Energy Use, Loss and Opportunities Analysis: *U.S. Manufacturing & Mining*

Prepared by Energetics, Incorporated and
E3M, Incorporated for the
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Industrial Technologies Program

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Preface

The U.S. Department of Energy's Industrial Technologies Program (DOE/ITP) conducts R&D to accelerate the development of energy efficient and environmentally sound industrial technology and manufacturing practices. To help focus its R&D portfolio, the DOE/ITP commissioned this multi-phase study to identify where and how industry is using energy, and to target opportunities for reducing energy consumption. The focus of the study is on energy systems (steam generators, power systems, fired heaters, heat exchangers, compressors, pumps, fans) used across the industrial sector. The results of this study were also used to help develop the *Technology Roadmap for Energy Loss Reduction and Recovery* (available at www.eere.energy.gov/industry), a joint effort between industry and government.

The principal authors of the report are shown below. Questions concerning this report should be directed to the authors. A copy of the report may be obtained on-line at www.eere.energy.gov/industry/energy_systems

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1.0 Overview of Energy Use, Loss and Opportunities

1.1 Background

The industrial sector uses about one-third of the total energy consumed annually in the United States (see Figure 1-1), most of it fossil fuels, at a cost of approximately $100 billion. Given that energy resources are limited, and demand for industrial products continues to rise, meeting industrial energy demand and minimizing its economic impact in the future will be a significant challenge.

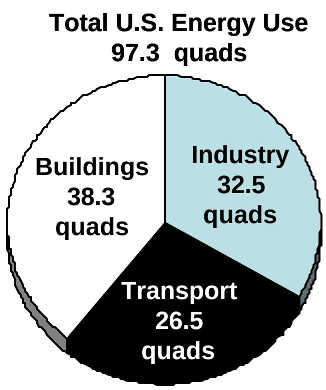


Figure 1-1 2002 U.S. Energy Consumption
[Energy Information Administration, Annual Energy Review 2003]

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). How efficiently energy is used, its cost, and its availability 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 decreased emissions of pollutants such as sulfur oxides, nitrogen oxides, particulates, and greenhouse gases (e.g., carbon dioxide).

Improved efficiency can also reduce the use of feedstock energy through greater yields, which translates to more product manufactured for the same amount of energy. Reducing the use of energy feedstocks impacts directly our dependence on imported oil, and alleviates pressure on increasingly scarce and expensive natural gas supplies.

Energy efficiency can 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. Thermal efficiency is essentially 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 is equal to the total heat absorbed divided by the total heat supplied; in an automotive engine, thermal efficiency is 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 implies that not all of the energy input is being converted to useful work – some is released as lost energy. In the manufacturing sector, these energy losses amount to several quadrillion Btus (quadrillion British Thermal Units, or quads) 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%
Thermal Cracking (refineries)	58-61%
EAF Steelmaking	56%
Paper Drying	48%
Kraft Pulping	60-69%
Distillation Column	25-40%
Cement Calciner	30-70%
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. A first step in understanding and assessing the opportunities for improving energy efficiency is to identify where and how industry is using energy – how much is used for various systems, how much is lost, how much goes directly to processes, and so forth. The second step is to then quantify the portion of lost energy that can be recovered technically and economically through improvements in energy efficiency, advances in technology, and other means. Answering these questions for the U.S. manufacturing and mining sectors is the focus of this report.

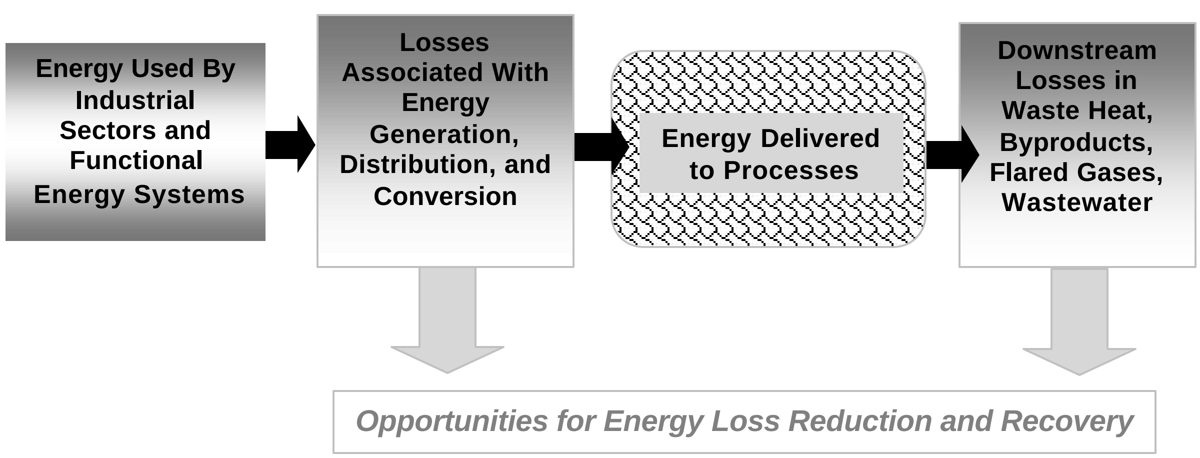
The U.S. Department of Energy's Industrial Technologies Program (DOE/ITP) conducts R&D to accelerate the development of energy efficient and environmentally sound industrial technology and manufacturing practices. To help focus its R&D portfolio, the DOE/ITP commissioned this multi-phase study to identify where and how industry is using energy, and to ultimately target the most significant opportunities for reducing energy consumption. The focus of the study is on energy systems – steam generators, power systems, fired heaters, heat exchangers, compressors, pumps, fans – that are used across the industrial sector to convert energy resources into useful work or products. A schematic illustrating the various phases of the study is shown in Figure 1-2.

The first phase of the study involved examining the use of energy in terms of broad categories such as steam, fired systems, motor drive, combined heat and power, and similar areas. This essentially provides a "footprint" of energy use across 15 sectors of manufacturing, plus mining, and outlines the energy lost in energy generation, distribution, and conversion. These energy losses represent the central targets of opportunity for more advanced and increasingly efficient energy systems.

The second phase of the study builds upon these initial results via are in-depth look at the largest industrial users of energy systems and subsequentially linking energy use and losses to industry-specific process operations and equipment. In addition, it examines the potential technology options for recapturing some of the energy that is currently lost in industrial processes and identifies technology R&D areas that could have potentially large impacts across more than one industry. The results of the first and second phases of the study were then used as the basis for developing a quantified list in terms of energy savings potential of the top opportunities for improving the efficiency of industrial energy systems.

The remainder of the report is organized by the results obtained for the aggregated manufacturing sector, with individual chapters on the most energy-intensive industries. A chapter is also devoted to selected functional areas (e.g., steam systems, process heaters, motor drives). The top recommendations emerging from the opportunities analysis are provided in a separate summary chapter. A brief description of the methodology and approach used in conducting the analysis is provided in the following section.

