industry.

Fuel and Electricity Use

Nearly 1.2 quads of fuels and electricity were consumed by the food and beverage industry in 1998. On average, about 79% of energy use is fuels, and the remainder is electricity (21%).

The food and beverage industry makes a vast variety of different products and uses many different processes in their manufacture. As a result, energy use patterns can vary significantly across sectors.

Figure 8-2 illustrates the energy purchase patterns across major sectors of the industry. Overall, grain milling, fruit and vegetable processing, and meat product production are responsible for the majority of energy purchases. Meat product production consumes the most electricity.
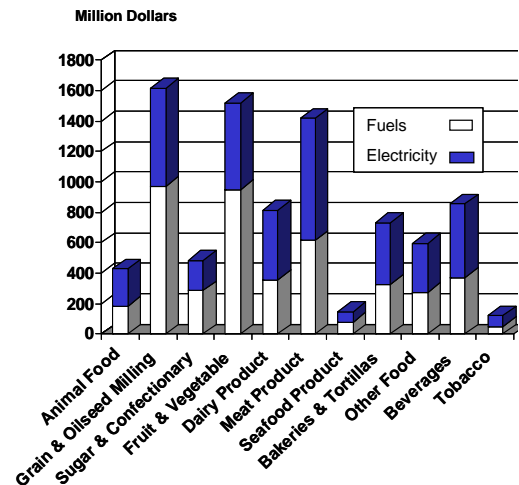
Source: ASM/DOC 2001

Figure 8-2 Fuel and Electricity Purchases in Selected Food and Beverage Industry Sectors, 2001

Onsite Generation and Electricity Demand

The food and beverage industry is ranked fourth in demand for electricity, at 258 trillion Btu per year. Electricity demand is equal to purchases of electricity, plus electricity generated onsite, minus electricity exported offsite. It provides the most complete picture of actual electricity use. On average, electricity use only accounts for about 21% of energy consumption across the industry. However, some sectors are more electricity-intensive than others.

As noted earlier, the food and beverage industry meets a moderate amount of electricity demand through onsite generation. A profile of onsite produced energy is shown in Figure 8-3. About 52 trillion Btu of energy use is associated with the production of onsite electricity. About 95% of electricity produced onsite in the food and beverage industry comes from cogenerating units, which also generate about 24 trillion Btu in steam. A small amount of electricity is produced in conventional steam and gas turbines or other systems that are not producing steam for process use.
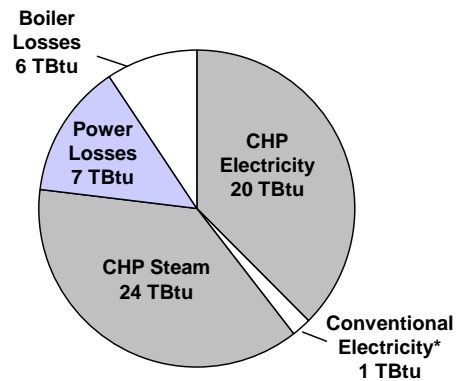
Figure 8-3 Onsite Power Generation Profile for Food and Beverage

*Steam or gas turbines not producing steam for process use

End Use Profile

Energy is consumed in food and beverage manufacture for process heating and cooling, to power motor-driven systems, and for various other purposes. A breakdown of energy end-use is shown in Figure 8-4. It should be noted that the energy trends shown here are an average for the industry and may not reflect sector differences.

Process heating and cooling systems represent the bulk of energy use in food and beverage manufacture (77%). These include steam systems, fired heaters such as ovens and furnaces, and cooling units. Motor systems, which include motor-driven units such as pumps, conveyors, compressors, fans, mixers, grinders, and other materials handling or processing equipment, rank second with 12% of energy use. Heating, cooling and lighting of facilities accounts for about 8% of energy use.

The industry ranks fourth in steam use within manufacturing and mining, and also fourth in the use of fired heaters. Food and beverage manufacture is also the fifth largest user of motor-driven systems in the industrial sector.
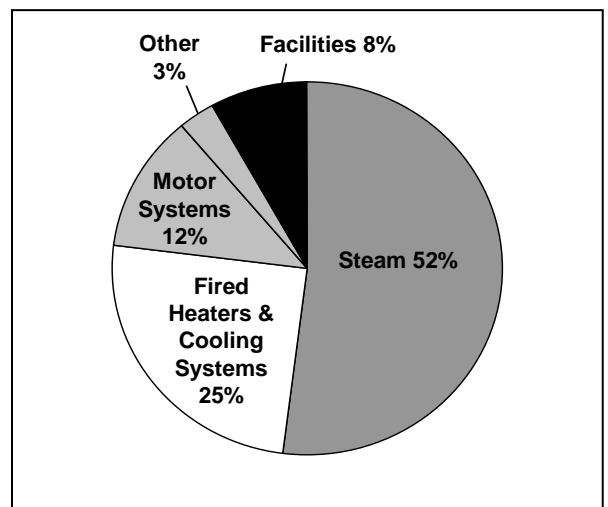
Figure 8-4 Energy End-Use in the Food and Beverage Industry: Total Delivered Fuel and Electricity - 1156 Trillion Btu

Loss Profile

The energy footprint for the food and beverage industry (see Appendix A) evaluates end-use and loss patterns to better understand the opportunities for energy efficiency improvements. Figure 8-5, which is based on the energy footprint, illustrates the general flow of energy and losses within the average food and beverage plant.
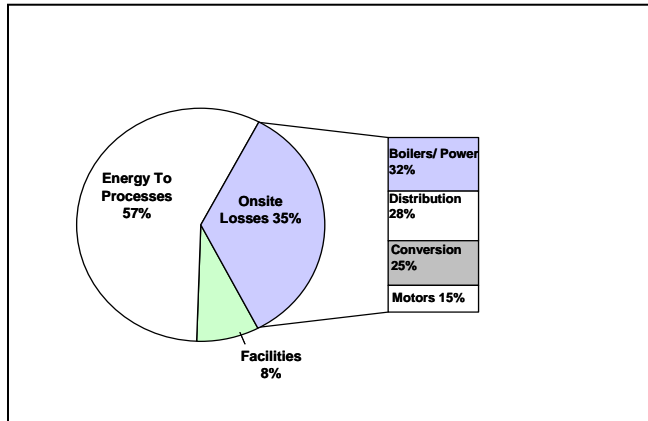
Figure 8-5 Onsite Energy Loss Profile for the Food and Beverage Industry (NAICS 311 and 312) Total Onsite Losses - 407 Trillion Btu

As Figure 8-5 shows, a substantial 35% of the energy that enters the plant is lost prior to use in process units. These losses occur in equipment and distribution systems that are supplying energy to process operations or converting energy to usable work (see Section 1.0 for an explanation of loss categories). Total energy conversion losses account for about 40 percent of onsite losses, including those of motor systems (15%) and other systems (25%). The remaining onsite losses are split nearly evenly between boilers and power generation and energy distribution.

System-Specific Losses

Detailed energy use and losses for component systems are summarized in Figure 8-6 and Table 8-2. These provide more insight into the source of energy losses and identify targets for energy-saving opportunities.
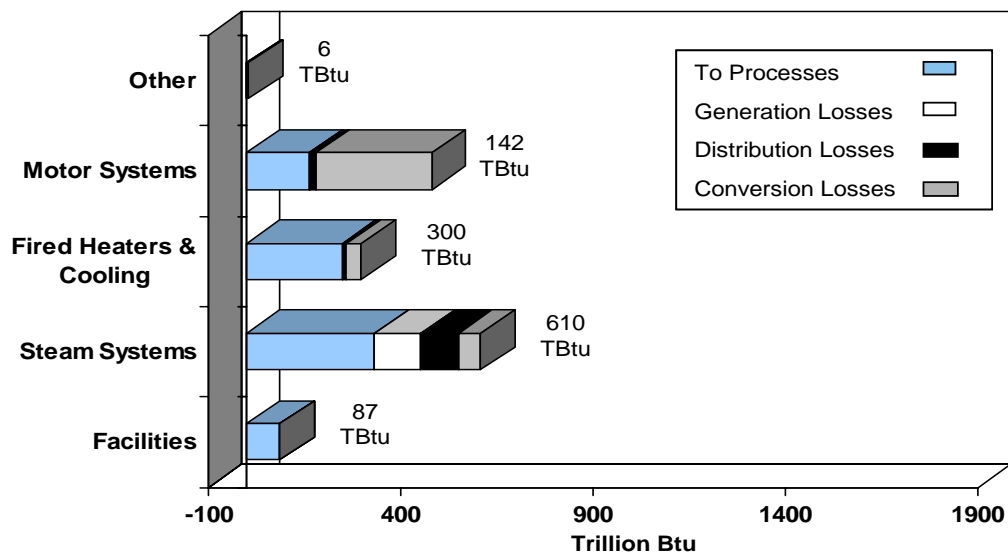
Figure 8-6 Energy End-Use and Loss Distribution in Foods and Beverages (NAICS 311 and 312)

As shown in Figure 8-6, the bulk of energy losses occur in process heating and cooling, which includes steam systems as well as fired heaters and cooling or refrigeration units. In terms of trillion Btus, steam system losses are the highest of all energy systems, about 277 trillion Btu, which represents about 45% of the total energy input to steam systems. Proportionally, however, motor system losses are even higher. About 49% of the energy input to motor-driven systems is lost due to system inefficiencies.