Figure 1-2 Flow of the Multi-phase Study on Energy Use, Loss and Opportunities



1.2 Methodology

1.2.1 Energy Use and Loss Analysis

1.2.1.1 General Methodology

The basic objective of the study was to evaluate the energy use and loss patterns of individual industries as well as that of the entire manufacturing sector. Industries were selected based on total energy use, contribution to the economy, and relative importance to energy efficiency programs. Industries not selected for individual 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 consumed in these industries is included in the overall manufacturing energy analysis.

Table 1-1 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, NA ICS 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 & 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

Using this approach, the study examined a large subset of the mining and manufacturing sector, with the objective of capturing the bulk share of energy consumption. Table 1-1 lists the industrial sectors covered and defines the sixteen groupings selected for analysis, organized by their respective North American Industrial Classification System (NAICS) codes [NAICS 1997]. The industries shown in Table 1-1 represent over 80% of U.S. industrial energy use. For simplicity, some related sectors were grouped (e.g., textiles). Appendix D gives an overview of the specific products manufactured in each sector.

Energy use figure were obtained from the 1998 Manufacturing Energy Consumption Survey (MECS) and other sources listed in the Reference section of this report. This represents the most current source of energy use available by individual NAICS codes. The Annual Survey of Manufactures also provides information on energy use by NAICS codes, but data is not given in physical units except for electricity (e.g., fuel data is given is terms of dollars expended).

The general approach used to evaluate and compare energy use and losses across industry involved the development of "energy footprints" for each sector using primarily MECS data, incorporating other sources as necessary. This methodology is described in more detail in the following section.

1.2.1.2 Energy Footprints

Using the MECS data as a basis, a series of *Energy Footprints* was developed to map the flow of energy supply and demand in U.S. manufacturing and mining. 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 set of industry-specific energy footprints is provided in Appendix A along with sample calculations.

The generic energy footprint schematic is shown in Figure 1-3. On the supply side (far left of the diagram), 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 (right side of diagram, inside the plant boundary), 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. To aid in the interpretation of these diagrams, particularly energy losses, a comprehensive set of definitions of terms is included in Section 1.2.3.

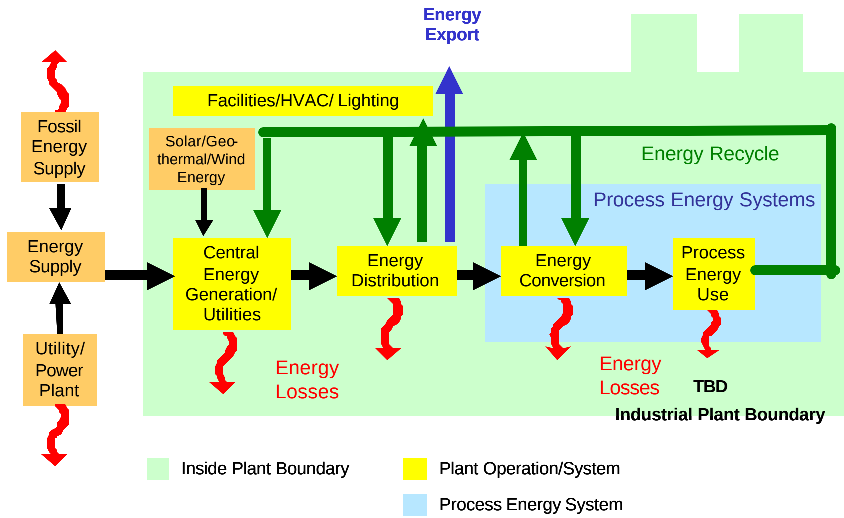


Figure 1-3 Generic Energy Footprint

As Figure 1-3 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 (noted as energy recycle). Notable examples are the use of black liquor and wood byproducts in pulp and paper mills, still gas from petroleum refining processes, light gas mixes produced during chemicals manufacture, and blast oven gases in iron and steel mills.

For simplicity, byproduct energy is shown on the energy footprint as contributing to the total fossil energy supply coming into the plant, even though it is produced onsite. Renewable energy sources such as solar, geothermal, and wind power are shown as separate energy resources, and are most often used to produce electricity.

Once energy crosses the plant boundary, it flows either to a ***central energy generation utility system*** (e.g., steam plant, power generation, cogeneration) or goes directly to process units. Central energy generation represents the production of electricity and steam in a centralized location, with the energy transported subsequently through ***distribution systems*** to various process units. This is a generalization of what may be actually occurring at the plant site, as energy producers are often situated close to where energy is required. Energy production facilities within the plant boundary also sometimes create more energy than is needed for process use. In this situation, the excess energy is exported off-site to the local grid or another plant within close proximity. For the energy footprint analysis, all the ***energy export*** is assumed to be electricity although a small portion may be steam.

Fuels and power are often routed to ***energy conversion*** equipment that is generally integrated with specific processes. For the energy footprint analysis, energy conversion represents the conversion of energy to usable work that occurs prior to the process. This would include, for example, a motor-driven compressor or pump, or an air preheater. The converted energy is utilized as ***process energy***, 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 1-3). A simplified flow of losses from energy supply through industrial processing is shown in Figure 1-4. Energy is lost in power generation and steam systems, both off-site at the utility and on-site within the plant boundary, due to equipment inefficiency and mechanical and thermal limitations. Energy is lost in distribution and transmission systems carrying energy both to the plant and within the plant boundary.

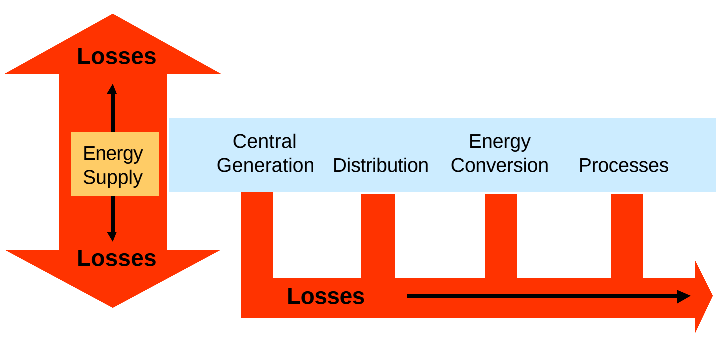


Figure 1-4 Simplified Flow of Energy Losses

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 located optimally near heat sinks, and it may be economically impractical to recover that excess energy. Energy is sometimes lost simply because it cannot be stored. Energy is also lost from processes when waste heat is not recovered and when waste by-products with fuel value are not utilized.

It is difficult to distinguish between energy conversion occurring prior to the process versus during the process as equipment is often closely integrated with the process unit. For the purpose of calculating energy losses, it was assumed that a portion of losses would occur prior to the process (these are calculated) and another portion would occur downstream (not calculated). As a result, pre-process losses may overlap somewhat with post-process (downstream) losses. Downstream losses, which manifest typically as flue or exhaust gases, radiative and convective heat losses, wastewater, and/or low quality steam, are process-specific and can be substantial (shown as TBD on the energy footprint). These were not included in the scope of the energy use and loss analysis, but are dealt with to some extent in the opportunities analysis (Section 1.2.2).

Table 1-2 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 – 90% Motor windings – 5%

Losses were determined by applying equipment loss factors to the energy used in selected functional categories: steam systems, fired systems (heating and cooling), refrigeration, and others. The loss factors used in this study, listed in Table 1-2, were obtained from literature sources and through discussions with equipment experts (see Reference section).

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 contributing factors to boiler efficiency. As shown in Table 1-2, an average loss factor of 20% was used. 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]. A conservative value of 20% was used for steam distribution losses in this study.

As shown in Table 1-2, 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 strongly site-specific and depend largely on plant size and configuration. The loss factors shown in Table 1-2 may underestimate these losses, which have been reported to be as high as 10-40%. For simplicity, distribution losses are spread among the largest end-use categories.

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. Effective rewind practices can reduce these losses.

The energy footprints represent an average picture of energy use and losses across an industry. They provide the means to begin assessing the relative losses due to inefficiencies in addition to sources of energy-intensity. They also provide a baseline from which to calculate the opportunities for improving energy efficiency.

1.2.1.3 Industry Rankings

Using the results of the energy footprint analysis, 16 industrial sectors were compared in a number of categories including: primary energy use, energy use for fuel and power, use of fuel versus power, use of steam and fired systems, onsite cogeneration, and others. Chapter 2, U.S. Manufacturing and Mining, contains the results of each ranking exercise. The rankings provide a useful diagnostic tool for identifying the top energy consumers, the primary functional uses of energy, and the propensity of industry to use onsite power generation rather than purchased electricity.

These rankings also revealed a select subset of the industrial sector that warranted further study and analysis. Consequently six industries were the chosen focus for the remainder of this report: chemicals, petroleum refining, forest products, iron and steel, food processing, and mining. The top functional categories – steam, fired systems, motor-driven equipment, and onsite generation – are also highlighted. Separate chapters describe the unique energy characteristics of each industry and technology area, potential sources of energy loss, and potential opportunities for energy loss reduction and recovery.

1.2.2 Loss Reduction and Recovery Opportunities Analysis

Using the rankings of the top energy systems users provided by the energy use and loss study as a starting point (see Table 1-3), additional analyses were conducted to narrow down process-specific opportunities. The following criteria were used to guide the selection of industries for further analysis: 1) energy use and losses were large, 2) waste heat represented a significant source of energy losses, and 3) the potential for cross-industry impacts was high.

Table 1-3 Major Industrial Users of Energy Systems

Industry	Steam Systems (Rank)	Fired Systems (Rank)	Motor Driven Systems (Rank)	Energy Used in Energy Systems (TBTU)
Petroleum Refining	3	1	4	3401
Chemicals	2	3	1	3334
Forest Products	1	8	2	3082
Iron and Steel	7	2	6	1593
Food and Beverage	4	4	5	1052
Cement	16	5	10	353
Fabricated Metals	11	10	7	332
Transport Equipment	6	13	9	324
Textiles	5	15	9	297
Mining	15	13	3	290

For example, the thermal processes used in chemicals, petroleum refining, forest products and food processing share many characteristics, and waste heat is a substantial potential energy source in each of these industries. Thus, based on their energy use profile, the industries ultimately selected for further study included petroleum refining, chemicals, forest products, iron and steel, food and beverage, and cement.

For the six industries selected, estimates of the energy intensity (Btu/product unit) and production values associated with specific energy systems were made for each industry. Process energy estimates were based upon data available currently in open literature, and were correlated with the 1998 MECS to validate order of magnitude.

Average equipment efficiencies were estimated and energy losses were then calculated for each process to ascertain quantifiable energy reduction opportunities for each major process. Average equipment efficiencies were determined based on open literature, communication with industry experts, and equipment suppliers and energy system consultants. In some cases, assumptions of equipment efficiency were made based on widely known best practices. Details for each industry analysis are provided in Appendix B.

The second phase of the study differs from the first in that energy loss calculations encompass those losses occurring at the end of the process (e.g., exit gases, flue gases, hot water). The first phase of the study concentrated entirely on losses occurring *prior to use in the process operation* (e.g., central energy generation losses, losses in distribution and conversion to work). However, because energy systems are often integrated closely into the process, energy conversion losses are difficult isolate. Thus, there may be some overlap with end-of-process losses. The second phase of the analysis focused on the major process level, with the primary objective of pinpointing the major loss targets in each industry and later tying those losses to specific processes and energy systems equipment. By doing so, conclusions can then be reached regarding high profile targets and possible technology options for reducing energy system losses.

After assessing the potential opportunities, estimates were made concerning the percent of energy that could be likely reduced or recovered and the various technology options that might be suitable candidates. These estimates were based on communications with equipment and industry experts, open literature citations documenting potential efficiency improvements, and best engineering practices. Assumption details are provided in the individual industry chapters and in Appendix B.

Energy systems were grouped according to specific thermal processes, as defined in Table 1-4. Two major categories are used to encompass all the thermal processes shown in Table 1-4 – steam systems (e.g., boiling or distillation) and fired systems (all other thermal processes shown). Most of the results in this report are presented within the context of these two categories. In some cases, where it is difficult to separate steam from other thermal systems (e.g., chemicals manufacture) thermal energy use was combined into one aggregate table.

Estimates of potential energy savings were distributed among categories that range from near-term best practices to completely new technology that must be developed through R&D. Best practices opportunities, are those that may be achieved in the relatively near term (immediately to 2-3 years), whereas revolutionary R&D might take much longer to achieve results (7-10 years and beyond). A summary of the categories is provided in Table 1-5.

Table 1-4 Definition of Thermal Processes

Process	Temperature Regime (^{o}F)	Description	Typical Applications
Fluid Heating	150-800	Heating of liquid or gas to raise its temperature without significant vaporization or separation of its constituents	Heating of water, petroleum crude, chemical feedstocks, and other liquids
Boiling or Distillation	300-1000	Vapor generation from water or other liquid	Steam generation
Drying	200-700	Removal of physically mixed water or other liquid from material	Drying of lumber, paper, paint, ore, grain, food products, chemicals
Curing and forming	300-2500	Heating of material (to promote binding of constituents or changing strength) for further processing	Heating of plastic, rubber, bricks, ceramics
Metal or non-metal heating	200-2500	Raising temperature of the metallic or non-metallic material for further processing	Heating of steel, aluminum , or other materials for rolling, forging
Heat treating	400-2500	Heating of material to change its structure and/or composition in air or in presence of special gas mixture (atmosphere)	Heat treating of steel or aluminum to make it soft or hard
Metal Melting	800-3000	Heating of metal to change from solid to liquid form	Melting of steel, aluminum, copper, and other materials in furnaces
Non-metal melting	1500-3000	Heating of non-metallic material to change from solid to liquid form	Melting of glass, salts, non-metallic minerals
Calcining	1500-2000	Heating of material (mostly non-metallic) to remove chemically bound water	Lime, ore, or chemical calcining
Smelting	>2000	Heating of material-ore in presence or mixed with other material (carbon) to produce molten metal	Iron ore, copper, and zinc ore smelting
Agglomeration - sintering	>2000	To heat material to produce material that is fused or "agglomerated" by the effect of high temperature	Powder metal, iron ore pelletizing
Other	200-500	To heat material for a variety of end-uses or processing	Frying, cooking, baking