Table 8-2 Food and Beverage Energy Use and Losses (Trillion Btus)						
	To Process/ End Use	Generation Losses	Distribution Losses	Conversion Losses	TOTAL Onsite Losses	Total
Facilities	87	na	na	na		87
Steam Systems	333	121	97	59	277	610
Fired Heaters & Cooling	250	na	10	40	50	300
Motor Systems	73	na	6	63	69	142
Other Uses	2	na	na	4	4	6
Onsite Power	(21)*	7	na	na	7	7
Export of Power	4	na	na	na		4
TOTALS	**749**	**128**	**113**	**166**	**407**	**1156**

*Onsite power generation is distributed among end-uses and is not included in the totals.
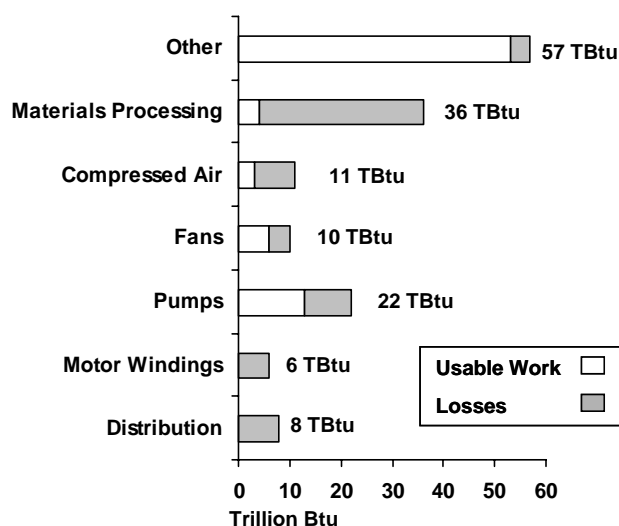
Figure 8-7 Food and Beverage Industry Motor System Energy Use and Loss Profile

A motor use profile for food and beverage is shown in Figure 8-7. The losses, indicated in gray, illustrate the substantial amounts of energy that are wasted due to the inefficiency of some motor-driven equipment. Compressed air and materials processing (e.g., grinding, mixing, crushing) exhibit the greatest proportion of losses. Some of these systems have efficiencies as low as 10-20%.

Motor system energy conversion losses total 57 trillion Btu; conversion losses in motor windings comprise another 6 trillion Btu. The associated energy distribution losses are 6 trillion Btu. Combined losses attributed to motor systems (excluding distribution) are about 63 trillion Btu. Most of the energy used for motor systems is electricity (over 90%), although small amounts of fuel are also employed.

Energy Conversion Losses 10% (59 Tbtu)

Distribution Losses 16% (97 Tbtu)

Steam to Processes 55% (333 Tbtu*)

Boiler Losses 20% (121 Tbtu)

**Energy to Steam Systems
610 TBtu**

**Overall Steam System Losses
~45%**

**Figure 8-8 Steam Use and Loss Profile for the
Food and Beverage Industry**
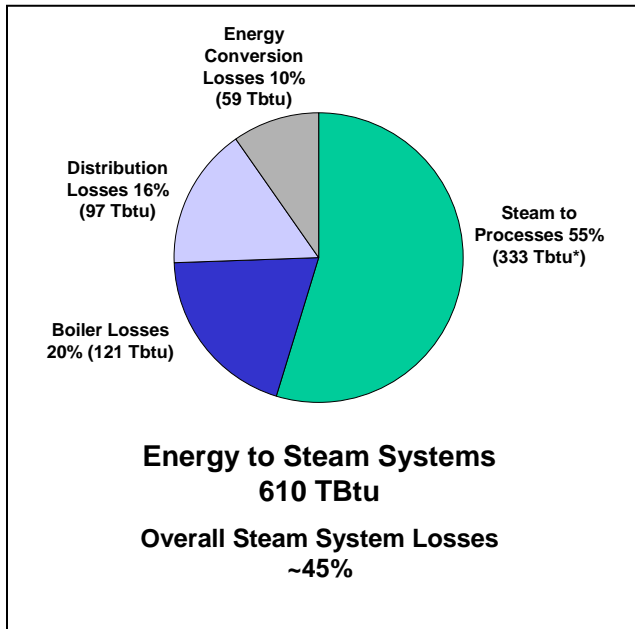
A profile of food and beverage industry steam use and associated losses is shown in Figure 8-8. About 45% of energy inputs are lost due to system inefficiencies. The bulk of these occur in the boiler, where thermal efficiencies range from as low as 55% to as high as 85%, depending upon the age of the boiler and fuel burned. Waste heat boilers, for example, will have much lower overall thermal efficiency than natural gas-fired boilers.

Distribution losses are also significant. These occur in steam traps, valves, and pipes carrying steam to processes and energy conversion units. These losses can vary widely between facilities, and are very dependent on plant configurations, how effectively heat sources and sinks are integrated, and operating and maintenance practices.

9.0 Fired Systems

9.1 Fired Systems Overview

Fired systems (heating and cooling systems) play a crucial role in today's manufacturing processes. Fired heaters supply heat to produce basic materials and commodities, and cooling systems provide cooling and refrigeration for processes where achieving lower temperatures is vital. Almost 39% of the total energy end use of the manufacturing and mining sectors is accounted for by fired systems.
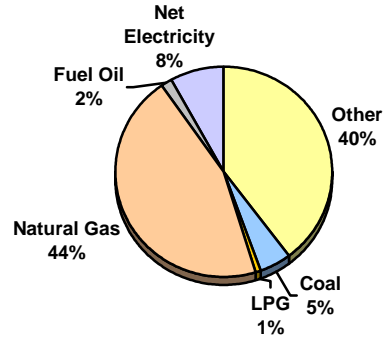
Figure 9-1 End Use Fuel Consumption for Fired Heaters and Cooling Systems

Natural gas accounts for 44% of the energy end use in fired systems. Electricity and coal are also an important energy source for these systems, and together represent 13% of the total end use. Figure 9-1 shows the fuel mix used for fired heaters and cooling systems in manufacturing.

9.2 Energy Use and Loss Analysis for Fired Systems

Energy to Fired Heating and Cooling Systems 7279 TBTU
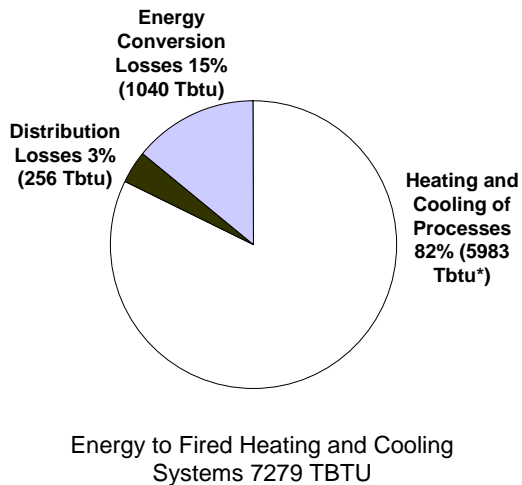
Figure 9-2 Profile of Energy Use and Losses in Fired Systems

Fired Systems Energy Use

The U.S. manufacturing and mining energy use for fired systems is 7.3 quads (including onsite losses.). Of these, only 255 trillion Btu are consumed by cooling systems. Approximately 3% of the energy delivered to these systems is lost during distribution and an additional 15% is lost in the conversion of fuel to useful work. Fired heating equipment includes direct or indirect-fired heaters such as furnaces, dryers, calciners, evaporators, condensers, and other direct-fueled heating systems. Cooling systems include cooling towers and ponds, heat exchangers, cryogenic equipment, chillers, and other equipment.

Table 9-1 Industries Ranked by Use of Fired Heaters

Sector	Fired Heaters	
	TBtu	Rank
Petroleum Refining	2156	1
Iron & Steel Mills	1372	2
Chemicals	1207	3
Food & Beverage	300	4
Cement	296	5
Mining	204	6
Glass & Glass Products	204	7
Forest Products	196	8
Heavy Machinery	182	9
Fabricated Metals	182	10
Alumina & Aluminum	164	11
Foundries	147	12
Transportation Equipment	94	13
Computers, Electronics	65	14
Textiles	62	15
Plastics & Rubber	60	16

Energy Use for Fired Heaters

In 1998, the total U.S. manufacturing and mining energy use for fired heaters was 6.7 quads. The petroleum refining sector is the largest energy consumer for fired heaters, accounting for 31% of the total. The iron and steel, and chemicals industries are the second and third largest consumers with 20% and 17% of the total energy use, respectively. Together, these three industries consume as much as 67% of the total manufacturing and mining energy use for fired heaters. The reason behind this is that all three industries rely heavily in obtaining high processing temperatures to convert raw materials. Table 9-1 shows an industry ranking based on the use of fired heaters.

Fired Systems as a Percentage of Total Energy End Use

Figure 9-3 shows the energy used for fired systems as a percentage of the total energy end use for each industry. More than 81% of the iron and steel industry's energy end use is consumed in these systems (ironmaking and blast furnaces). Energy systems are a major portion of energy use in the petroleum refining (62%), and includes the use of thermal cracking processes for fuels and chemicals production. The industry is a large producer of ethylene, which is accomplished primarily in a pyrolysis furnace.
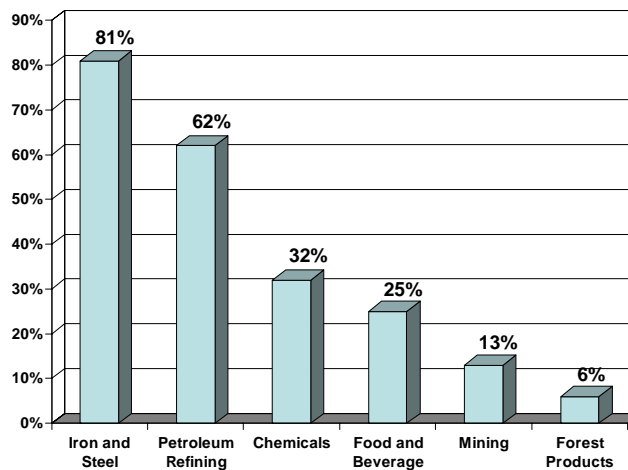
Figure 9-3 Fired Systems
Energy Use as a Percentage of Total Energy End Use

Fired Systems Losses

Figure 9-4 shows the energy use and losses in fired systems for the six largest energy consuming industries. As previously shown in Table 9-1, petroleum refining is the largest consumer of energy for these systems, and experiences the largest losses as well. In all six industries, energy conversion represents the bulk of the system's losses.
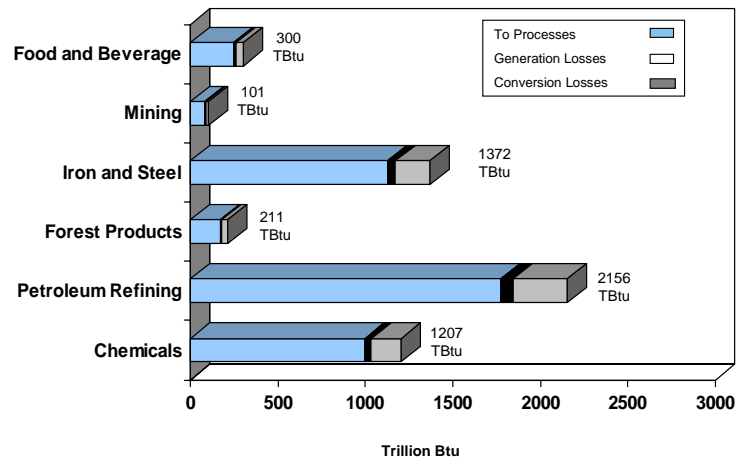
**Figure 9-4 Fired Systems
Energy Use and Losses by Industry**

Figure 9-5 and Table 9-2 show in greater detail the fired systems losses for each industry. The total losses in attributed to these end-users in manufacturing and mining are 1.3 quads. The six largest users account for 77% of the total losses for this catetory (937 Trillion Btu).
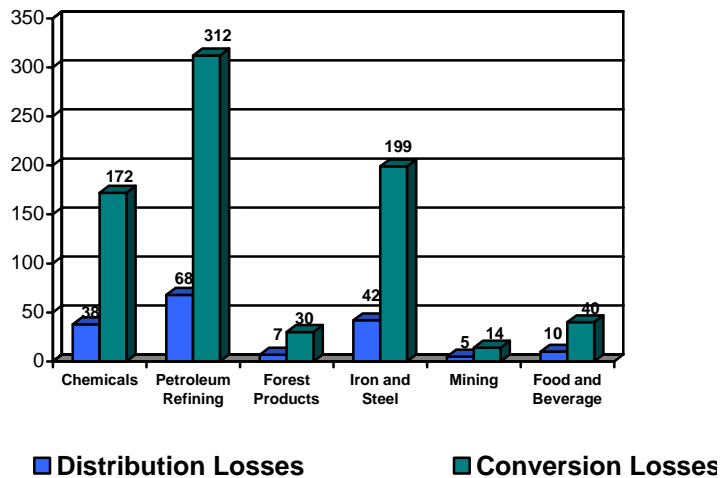
Figure 9-5 Fired Heaters and Cooling System Losses

Table 9-2 Energy Delivered and Losses of Fired Systems						
	Chemicals	Petroleum Refining	Forest Products	Iron and Steel	Mining	Food and Beverage
To Processes	997	1776	174	1131	82	250
Generation Losses	0	0	0	0	0	0
Distribution Losses	38	68	7	42	5	10
Conversion Losses	172	312	30	199	14	40
Industry Totals	**1207**	**2156**	**211**	**1372**	**101**	**300**

10.0 Steam Systems Energy Use and Loss Analysis

10.1 Steam Systems Overview

Steam is used to heat raw materials, to generate electricity, to provide heat for buildings, and to power equipment. In the U.S., the total cost of fuels used to feed boilers for steam generation is estimated at $18 billion (1997 dollars). The age of steam systems in operation varies widely along with thermal efficiency which depends on age and configuration as well as fuel type.. In the top six energy intensive industries alone, steam system inefficiencies are responsible for 2.7 quads of energy losses, which occur during steam generation, distribution, and energy conversion. Overall, more than 60% of the boiler population is concentrated in five of the industries that are focus of this report.
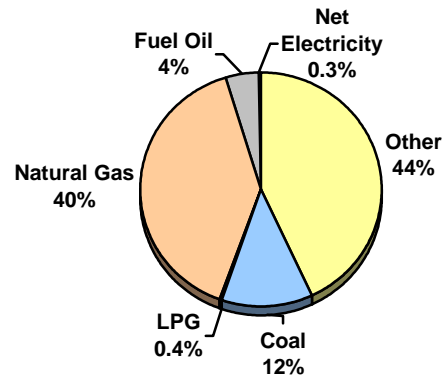
Figure 10-1 End Use Fuel Consumption for Boilers

In the manufacturing sector, byproduct fuels (fuel gas, black liquor, petroleum byproducts) account for 43% of energy inputs to boilers. Almost 40% of the fuel used in boilers for steam generation is obtained from natural gas. Coal is the third largest energy source, accounting for 12% of the total fuel used [MECS 1998]. Figure 10-1 shows the boiler fuel mix for steam generation used in manufacturing.

10.2 Energy Use and Loss Analysis for Steam
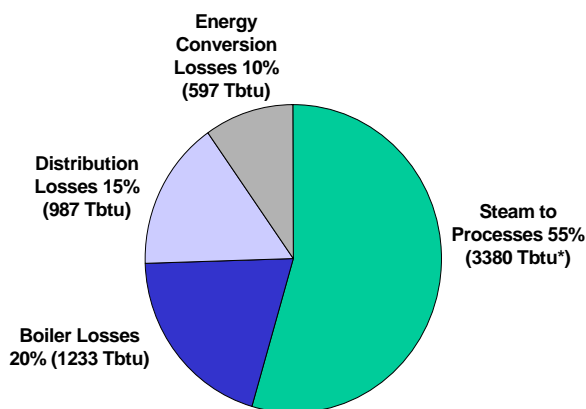
Energy to Steam Systems: 6201 Tbtu

Figure 10-2 Steam Use and Losses in Manufacturing and Mining

Steam Energy Use

Steam systems represent 35% of the total energy end use of the manufacturing and mining sectors, 6.2 quads (including losses). Only 55% of this energy is used in processes, and the remaining 45% is lost due to inefficiencies in boilers, distribution, and energy conversion systems. Boilers, with inefficiencies ranging from 55 - 85%, account for the largest losses. Distribution losses are the second largest, and these occur in steam traps, valves, and pipes where steam is transported throughout the plant site. In some industries, miles of pipe may be used to convey steam to process units.

Energy conversion losses occur in heat exchangers, steam injectors and other equipment where steam heat is used to facilitate product conversion. Figure 10-2 shows a breakdown of steam use and losses for manufacturing and mining.

Table 10-1 Industry Ranked by Steam Use		
	Steam Use	
Sector	Tbtu	Rank
Forest Products	2442	1
Chemicals	1645	2
Petroleum Refining	1061	3
Food & Beverage	610	4
Textiles	132	5
Transportation Equipment	112	6
Iron & Steel Mills	96	7
Plastics & Rubber	81	8
Computers, Electronics	53	9
Alumina & Aluminum	41	10
Fabricated Metals	35	11
Heavy Machinery	25	12
Foundries	22	13
Glass & Glass Products	5	14
Mining	4	15
Cement	1	16

Note: Steam use includes small amount of electrically-generated steam (e.g., coils, rods).

The forest products sector is the largest steam user, consuming over 38% of the total steam used in manufacturing and mining. Steam uses in the forest products industry include kiln drying, digesters, wood chip preparation, black liquor recovery, and bleaching. The chemicals and petroleum refining industries are the second and third largest users, consuming 26% and 17% of the total, respectively. In these two industries, steam is an input to nearly every single production process and unit operation. The food and beverage industry is another significant steam user (10%) relying heavily on steam for processing, sterilization, and cleaning. Together, these four industries account for more than 90% of the total energy used for steam systems. Table 10-1 shows an industry ranking based on the energy use of steam.

Steam as a Percentage of Total Energy End Use

Figure 10-3 shows the energy used for steam systems as a percentage of the total energy end use for each industry. The forest products industry is the largest steam user of the U.S. manufacturing and mining sectors, accounting for 75% of the industry's energy end use. The chemicals, petroleum refining, and food and beverage industries are also large steam users.
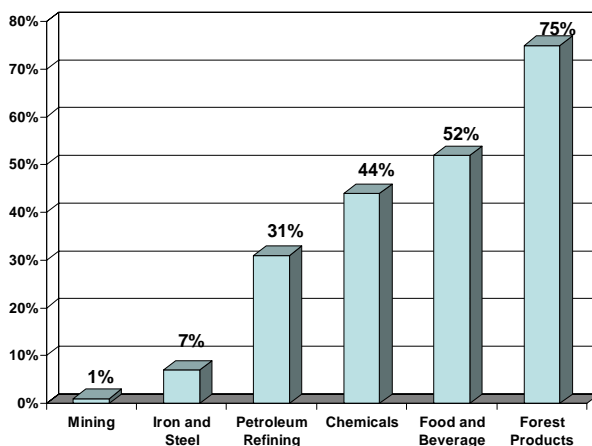
Figure 10-3 Steam Energy Use as a Percentage of Total Energy End Use