Table 1-5 Improvement Potential Categories

Best Practices	
Existing potential	Can be attained with existing operations using tools and methodologies for best practices
Future or new potential	Will require new tools and methodologies for best practices
Technology	
Commercially available technology and equipment	Can be attained with available technology and equipment; may be currently constrained by lack of proven track record in operating practice, lack of awareness on the part of industry, capital or operating cost, or investment climate
Commercially available alternative technology and equipment	Same as above, only technology is an alternative to conventional practice and may not be proven in the particular application, which will increase risk
Future R&D for new technology and equipment	Will require R&D to develop new technology and equipment that does not currently exist or is currently not technically feasible, practical, or economic
Future R&D for alternative technology and equipment	Same as above, only the technology will be take a completely different approach to providing thermal energy (e.g., alternate - innovative heat generation method, direct heat instead of steam)

1.2.3 Definition of Terms

Throughout this report a number of parameters are utilized to interpret the energy footprints and to describe energy use and losses. These are defined below, in alphabetical order.

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.

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

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

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.

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

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

Energy source flexibility – feasibility of alternative energy systems, such as using direct heat rather than steam or electricity, or systems fired with renewable fuels

.

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

Feedstock energy – energy 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/petroleum derivatives and natural gas.

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

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.

Motor systems– motor-driven systems, such as compressors, fans, pumps, materials handling and processing equipment, and refrigeration. Materials handling equipment includes conveyors and assembly processes that are typically 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.

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 approximately 3%.

Onsite losses– losses incurred in energy distribution and conversion systems, and in the central energy plant where steam and electricity are generated. Boiler generation losses represent energy lost due to boiler inefficiency. Onsite power generation losses are those associated with generation or cogeneration of electricity. Distribution losses represent steam heat lost in traps, valves, and steam pipes, and transmission losses in onsite fuel and electricity lines. Energy conversion losses occur in heat exchangers, preheat systems, motor driven systems, or other equipment where the transfer of energy from steam, direct heat or cooling, or electricity takes place, prior to delivery of energy to the process. In many cases energy conversion equipment is integrated directly with the process unit, making it difficult to estimate pre-process losses.

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

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.

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

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.

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

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).

Waste heat source reduction – reducing the amount of heat required through the use of innovative energy systems, heat integration, heating system redesign, or other means.

Waste heat recovery – recovering or recycling of high; medium; and low-temperature waste energy through means such as energy recycling, energy cascading, absorption heat pumps, optimized condensate recovery, or other technology.

Controls, automation, and robotics– advanced controls, automation, and robotics to improve energy system efficiency.

2.0 U.S. Manufacturing and Mining

2.1 Background

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. For example, mining provides raw materials for the production of intermediate steel products, which are then sent to forgers and fabricators, and supplied 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.

This study looks at the 16 industrial sectors described in Chapter 1, representing a large subset of the mining and manufacturing sector and capturing about 95% of energy consumption. Comparative rankings of the industries are provided for overall energy use, energy use in specific functional systems, and energy losses.

2.2 Energy Use and Loss Analysis

Overview

Primary energy – A snapshot of primary energy use (fuels and power, plus offsite losses) for the manufacturing and mining sector is shown in Table 2-1. 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].

Table 2-1 Snapshot of Energy Use and Losses in U.S. Manufacturing and 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	1343
Energy Conversion	2862	281	3143
Facilities Energy	**1405**	**neg**	**1405**
Energy Exported	**79**	**~0.01**	**79**
Energy Delivered to Processes	**10699**	**442**	**11141**

*Excludes feedstock energy.

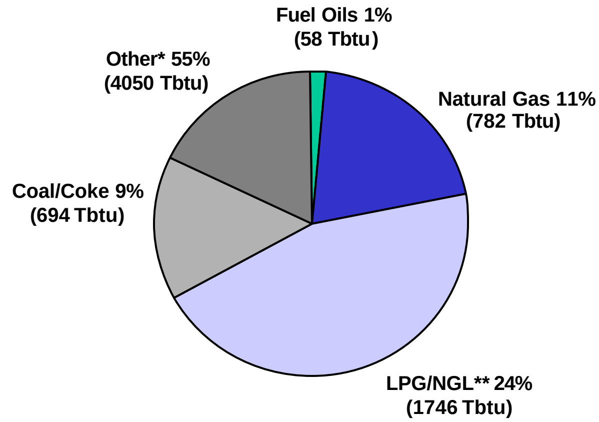
Fuel type – In manufacturing, natural gas accounts for the major portion of purchased fuel use, at about 38%, followed by smaller amounts of purchased electricity (17%) and coal, petroleum, and other fuels (13%). A significant portion of energy is byproduct fuels, which account for about 32% [MECS 1998]. Byproduct fuels are comprised mostly of fossil-based fuel gases and liquid byproducts, and wood processing byproducts. Major users of byproduct fuels include petroleum refining, chemicals, forest products, and iron and steel. Mining relies heavily on transportation fuels for both onsite transport and electricity to power drilling and other operations. [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 mentioned only in subsequent chapters to providing a context for 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 more than 33 quads. Of this total, feedstocks account for a substantial 22%. The largest users of feedstock energy include chemicals, petroleum refining, and iron and steel. Feedstock energy is used in small quantities in forest products, food and beverage, and textiles, and for anode manufacture.

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 energy associated with an industrial sector. With this approach, the petroleum and coal products industry ranks first 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 combusted fuels that produce byproducts later used as feedstocks. This adjustment is only significant for the chemicals, petroleum refining, and iron and steel industries.

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. Since it includes feedstock energy, however, it does not illustrate the energy that is used strictly for heat, cooling and power 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.



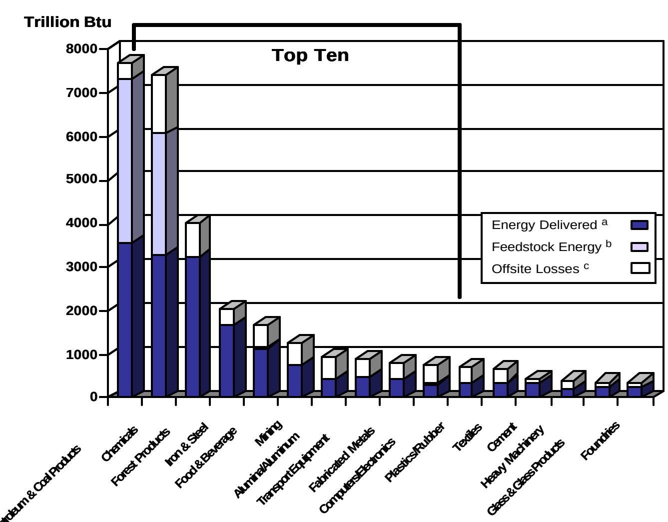
*Other includes petroleum-derived byproduct gases and solids, woody materials, hydrogen, and waste materials.

**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

For the purposes of this report, primary energy use and fuels and electricity (or power) use 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, *both external and internal to the plant boundary*. Fuels and power does not include offsite losses, and represents the energy associated with industrial processes strictly *inside the plant boundary*.

Differentiating between inside or outside the plant boundary is important when evaluating technology options for improving energy efficiency. Within the plant boundary, an industry has control over its energy consumption. Outside the plant boundary, where energy is generated by or provided by utilities, an industry has little or no control over technology efficiency. However, an industry can reduce energy losses associated with external energy supply by adopting technologies that allow it to generate more energy onsite more efficiently than the utility (e.g., cogeneration).

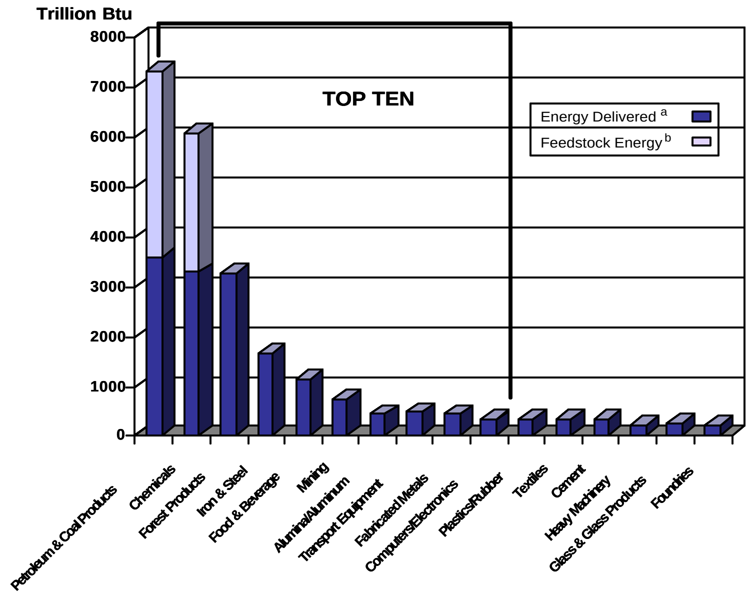


a Includes energy (fuels, power) delivered from utilities and energy generated onsite from byproducts.

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.

c Includes offsite losses incurred during the generation and transmission of electricity, and during transport of fuels through pipelines or other systems.

Figure 2-2 Total Energy Use in Manufacturing and Mining



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.

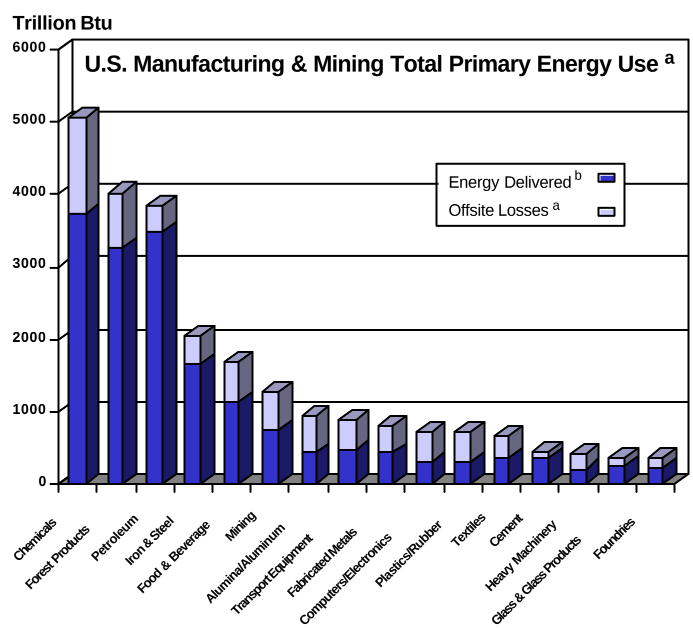
b Energy (mostly petroleum and natural gas) used to produce non-fuel products (e.g., chemicals, asphalt, tar); not included for iron and steel to avoid double-counting of energy inputs.

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

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 (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 approximately 30% of all U. S. energy use. As Figure 2-4 illustrates, energy use ranges widely across industrial sectors, with the heavy industries (chemicals, forest products, petroleum, iron and steel) emerging as the most energy-intensive.



a Includes offsite losses incurred during the generation and transmission of electricity, and during the transport of fuels through pipelines or other systems.

b 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.

Figure 2-4 U.S. Manufacturing and Mining Total Primary Energy

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

The top three industries share several characteristics 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, each consumes vast amounts of steam energy. Third, the energy efficiency of some core processes is far below optimal, 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 inefficiency" – elevate energy use in all other large, energy-intensive industries.

Table 2-2 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 users are 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 by industrial sector are: chemicals, petroleum refining, forest products, iron and steel, food and beverage, and mining.

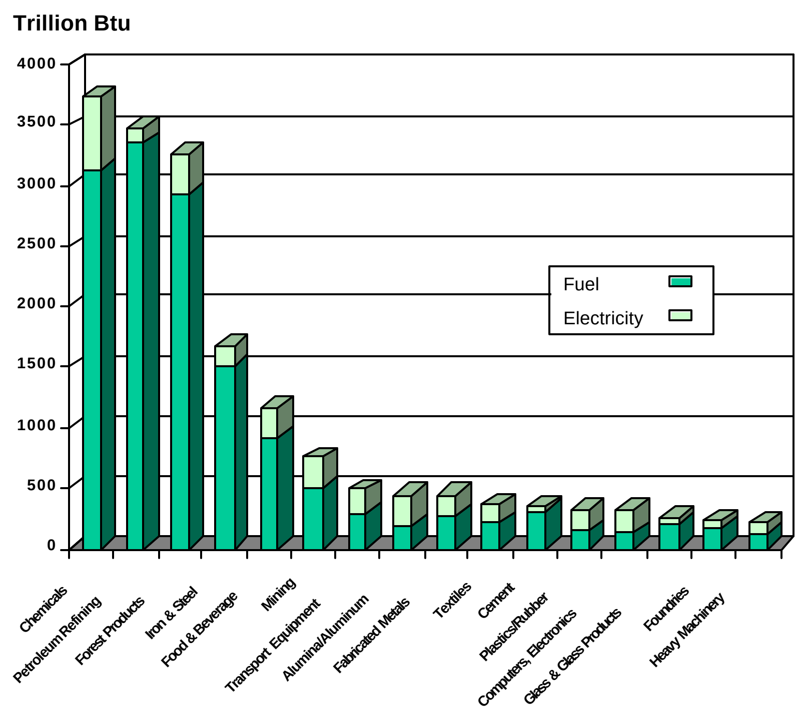


Figure 2-5 U.S. Manufacturing and Mining Direct Use of Fuel and Electricity

Table 2-3 Comparison of Fuel and Electricity 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 top ten ranking for total fuel and electricity use.