Steam Losses

Figure 10-4 shows the energy use and losses in steam systems for the six largest energy consuming industries. As previously shown in Table 10-1, the forest products industry is the largest steam energy consumer, and possesses the largest losses as well. In all six industries, boiler inefficiencies are responsible for nearly half of steam system losses.
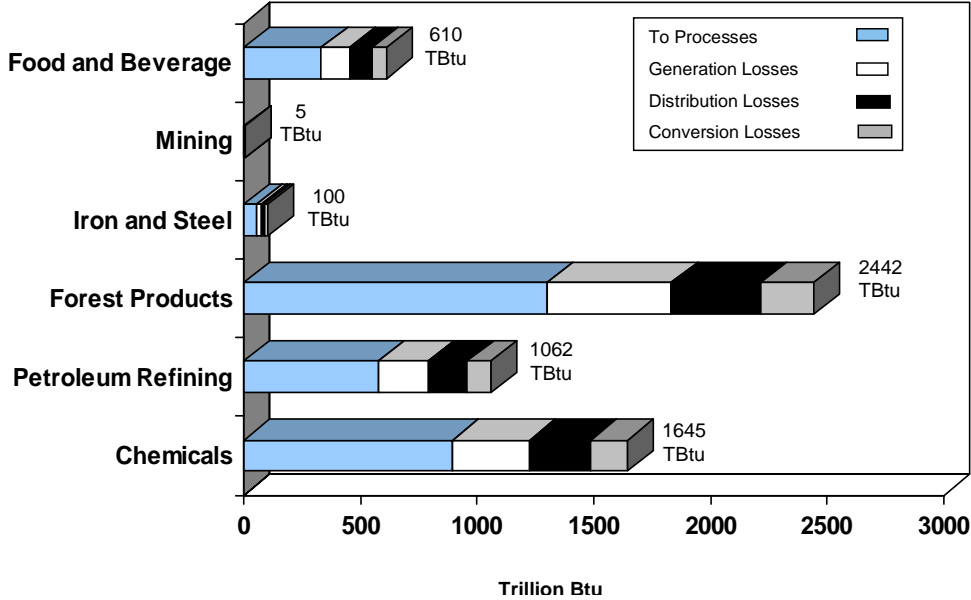
Figure 10-4 Steam Energy Use and Losses by Industry

Figure 10-5 and Table 10-2 show, in greater detail, the components of steam system losses for each of the six industries. These six industries represent 96% of steam system losses and are significant targets for potential steam-system improvements in manufacturing and mining (2.7 out of 2.8 quads). Steam generation represents 45% of these losses, followed by energy conversion (34%), and distribution (21%). The forest products industry has the largest losses in all three categories, and accounts for 42% of all steam losses in manufacturing and mining.
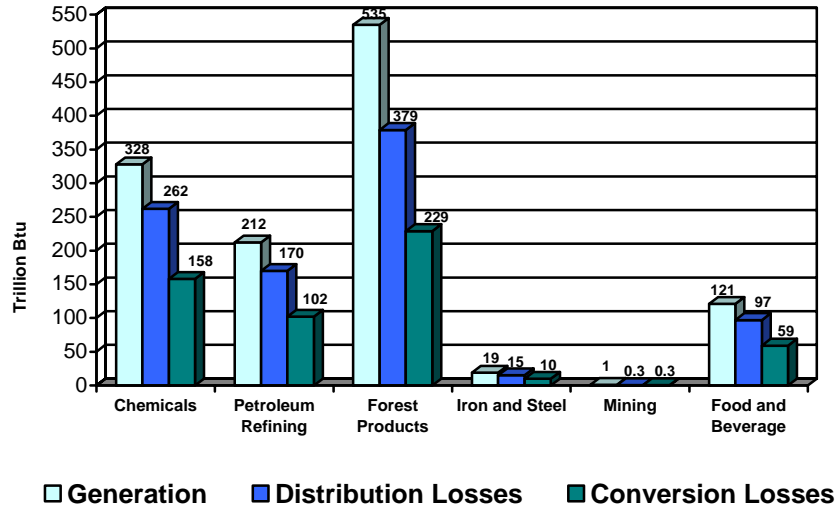
Figure 10-5 Steam Losses – 2697 Trillion Btu

Table 10-2 Energy Delivered and Losses of Steam Systems						
	Chemicals	**Petroleum Refining**	**Forest Products**	**Iron and Steel**	**Mining**	**Food and Beverage**
To Processes	897	578	1299	56	3	333
Generation Losses	328	212	535	19	1	121
Distribution Losses	262	170	379	15	0.3	97
Conversion Losses	158	102	229	10	0.3	59
Industry Totals	**1645**	**1062**	**2442**	**100**	**4.6**	**610**

11.0 Onsite Power Generation Systems

11.1 Onsite Power Generation Overview

Onsite power generation systems allow industries to satisfy their power demand while reducing energy costs and in most cases reducing greenhouse gas emissions. Combined heat and power (CHP) accounts for 92% of the total power generated onsite. The remaining power generation is obtained from gas turbines, combustion turbines, and renewable electricity generating technologies (solar, geothermal, bioenergy, ocean, wind, hydropower, and hydrogen). CHP systems are used to produce power and then recover the resultant waste heat for use in processes. This recovered heat can be used to produce mechanical energy, heat or cool water, make steam, or for humidity control in buildings. Many of the currently used power generation systems exhibit low efficiencies ranging from 28-39%. On average, roughly two thirds of the fuel used for electricity generation is lost in the process. CHP systems help reduce these losses, by recovering waste heat and increasing overall thermal efficiency. The use of cogeneration is rising, but is still limited by high capital costs and permitting issues. In the manufacturing and mining sectors, cogeneration only represents 12% of the total power, and 8% of the total steam demand. Given that power systems require large capital investments, some industries are reluctant to adopt onsite generation systems. In addition, for CHP to be practical, the industry must also be a large user of steam or have another use for the recovered waste heat.

11.2 Energy Use and Loss Analysis
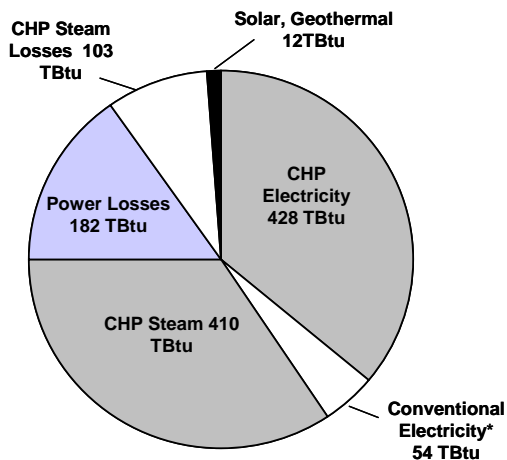
Figure 11-1 Onsite Power Generation and Loss Profile for manufacturing and Mining

*Onsite power systems producing only electricity.

CHP Vs Conventional Power

Onsite electricity generation meets 13% of the total manufacturing and mining electricity demand. CHP accounts for 428 trillion Btu, out of the total 468 trillion Btu of power generated onsite by the manufacturing and mining sectors. The proportionally large use of CHP can be attributed to the high thermal efficiencies of these systems, which are as much as 30% greater than conventional power systems. Figure 11-1 shows an onsite power generation and loss profile for manufacturing and mining.

Table 11-1 Industry Ranked By CHP Use		
	CHP Use	
Sector	Tbtu	Ranking
Forest Products	161	1
Chemicals	148	2
Petroleum Refining	39	3
Food & Beverage	24	4
Iron & Steel Mills	18	5
Mining	3	7
Alumina & Aluminum	3	6
Cement	2	8
Plastics & Rubber	1	9
Heavy Machinery	0	10
Textiles	0.5	11
Foundries	small	*
Glass & Glass Products	0	*
Other	0	*

* Not available.

The forest products industry is the largest user of combined heat and power, followed closely by the chemicals industry. These two industries alone represent 77% of the total manufacturing and mining CHP energy use. Petroleum refining, the food and beverage industry, and Iron and steel, are much smaller users, but are significant when compared to the whole manufacturing and mining group. All four industries are large consumers of byproduct fuels, and large steam and/or electricity users, and logically can take more advantage of the benefits of cogeneration. Table 11-1 shows an industry ranking based on the use of CHP.

CHP as a Percent of Total Electricity Demand

Figure 11-2 shows the total electricity and CHP demand by industry. When compared to other industries, forest products is not only the largest CHP user, but it also satisfies the largest amount of its electricity needs with CHP (32%). The petroleum refining and chemicals industries also meet a considerable portion of their electricity requirements with CHP (22% and 20% respectively).
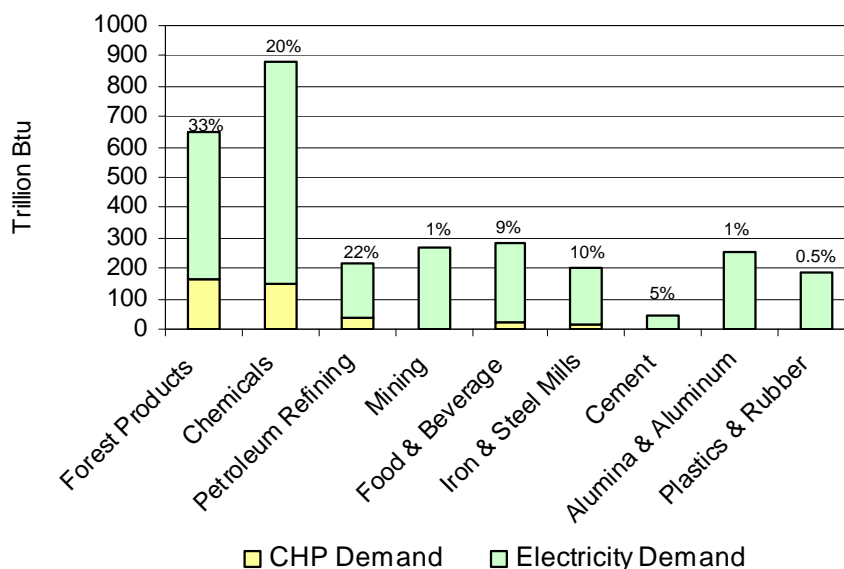
Figure 11-2 CHP as a Percentage of Total Electricity Demand for the Top CHP Users