Table 2-3 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 2-3 illustrates, the top 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). Table 2-4 shows the relative importance of electricity and fuels for each sector, which is important when assessing the vulnerability of individual industries to energy price or energy supply volatility.

Table 2-4 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 accounts for 40% or more of energy requirements in these industries.

Table 2-4 % 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

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, all but one industry also rely heavily on byproduct fuels. Other relatively heavy fuel users include mining, food and beverage, fabricated metals, foundries, and glass making.

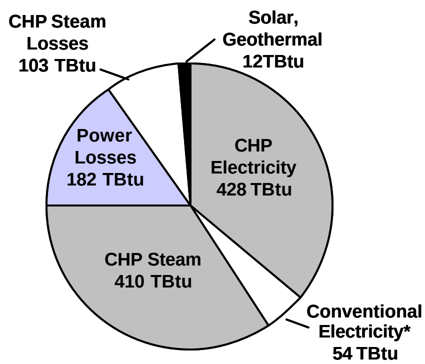
Onsite Generation and Electricity Demand

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 excess electricity exported offsite.

Electricity demand for individual industries is shown in Table 2-5, along with the percent of electricity that is generated and used onsite. 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 most dependent on electricity (i.e., greater than 40% of total energy use) rely almost entirely on purchased electricity. These industries include: aluminum, computers and electronics, plastics and rubber, heavy machinery.

Figure 2-6 illustrates the use of onsite power systems to meet demand for energy in manufacturing and mining. 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.

Cogeneration is the optimal choice for onsite generation, as it provides power and steam with thermal efficiencies 20-30% higher than non-cogenerated power. Despite its advantages, cogenerated steam currently only accounts for approximately 8% of total steam demand. The adoption of cogeneration is limited by large capital investments for power systems and the capacity to utilize additional steam onsite. As large steam and electricity users, chemicals, forest products, and petroleum refining are logically large cogenerators (see Table 2-5).



*Onsite power systems producing only electricity.

Figure 2-6 Onsite Power Generation and Loss Profile for Manufacturing and Mining

Table 2-5 Industries Ranked by Electricity Demand

Sector	Electricity Demand 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

End-Use Profile

Energy is consumed throughout industry to generate steam, to provide 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.

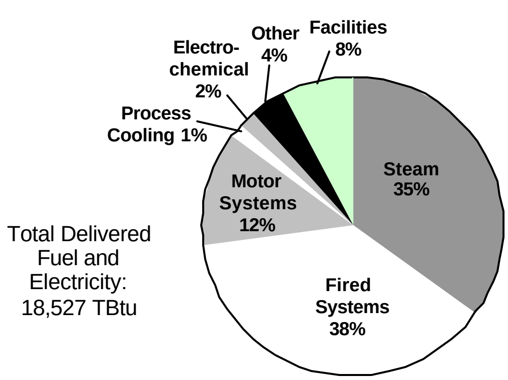


Figure 2-7 Energy End-Use in Manufacturing and Mining

Total fuel and electricity delivered to manufacturing and mining (excluding any offsite energy losses) totals more than 18.5 quads. Steam, fired systems and cooling systems dominate industrial energy use 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 systems 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 about 40% of energy use.

Other energy uses include mostly onsite transportation systems for conveying products within the plant boundary, and for the heating, cooling, and lighting of facilities. Energy for facilities conditioning averages about 8% industry-wide, but can be as little as 1% or less in some industries where operations are conducted mostly outdoors (e.g. mining) or more than 10-15% in highly conditioned facilities (e.g., cold or clean room operations).

Table 2-6 Industry Ranked by Steam Use		
Sector	Steam Use	
	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).

Use of steam by industrial sector is shown in Table 2-6, ranked by 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 particular sectors are discussed in the opportunities analyses of individual industries.

Fired systems account for a substantial share of energy use and losses. These systems are used widely across many industries for the direct and indirect heating of gases, fluids and solids (e.g., metals). As Table 2-7 illustrates, energy use attributed to fired systems is significant (more than a quad) in three industries (petroleum refining, iron and steel mills, and chemicals) and is prominent (above 200 TBtus) in another five industries. The primary fuel used for fired systems 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.

Table 2-8 shows the primary users of motor-driven equipment. Chemicals and forest products are the leading users, followed by mining and petroleum refining.

Table 2-7 Industries Ranked by Use of Fired Systems		
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

Table 2-8 Industry Ranked by Motor Systems Use		
Sector	Motor Use	
	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
Fabricated Metals	104	7
Heavy Machinery	99	8
Transportation Equipment	99	9
Plastics & Rubber	98	10
Textiles	85	11
Computers, Electronics	56	12
Cement	40	13
Alumina & Aluminum	33	14
Glass & Glass Products	22	15
Foundries	19	16

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 fuel losses in pipes and other transport and storage systems. Electricity losses are the result of turbine and power system efficiencies from (as low as 25% for older steam-based systems, up to 40% or more 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.

As stated earlier, 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 decrease 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 Sections 1.2.1 and 1.2.3). 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 highly specific to the industrial processes employed. This study estimates the onsite prior-to-process energy losses common to many industries, using standard loss factors obtained from literature and experts in their respective fields. 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 from left to right. This figure illustrates clearly that offsite losses are substantial, and in most cases much larger than those experienced onsite.

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 limited 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 its 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 2-8. The same is true to a lesser extent for forest products.

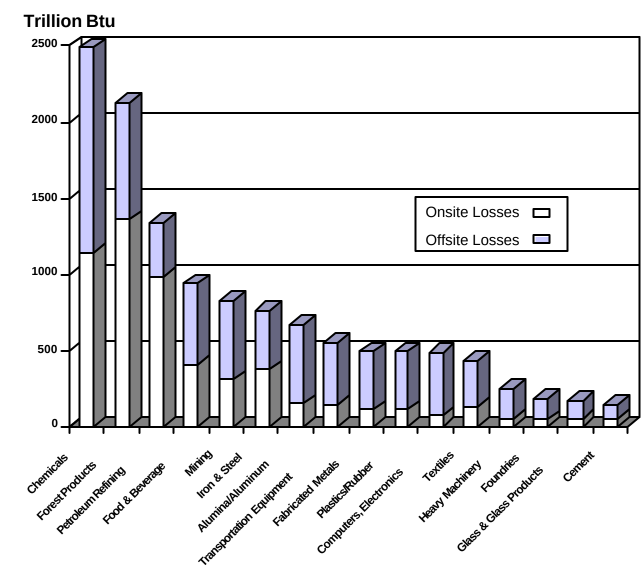


Figure 2-8 U.S. Manufacturing and Mining Offsite and Onsite Energy Losses

In targeting efficiency improvements for energy systems in industrial plants, it is important to define preliminarily 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 20–50% or more of energy inputs is possibly lost at the end of the process through exit gases, evaporative or radioactive heat losses, and in waste steam and hot water. This study does not attempt to determine these losses, but they can be considerable, as illustrated in Figure 2-9.

As noted previously, onsite losses are substantial and account for 32% of energy inputs to industrial plants. Translated, that means about one-third of energy input 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). Lost energy coupled with energy used to condition and light facilities, means only about 60% of the energy input is actually used to drive industrial processes. Thus of the 17.8 quads that arrive at industrial facilities, about 5.7 quads are lost prior to process units and never recovered.

Total Fuel and Electricity Use: 18,527 TBtu
Total Onsite Losses: 5,902 TBtu

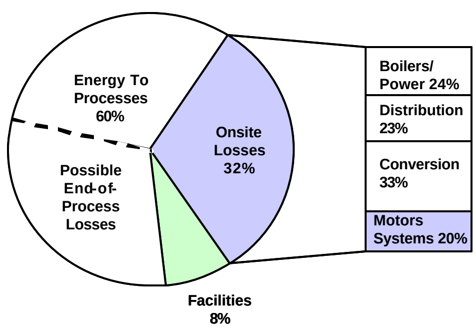


Figure 2-9 Onsite Energy Loss Profile for U.S. Manufacturing and Mining Sector

Energy conversion systems (heat exchangers, preheaters, heat pumps, reboilers, condensers, and others) account for about one-third of onsite losses, and represent large targets for improvement. The remainder of onsite 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 10 out of 16 industries, offsite losses account for more than 25% of energy use (i.e., 25% of energy entering the plant is lost due to equipment and distribution system inefficiencies). In seven of these industries, onsite losses are more than one-third of fuel and electricity inputs.

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

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

System-Specific Losses

Examining 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 systems and cooling systems. Steam system losses account for the largest share of losses in this category, at 2.8 quads, or about 45% of total energy input to steam systems. Fired heating and cooling systems account for another 1.3 quads, or about 18% of energy inputs to those systems. Motor system losses, which include losses in motor windings as well as mechanical components in pumps, compressors, and so forth, amount to 1.3 quads or 55% of motor system 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 does not include 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 (if just the distribution and conversion losses are taken into consideration), the assumption could be made that these systems are roughly 80% efficient. When considered from when energy enters the plant gate to the end of the process, as much as 50% 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 generally outside the scope of the study, although they are examined to some extent in the opportunities analysis from the perspective of recoverable energy.

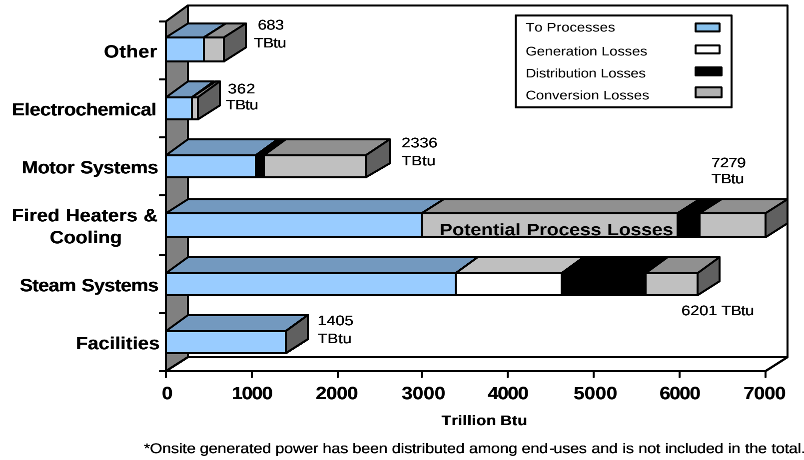


Figure 2-10 Energy End-Use and Loss Distributions in Manufacturing and Mining

Table 2-10 Manufacturing Energy Use and Losses (Trillion Btus)

	To Process/ End-use	Generation Losses	Distribution Losses	Conversion Losses	Total Onsite Losses	Associated Carbon (MMTCE)**	Total Energy
Facilities	1405	na	na	na	na	Na	1405
Steam Systems	3382	1234	987	598	2819	49.3	6201
Fired Systems and Cooling	5983	na	256	1040	1296	20.9	7279
Motor Systems	1047	na	85	1204	1289	24.2	2336
Electrochemical	295	na	15	52	67	1.3	362
Other Uses	434	na	Na	249	249	1.2	683
Onsite Power	*(482)	182	Na	na	182	3.6	182
Export of Power	79	na	Na	na	na	0	79
TOTALS	12625	1416	1343	3143	5902	103.9	18527

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

**Carbon emissions associated with energy losses, in million metric tons of carbon equivalents (MMTCE).

The carbon emissions (in million metric tons of carbon equivalent – MMTCE) associated with energy losses in the U.S. manufacturing and mining sectors are also shown in Table 2-10. These total nearly 104 MMTCE, which represents about 7% of carbon emissions in the United States from anthropogenic (manmade) sources. The carbon emissions shown in Table 2-10 are those generated by the combustion of fuels. Smaller amounts not shown here are also generated through fugitive emissions, and as byproducts of ammonia, lime and soda ash manufacture.

Figure 2-11 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, and are reported as boiler losses. The remaining losses occur in distribution and conversion. Distribution losses (including pipes and valves) were estimated to be approximately 15% of steam systems energy inputs.

Energy conversion systems are closely connected with process units, resulting in some overlap of steam conversion losses and those that occur both in process units and at the end of the process. These end-of-process losses have not been studied fully, but are estimated to some degree in the opportunities analysis.

Boiler capacity and size varies by industry. Overall, the largest share of boilers are in the 100-250 MMBtu/hr capacity range (35%), followed by boilers in the 250-500 MMBtu/hr range (23%), and 50-100 MMBtu/hr range (18%). Chemicals, petroleum refining, food processing, and forest products dominate the industrial boiler population, with more than 70% of package boiler capacity [ADL 2000].