CHP System Losses

The top three CHP users are the same three industries that satisfy the largest portion of their electricity needs with CHP (Forest Products, Chemicals, and Petroleum Refining). The largest losses in CHP systems also occur in these three industries. Figure 11-3 shows the energy use and losses in CHP systems for each industry. Losses occur in the power generation system (conversion of fuels to electricity) and in boilers and auxiliary systems where waste heat is recovered.
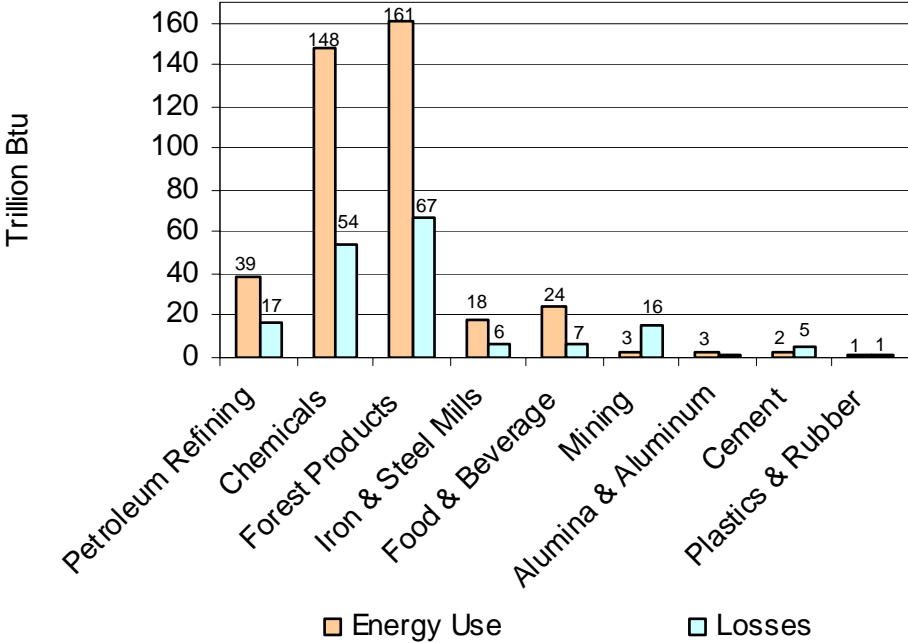
Figure 11-3 CHP Energy Use and Losses

12.0 Motor Systems Energy Use and Loss Analysis

12.1 Motor Systems Overview

Motor driven systems include pumps, fans, compressors, conveyor belts, and other indispensable industrial applications. Motor systems consume a significant portion of the total energy used by the most energy intensive industries in the manufacturing and mining sectors. Total energy consumption attributed to motor systems is in excess of 2.3 quads. About 56% is lost due to inefficiencies in motor windings, energy distribution and energy conversion systems. In the top six energy intensive industries alone motor systems account for over 1.5 quads of energy, and losses of nearly one quad.
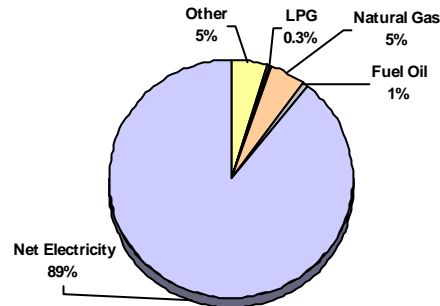
Figure 12-1 End Use Fuel Consumption for Machine Drive Systems

Motor systems are large electricity consumers. Over 89% of the total energy used to power these systems is obtained from electricity. Natural gas is the second most important energy source, but only represents 5% of the total energy consumption for motor systems [MECS 1998]. Figure 12-1 shows the energy consumption for machine drive systems by fuel type.

12.2 Energy Use and Loss Analysis for Motor Systems by Industry

Motor Systems Energy Use by Industry

Motor systems represent 13% of the total energy end use of the manufacturing and mining sectors. Only 45% of this energy is used in processes, and the remaining 55% is lost due to inefficiencies in equipment and distribution systems. Energy conversion losses represent the largest motor losses (51%), while the remaining losses occur during energy distribution. Figure 12-2 shows a breakdown of motor systems use and losses for manufacturing and mining.

Figure 12-2 Motor Systems Use and Losses in Manufacturing and Mining

Table 12-1 Industry Ranked by Motor Systems Use		
	Motor Use	
Sector	**Tbtu**	**Rank**
Chemicals	482	1
Forest Products	429	2
Mining	185	3
Petroleum Refining	183	4
Food & Beverage	142	5
Iron & Steel Mills	121	6
Heavy Machinery	99	7
Transportation Equipment	99	8
Plastics & Rubber	98	9
Textiles	85	10
Cement	40	11
Alumina & Aluminum	33	12
Glass & Glass Products	22	13
Foundries	19	14

The chemicals industry is the largest energy user for motor systems, consuming over 21% of the total motor systems energy used in manufacturing and mining. The forest products industry is the second largest user, consuming another 18% of the total. Both of these industries are large users of motor-driven pumps, fans, compressed air system, and materials processing equipment. Mining (8%), petroleum refining (8%), food and beverage (6%), and iron and steel mills (5%) are also significant users of motor-driven systems. Together, these six industries account for 66% of the total energy used for motor systems in manufacturing and mining. Table 12-1 shows an industry ranking based on the energy use for motor systems.

**Motor Systems as a Percentage of Total Energy End Use by Industry**

Figure 12-3 shows the energy used for motor systems as a percentage of the total energy end use for each industry. Although the mining industry is only the third largest energy user for machine drive systems, motors represent 25% of the industry's total energy end use, which is almost twice as much as the first and second industries in the ranking. This reflects the mining industry's dependence on motor-driven drills, grinders, fans, and crushers. The chemicals and petroleum refining industries are the first and second largest energy users for motor systems, although these systems only represent 13% of their total energy end use.
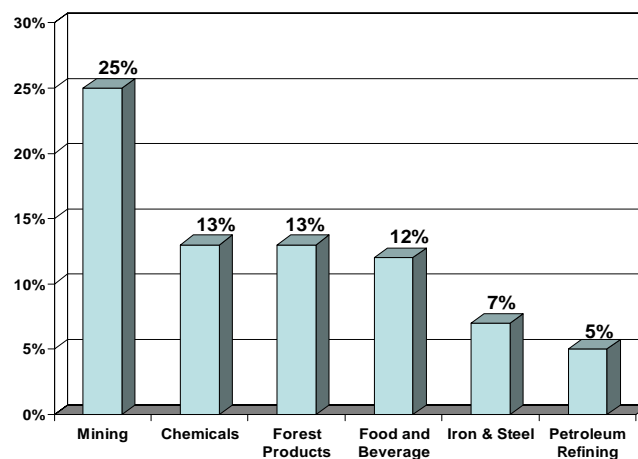
Figure 12-3 Motor Energy Use as a Percentage of Total Energy End Use

Motor Losses by Industry

Figure 12-4 shows the energy use and losses in motor systems for the six largest energy consuming industries. The chemicals industry is the largest user of energy for motor systems (considering energy used to process/end use and total losses), and accounts for the largest losses. In all six industries, energy conversion losses represent the bulk of the total motor losses. The substantial energy conversion losses in chemicals and other industries are due to the large inherent inefficiencies of some of the most commonly used systems, particularly pumps, compressors and materials processing systems. Note that only onsite losses are included in Figure 12-3. Energy losses associated with electricity generated offsite and used to power motor systems is not included.
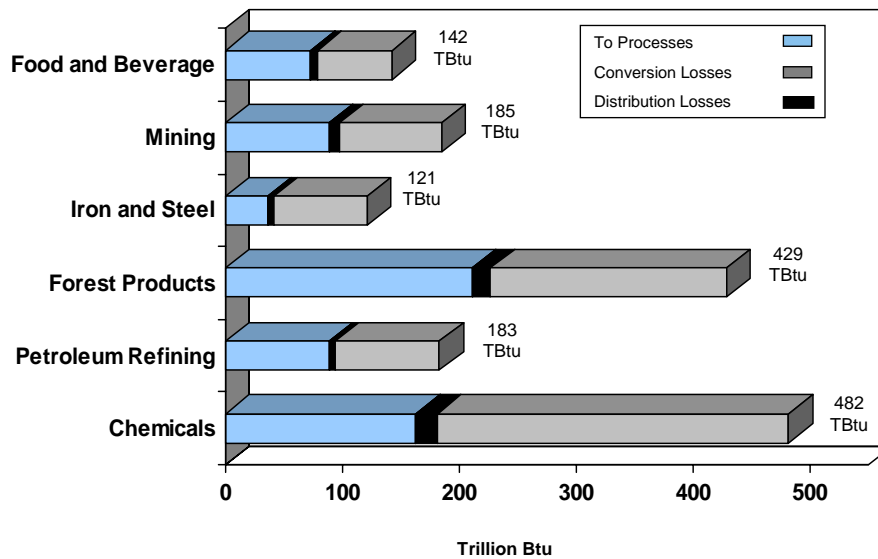
Figure 12-4 Motor Systems Use and Losses by Industry
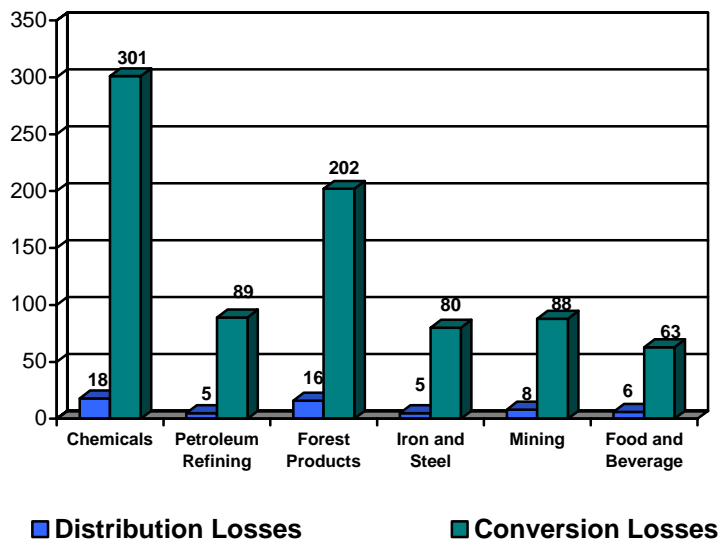
Figure 12-5 Motor System Losses – 881 Trillion Btu

Figure 12-5 and Table 12-2 show, in greater detail, the components of motor system losses for each industry. The total motor losses in manufacturing and mining are 1.3 quads. Energy conversion inefficiencies account for 93% of these losses, and distribution represents the remaining 7%. Chemical industry motor losses represent 25% of the total motor losses in manufacturing and mining, followed by forest products at 17%.

Table 12-2 Energy Delivered and Losses of Motor Systems						
	Chemicals	**Petroleum Refining**	**Forest Products**	**Iron and Steel**	**Mining**	**Food and Beverage**
To Processes	163	89	211	36	89	73
Generation Losses	0	0	0	0	0	0
Distribution Losses	18	5	16	5	8	6
Conversion Losses	301	89	202	80	88	63
Industry Totals	**482**	**183**	**429**	**121**	**185**	**142**

13.0 Facilities HVAC and Lighting, Electrochemical Processes, Onsite Transport, and Other Systems Energy Use and Loss Analysis

13.1 Other Systems Overview

Other typical energy systems used in industry include onsite transport equipment, electrochemical systems, facilities HVAC and lighting, process controls (such as sensors), and other industry specific systems. Electrochemical energy use occurs in systems that convert raw inputs to products through an electrochemical reaction; onsite transport accounts for the energy used to fuel equipment (trucks, forklifts, etc.) that carry materials between locations at the plant site. The energy used in facilities HVAC and lighting consists of energy used to provide heat, cooling, and lighting for building envelopes at the plant site. The amount of energy used in these miscellaneous systems is specific to each industry.
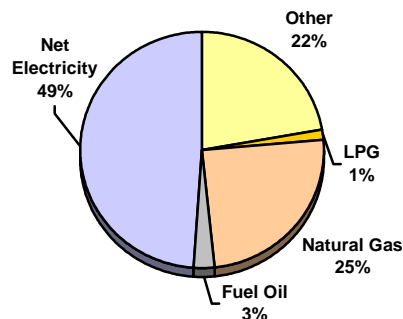
Figure 13-1 Energy Consumption by Source for Facilities HVAC and Lighting, Electrochemical Processes, and Other Uses

Almost half of the total energy consumption of these "other" systems is obtained from electricity. Natural gas is another large energy source, accounting for 25% of the total fuel mix [MECS 1998]. Figure 13-1 shows the boiler fuel mix for steam generation used in manufacturing. In the figure, coal is not included as a fuel source as it represents a very small percentage of the total.

13.2 Energy Use and Loss Analysis for Other Systems

Other Systems Energy Use

Figure 13-2 shows an industry breakdown of the energy used in facilities, electrochemical processes, and other uses. The mining industry has a large amount of energy use classified as "other" uses. Because the mining industry's energy consumption data is not classified by the U.S. Department of Energy's Manufacturing Energy Consumption Survey (MECS), there is scarce data on energy use, mining use specific equipment categories. However, from information that is available, this category includes onsite transport of mined materials, crushing, grinding, drilling, and other energy intensive mining equipment. The aluminum industry is the largest energy user for electrochemical processes, totaling 172 trillion Btu. The chemicals industry is the largest energy user for facilities HVAC and lighting systems (123 trillion Btu), and the second largest user of electrochemical processes (117 trillion Btu).
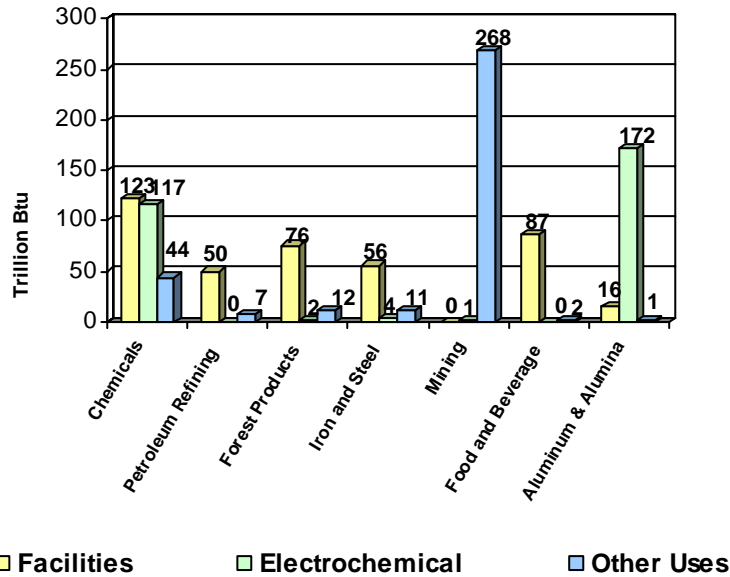
Figure 13-2 Energy Used in Facilities HVAC and Lighting, Electrochemical Processes, and Other Uses

Other Systems as a Percentage of Total Energy End Use

The total energy used for facilities HVAC and lighting, electrochemical processes, and other systems accounts for 14% of the total manufacturing and mining energy end use. More specifically, facilities account for 8%, electrochemical processes for 2%, and other systems are 4%. Figure 13-3 shows the energy used for these systems as a percentage of the total energy end use for each industry. The mining industry has the largest portion of its energy end use classified under "other systems" 61%. In the aluminum industry 40% of the total energy end use is consumed in electrolysis.
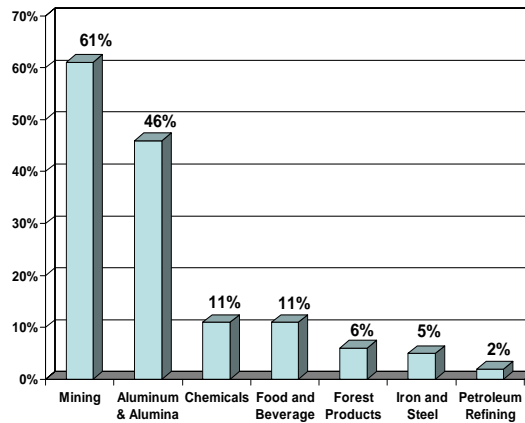
Figure 13-3 Other Systems Energy Use as a Percentage of Total Energy End Use

Other Systems Losses

The total energy use and losses for the seven most energy intensive users of facilities HVAC and lighting, electrochemical processes, and other systems is 1.4 quads. When combining the total energy used for facilities, electrochemical systems, and other processes, the mining and chemicals industries are the two largest end users. The mining industry accounts for 57% of the losses of these seven industries, because materials processing systems (which represent the majority of the industry's energy use) are highly inefficient. The aluminum and alumina industry is the third largest end user for these systems, and also exhibits substantial losses. Figure 13.4 and Table 13-1 show the energy use and losses in facilities HVAC and lighting, electrochemical processes, and other uses for each industry.
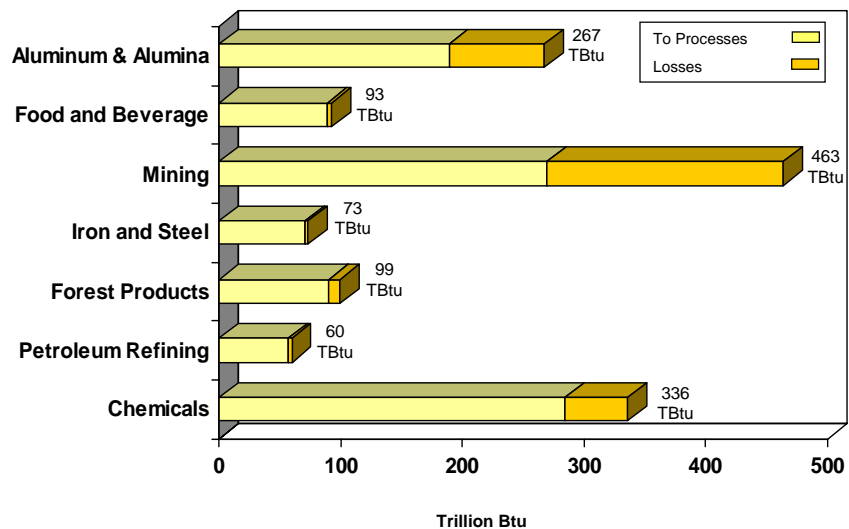
Figure 13-4 Energy Use and Losses in Facilities HVAC and Lighting, Electrochemical Processes, and Other Uses

Table 13-1 Energy Delivered and Losses of Other Systems							
	Chemicals	**Petroleum Refining**	**Forest Products**	**Iron and Steel**	**Mining**	**Food and Beverage**	**Aluminum & Alumina**
Facilities	123	50	76	56	0	87	16
Electrochemical	117	0	2	4	1	0	172
Other Uses	44	7	12	11	268	2	1
To processes	284	57	90	71	269	89	189
Losses	52	3	9	2	194	4	78
Industry Totals	**336**	**60**	**99**	**73**	**463**	**93**	**267**

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Appendix A

Energy Footprints

U.S. Manufacturing Energy Footprint: 24658 Trillion Btu

Energy Export 79

Distribution losses 440

Fossil Energy Supply 14660

Energy Supply 17762
- Fuels
- Purchased Electricity and Steam

Utility/ Power Plant 3102

Electricity generation and transmission losses **6444**

Facilities/HVAC/Lighting 1405

Solar/Geo-thermal/Wind Energy 12

Recycle Energy

Process Energy Systems

Steam, heat

Recycle Energy
By-product fuels and feedstocks, heat

Central Energy Generation/ Utilities 17774
- Steam Plant **(4934)**
- Fossil Power **(463)**
- Renewable Power **(12)**
- Direct Fuel Supply **(7864)**
- Purchased Electricity **(3102)**

Energy Distribution 16375
- Steam Piping
- Fuel Piping
- Transmission Lines

Energy Conversion 13561
- Process Heating   **(10649)** (heat exchangers, condensers, fired heaters, heat pumps)
- Process Cooling/ Refrigeration   **(255)**
- Electrochemical **(346)**
- Machine Drives   **(2074)** (pumps, compressors, fans, blowers, conveyors, mixers)
- Onsite Transport **(118)**
- Other **(119)**

Process Energy Use 10699
- Separations
- Furnaces
- Melters
- Reactors
- Electrolytic Cells
- Drying
- Mixing/Grinding
- Forming
- Fabrication
- Energy Storage
- Waste Handling

Energy Losses

Losses in boilers and electricity generation losses **1399**

Losses in pipes, valves, traps, electrical transmission lines **1330**

Energy Losses

Losses due to equipment inefficiency (motors, mechanical drive, waste heat) **2862**

Process energy losses from waste heat, flared gases, by-products **TBD**

Industrial Plant Boundary

NAICS 325 Chemicals Total Energy Supply: 5074 Trillion Btu

Distribution losses **94**

Energy Export **25**
Electricity

Facilities/HVAC/Lighting 123

Recycle Energy

Process Energy Systems

Recycle Energy
By-product fuels and feedstocks, heat

Fossil Energy Supply 3127

Energy Supply 3729
•Fuels
•Purchased Electricity and Steam

Utility/ Power Plant 602

Electricity generation and transmission losses **1251**

Central Energy Generation/ Utilities 3729
• Steam Plant **(1312)**
• Power Generation **(156)**
• Direct Fuel Supply **(1277)**
• Purchased Electricity **(602)**

Energy Distribution 3347
• Steam Piping
• Fuel Piping
• Transmission Lines

Steam, heat

Energy Conversion 2877
• Process Heating **(2154)**
(steam systems, heat exchangers, reboilers, condensers, fired heaters heat pumps)
• Process Cooling/ Refrigeration **(70)**
• Electrochemical **(136)**
• Machine Drives **(464)**
(pumps, compressors, fans, blowers, conveyors, mixers)
• Other **(53)**

Process Energy Use 2221
• Distillation
• Reactors
• Steam Crackers
• Electrolytic Cells
• Other Separations
• Mixing/Agitation
• Energy Storage
• Waste Handling

Energy Losses

Losses in boilers and electricity generation losses **382**

Losses in pipes, valves, traps, electrical transmission lines **322**

Energy Losses

Losses due to equipment inefficiency (motors, mechanical drive, waste heat) **656**

Losses from waste heat, flared gases, by-products **TBD**

Chemical/Petrochemical Plant Boundary

Energy Export 1

Distribution losses **101**

Fossil Energy Supply 3355

Energy Supply 3478

- Fuels
- Purchased Electricity and Steam

Utility/ Power Plant 123

Electricity generation and transmission losses **256**

Facilities/HVAC/Lighting 50

Recycle Energy

Central Energy Generation/ Utilities 3478

- Steam Plant **(849)**
- Fossil Power **(52)**
- Direct Fuel Supply **(2225)**
- Purchased Electricity **(123)**

Energy Distribution 3249

- Steam Piping
- Fuel Piping
- Transmission Lines

Process Energy Systems

Steam, heat

Recycle Energy
By-product fuels and feedstocks, heat

Energy Conversion 2956

- Process Heating **(2747)** (steam systems, heat exchangers, condensers, fired heaters, heat pumps)
- Process Cooling **(21)**
- Machine Drives **(178)** (pumps, compressors, fans, blowers, conveyors, mixers)
- Onsite Transport **(3)**
- Other **(7)**

Process Energy Use 2442

- Distillation
- Thermal Cracking and Coking
- Catalytic Cracking
- Hydrotreating
- Alkylation
- Isomerization
- Hydrogen Production
- Energy Storage
- Waste Handling

Energy Losses

Losses in boilers and electricity generation losses **229**

Losses in pipes, valves, traps, electrical transmission lines **242**

Energy Losses

Losses due to equipment inefficiency (motors, mechanical drive, waste heat) **514**

Losses from waste heat, flared gases, by-products **TBD**

Industrial Plant Boundary

NAICS 321 and 322 Forest Products Energy Footprint: 4039 Trillion Btu

Distribution losses **88**

Fossil & Biomass Fuels **2936**

Energy Supply **3263**
- Fuels
- Purchased Electricity and Steam

Utility/ Power Plant **327**

Electricity generation and transmission losses **679**

Energy Export 24

Facilities/HVAC/Lighting 76

Solar/Geo-thermal/Wind Energy 9

Recycle Energy

Process Energy Systems

Recycle Energy
By-product fuels and feedstocks, heat

Steam, heat

Central Energy Generation/ Utilities 3272
- Steam Plant **(1895)**
- Fossil & Biomass Power **(188)**
- Renewable Power **(9)**
- Direct Fuel Supply **(251)**
- Purchased Electricity **(327)**

Energy Distribution 2670
- Steam Piping
- Fuel Piping
- Transmission Lines

Energy Conversion 2168
- Process Heating **(1724)** (heat exchangers, condensers, fired heaters, heat pumps)
- Process Cooling/ Refrigeration **(8)**
- Electrochemical **(2)**
- Machine Drives **(413)** (pumps, compressors, fans, blowers, conveyors, mixers)
- Onsite Transport **(15)**
- Other **(6)**

Process Energy Use 1698
- Digesters
- Gasifiers
- Pulping Processes
- Bleaching
- Evaporators
- Refiners
- Chemical Recovery
- Energy Recovery
- Energy Storage
- Waste Handling

Energy Losses

Losses in boilers and electricity generation losses **602**

Losses in pipes, valves, traps, electrical transmission lines **402**

Energy Losses

Losses due to equipment inefficiency (motors, mechanical drive, waste heat) **470**

Process energy losses from waste heat, flared gases, by-products **TBD**

Industrial Plant Boundary

NAICS 33111 Total Steel Industry Energy Input: 2056 Trillion

Energy Export ~0
Electricity

Distribution losses 45

Fossil Energy Supply 1509

Energy Supply 1672

- •Fuels
- •Purchased Electricity and Steam

Utility/ Power Plant 163

Facilities/HVAC/Lighting 56

Recycle Energy

Process Energy Systems

Recycle Energy
By-product fuels and feedstocks, heat

Steam, heat

Central Energy Generation/ Utilities 1672

- • Steam Plant **(77)**
- • Power Generation **(18)**
- • Direct Fuel Supply **(1389)**
- • Purchased Electricity **(163)**

Energy Distribution 1647

- • Steam Piping
- • Fuel Piping
- • Transmission Lines

Energy Conversion 1529

- • Process Heating **(1392)** (steam systems, coke ovens, blast furnaces, reheat furnaces)
- • Process Cooling/ Refrigeration   **(4)**
- • Electrochemical **(5)**
- • Machine Drives **(116)** (pumps, compressors, fans, blowers, conveyors, grinders)
- • Other **(12)**

Process Energy Use 1238

- • Cokemaking
- • Ironmaking
- • Steelmaking
- • Ladle refining
- • Casting
- • Reheating
- • Forming
- • Finishing
- • Waste Handling

Total EAF Steel Industry Energy Supply: 703 Trillion Btu

Energy Export ~0
Electricity

Facilities/HVAC/Lighting 25

Recycle Energy

Process Energy Systems

Steam, heat

Recycle Energy
By-product fuels and feedstocks, heat

Distribution losses **11**

Fossil Energy Supply 372

Energy Supply 476
- Fuels
- Purchased Electricity and Steam

Utility/ Power Plant 104

Electricity generation and transmission losses **216**

Central Energy Generation/ Utilities 476
- Steam Plant **(35)**
- Power Generation **(8)**
- Direct Fuel Supply **(318)**
- Purchased Electricity **(104)**

Energy Distribution 465
- Steam Piping
- Fuel Piping
- Transmission Lines

Energy Conversion 421
- Process Heat/Steam **(360)** (Steelmaking – 106; Ladle furnace – 15; Reheating – 75; Clean/anneal – 15; Heat treating – 20; Other process heating – 129)
- Process Cooling/ Refrigeration **(2)**
- Electrochemical **(2)**
- Machine Drives **(52)** (pumps, compressors, fans, blowers, conveyors, grinders)
- Other **(5)**

Process Energy Use 312
- Steelmaking - 85
- Ladle furnace - 13
- Reheating - 56
- Clean/anneal - 13
- Heat treating - 17
- Other - 109

Energy Losses

Energy Losses

Losses in boilers and electricity generation losses **11**

Losses in pipes, valves, traps, electrical transmission lines **19**

Losses due to equipment inefficiency (motors, mechanical drive, waste heat) **109**

Losses from waste heat, by-products **TBD**

Steel Plant Boundary

Total Integrated Steel Industry Energy Supply: 1353 Trillion Btu

Energy Export ~0
Electricity

Distribution losses 34

Fossil Energy Supply 1137

Energy Supply 1196

- Fuels
- Purchased Electricity and Steam

Utility/ Power Plant 59

Electricity generation and transmission losses **123**

Facilities/HVAC/Lighting 31

Recycle Energy

Process Energy Systems

Recycle Energy
By-product fuels and feedstocks, heat

Steam, heat

Central Energy Generation/ Utilities 1196

- Steam Plant **(42)**
- Power Generation **(10)**
- Direct Fuel Supply **(1071)**
- Purchased Electricity **(59)**

Energy Distribution 1182

- Steam Piping
- Fuel Piping
- Transmission Lines

Energy Conversion 1109

- Process Heat/Steam **(1031)** (Sintering - 18; Cokemaking - 52; Ironmaking - 641; Steelmaking - 53; Ladle furnace - 18; Reheating - 90; Clean/anneal - 18; Heat treating - 24; Other process heating - 117)
- Process Cooling/ Refrig **(2)**
- Electrochemical **(3)**
- Machine Drive **(64)** (Comp air - 9; Pumps - 6; Fans - 10; Crush/ grind - 35; Other - 9)
- Other **(7)**

Process Energy Use 832

- Sintering - 15; Cokemaking - 44; Ironmaking - 481; Steelmaking - 53; Ladle furnace - 15; Reheating - 68; Clean/anneal - 15; Heat treating - 21; Other process heating - 99; Comp air - 2; Pumps - 3; Fans - 6; Grind - 4; Other - 8

Energy Losses

Losses in boilers and electricity generation losses **14**

Losses in pipes, valves, traps, electrical transmission lines **42**

Energy Losses

Losses due to equipment inefficiency (motors, mechanical drive, waste heat) **277**

Losses from waste heat, by-products **TBD**

Steel Plant Boundary

NAICS 311 and 312 Food and Beverage Total Energy Supply for Heat and Power: 1685 Trillion Btu

Distribution losses **28**

Fossil Energy Supply 915

Energy Supply 1156
- Fuels
- Purchased Electricity and Steam

Utility/ Power Plant 241

Electricity generation and transmission losses **501**

Energy Export 4

Facilities/HVAC/Lighting 86

Recycle Energy

Solar/Geothermal/ Wind Energy 0.1

Process Energy Systems

Steam, heat

Recycle Energy
By-product fuels and feedstocks, heat

Central Energy Generation/ Utilities 1156
- Steam Plant **(485)**
- Fossil Power **(21)**
- Direct Fuel Supply **(281)**
- Purchased Electricity **(241)**

Energy Distribution 1028
- Steam Piping
- Fuel Piping
- Transmission Lines

Energy Conversion 824
- Process Heating **(613)** (steam systems, heat exchangers, condensers, fired heaters, heat pumps)
- Process Cooling/ Refrigeration **(69)**
- Machine Drives **(136)** (pumps, compressors, fans, blowers, conveyors, mixers)
- Onsite Transport **(8)**
- Other **(3)**

Process Energy Use 658
- Concentration
- Crystallization
- Drying/Evaporation
- Distillation
- Freezing
- Melting
- Mixing/Stirring
- Grinding
- Packaging
- Energy Storage
- Waste Handling

Energy Losses

Losses in boilers and electricity generation losses **128**

Losses in pipes, valves, traps, electrical transmission lines **113**

Energy Losses

Losses due to equipment inefficiency (motors, mechanical drive, waste heat) **166**

Losses from waste heat, flared gases, by-products **TBD**

Industrial Plant Boundary

Distribution losses **15**

Fossil Energy Supply 510

Energy Supply 753

- Fuels
- Purchased Electricity and Steam

Utility/ Power Plant 243

Electricity generation and transmission losses **505**

Energy Export ~0.01

Recycle Energy

Process Energy Systems

Recycle Energy
By-product fuels and feedstocks, heat

Steam, heat

Central Energy Generation/ Utilities 753

- Steam Plant **(3)**
- Onsite Power **(19)**
- Direct Fuel Supply **(471)**
- Purchased Electricity **(243)**

Energy Distribution 736

- Steam Piping
- Fuel Piping
- Transmission Lines

Energy Conversion 723

- Process Heating **(99)** (steam systems, heat exchangers, preheaters, fired heaters)
- Electrochemical **(1)**
- Machine Drives **(177)** (pumps, conveyors, crushing, grinding, drilling)
- Other Equipment, Mine Transport **(446)**

Process Energy Use 442

- Furnaces
- Smelters
- Calciners
- Electrolytic Cells
- Mixers/Grinders
- Waste Handling

Energy Losses

Losses in boilers and electricity generation **17**

Losses in pipes, valves, traps, electrical transmission lines **13**

Energy Losses

Losses due to equipment inefficiency (motors, mechanical drive, waste heat) **281**

Process energy losses from waste heat, flared gases, other mechanical losses **TBD**

Mining Operation Boundary

Appendix B

NAICS Descriptions

311 – Food Manufacturing
Establishments in the Food Manufacturing subsector transform livestock and agricultural products into products for intermediate or final consumption by humans or animals. The food products manufactured in these establishments are typically sold to wholesalers or retailers for distribution to consumers, but establishments primarily engaged in retailing bakery and candy products made on the premises not for immediate consumption are included.

312 – Beverage and Tobacco Product Manufacturing
Industries in the Beverage and Tobacco Product Manufacturing subsector manufacture beverages (alcoholic and nonalcoholic) and tobacco products. Redrying and stemming tobacco is included in the tobacco products sector while ice manufacturing is included with nonalcoholic beverage manufacturing because it uses the same production process as water purification.

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

314 – Textile Product Mills
Establishments in the Textile Product Mills subsector group manufacture textile products (carpets, rugs, linens, rope, twine, etc), excluding apparel. With a few exceptions, these industries generally purchase fabric to cut and sew into the final nonapparel textile products.

315 – Apparel Manufacturing
Industries in the Apparel Manufacturing subsector group are involved in two manufacturing processes: (1) the manufacture of garments using purchased fabric and cutting and sewing, and (2) the manufacture of garments in establishments that first knit fabric and then cut and sew the fabric into a garment. Knitting, when done alone, is classified in the Textile Mills subsector (313).

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

321 – Wood Product Manufacturing
Industries in the Wood Product manufacturing subsector manufacture wood products, such as lumber, plywood, veneers, wood containers, wood flooring, wood trusses, manufactured homes (i.e., mobile homes), and prefabricated wood buildings.

322 – Paper Manufacturing
Industries in the Paper Manufacturing subsector make pulp, paper, or converted paper products such as paperboard containers, paper bags, and tissue paper. The manufacturing of these products is grouped together because they constitute a series of vertically connected processes and more than one is often carried out in a single establishment.

324110 – Petroleum Refineries
This industry comprises establishments primarily engaged in refining crude petroleum. Petroleum refining involves one or more of the following activities: (1) fractionation; (2) straight distillation of crude oil; and (3) cracking.

325 – Chemical Manufacturing
The Chemical Manufacturing subsector is based on the transformation of organic and inorganic raw materials by a chemical process and the formulation of intermediate or end products. Exceptions include beneficiating operations such as copper concentrating, crude petroleum refining, and aluminum oxide production that are covered in other subsectors.

326 – Plastics and Rubber Products Manufacturing
Industries in the Plastics and Rubber Products Manufacturing subsector make goods by processing plastic materials and raw rubber. Plastics and rubber are combined in the same subsector because plastics are increasingly being used as a substitute for rubber; however, the subsector is generally restricted to the manufacture of products made of just one material, either solely plastics or rubber. Footwear and furniture manufacturing are therefore covered elsewhere.

3272 – Glass and Glass Product Manufacturing
This industry comprises establishments primarily engaged in manufacturing glass and/or glass products. They may start with silica sand or cullet, or purchased glass. Glass products that are classified elsewhere include glass wool (fiberglass), optical lenses, ophthalmic lenses, and fiber optic cable.

327993 – Mineral Wool
This industry comprises establishments primarily engaged in manufacturing mineral wool and mineral wool insulation products made of such siliceous materials as rock, slag, and glass or combinations thereof.

327310 – Cement Manufacturing
Establishments classified in this subsector are primarily engaged in manufacturing Portland, natural, masonry, pozzalanic, and other hydraulic cements. Establishments primarily involved in mining, quarrying, or manufacturing lime or manufacturing of ready-mix or dry mix concrete are classified elsewhere.

331111 – Iron and Steel Mills
This industry comprises establishments primarily engaged in one or more of the following: (1) direct reduction of iron ore; (2) manufacturing pig iron in molten or solid form; (3) converting pig iron into steel; (4) making steel; (5) making steel and manufacturing shapes (e.g., bar, plate, rode, sheet, strip, wire); and (6) making steel and forming tube and pipe. Establishments primarily engaged in manufacturing ferroalloys or operating coke ovens are classified elsewhere.

3313 – Alumina and Aluminum Production and Processing
This industry is composed of establishments primarily engaged in one or more of the following: (1) refining alumina; (2) making (i.e., the primary production) aluminum from alumina; (3) recovering aluminum from scrap or dross; (4) alloying purchased aluminum; and (5) manufacturing aluminum primary forms (e.g., bar, foil, pipe, plate, rod, sheet, tube, wire).

3315 – Foundries
This industry group comprises establishments primarily engaged in pouring molten metal into molds or dies to form castings. Establishments making castings and further manufacturing, such as machining or assembling, a specific manufactured product are classified in the industry of the finished product. When the production of the primary metal is combined with the casting, the establishment is classified in sector 331 with the primary metal being made.

332 – Fabricated Metal Product Manufacturing
Industries in the Fabricated Metal Product Manufacturing subsector transform metal into intermediate or end products, other than machinery, computers and electronics, metal furniture, and metal products fabricated elsewhere.

Important fabricated metal processes include forging, stamping, bending, forming, machining, welding, and assembling.

333 – Machinery Manufacturing

Establishments in the Machinery Manufacturing subsector create end products that apply mechanical force, such as the application of gears and levers, to perform work. Although this subsector uses processes similar to those used in Fabricated Metal Product Manufacturing (332), machinery manufacturing is different because it typically employs multiple metal forming processes in manufacturing the various parts of the machine. In addition, complex assembly operations are an inherent part of the production process.

334 – Computer and Electronic Product Manufacturing

Industry establishments in this subsector manufacture computers, computer peripherals, communications equipment, and similar electronic products, and components for such products.

335 – Electrical Equipment, Appliance, and Component Manufacturing

Industry establishments in this subsector manufacture products that generate, distribute, and use electrical power. Establishments are grouped into Electric Lighting Equipment, Household Appliances, Electrical Equipment (motors, generators, transformers, etc), and Other Electrical Equipment and Component Manufacturing.

336 – Transportation Equipment Manufacturing

Industries in the Transportation Equipment Manufacturing subsector produce equipment for transporting people and goods. Although transportation equipment is a type of machinery, an entire subsector is devoted to this activity because of the significance of its economic size in all three North American countries.