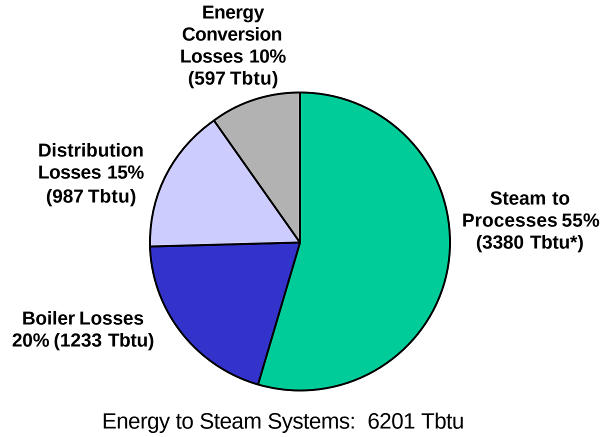


Figure 2-11 Steam Use and Losses in Manufacturing and Mining

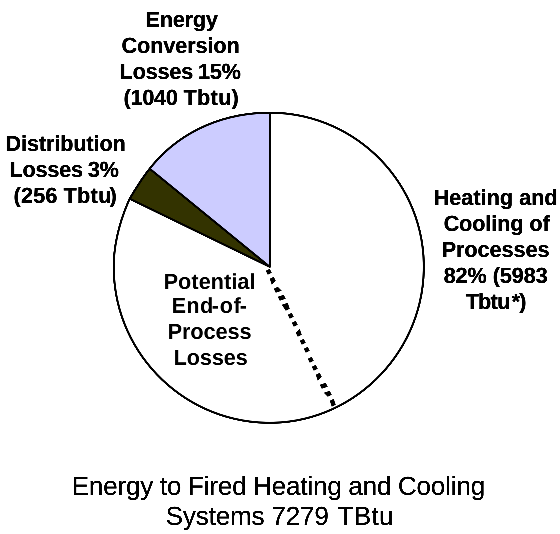


Figure 2-12 Profile of Energy Use and Losses in Fired Systems

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

Again, these systems are often connected integrally with process units, and pre-process losses were separated using the assumption that approximately half of energy conversion losses would occur upstream, and the remainder downstream. While significant energy losses may also occur in the actual process units, estimation of these losses is outside the scope of this study. They are addressed in part in subsequent opportunities analyses of several industries notably chemicals, petroleum refining, forest products, cement, and food processing.

A profile of motor use and losses is shown in Figure 2-13. This figure portrays 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 input is not converted to useful work. Compressed air systems are also extremely inefficient, converting typically only about 10-15% of energy inputs to useful work. Total losses in motors and motor-driven systems amount to 1.2 quads.

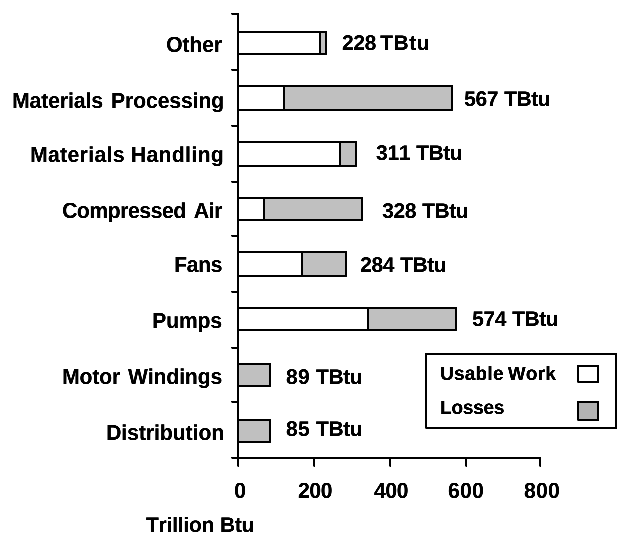


Figure 2-13 Motor System Energy Use and Loss Profile for Manufacturing and Mining

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. Chemical products are critical components of consumer goods and are found in everything from automobiles to plastics and electronics.

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 materials.

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 constrained by thermodynamic, kinetic, or transport limitations, and operating conditions may be severe (high temperatures, high 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

Overview

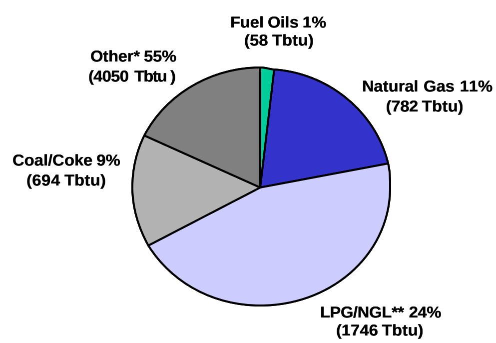
A snapshot of how the chemical industry ranks in terms of energy use and losses within manufacturing and mining is shown in Table 3-1. The chemical industry ranks in the top two in every energy end-use category. The industry is a large user of steam and fired systems, and ranks number one in energy used 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 of process energy use [MECS 1998].

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 energy is combined with fuels and electricity, total energy use amounts to about 6.2 quads.

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

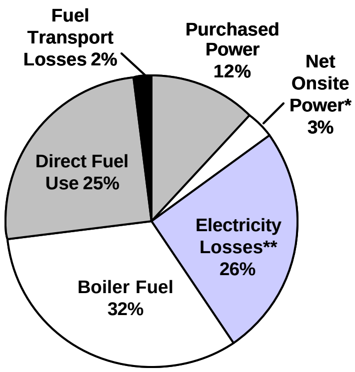
*Does not include feedstock energy



*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 3-1 Feedstock Energy Use in the Chemicals Industry – 2.8 Quads



* Includes 25 TBtu electricity export.
** Includes offsite and onsite electricity generation losses.

Figure 3-2 Primary Energy Use in U.S. Chemical Industry - 5074 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 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 improved greatly through the use of cogeneration. About 20% of chemical industry electricity demand is met by onsite power systems, and the industry is the second largest industrial cogenerator, 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. The chemical industry relies on hundreds of different chemical processes, and as a result, energy use patterns vary dramatically across sectors. Processes used to produce petrochemicals, for example, are distillation- and steam-intensive, resulting in substantial fuel consumption, while chlorine production depends heavily on electricity and electrolytic cells.

Figure 3-3 illustrates the energy use patterns across major sectors. Overall, the production of organic chemicals (petrochemicals plus other organics), 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.

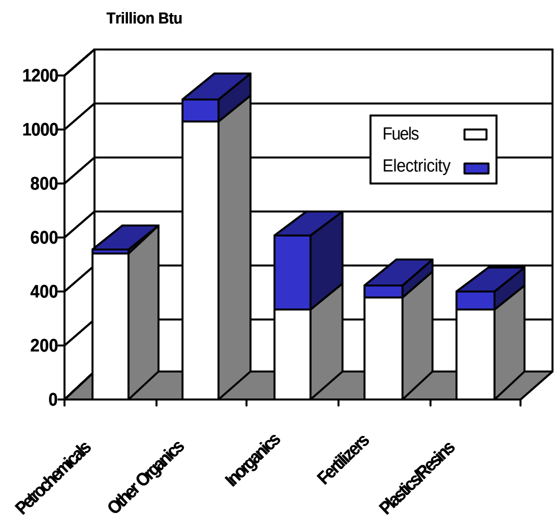
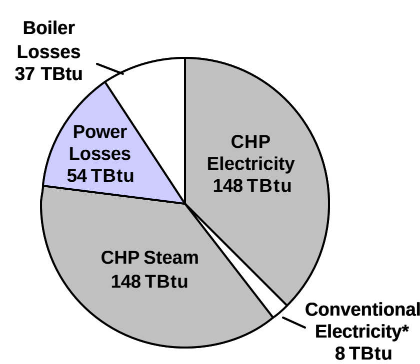


Figure 3-3 Fuel and Electricity Use in Selected Chemical Industry Sectors

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, and provides the most complete picture of actual electricity use. On average, electricity use accounts for about 16% of energy consumption across the industry. However, several sectors are electricity-intensive, such as alkali 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 (see Figure 3-4). About 95% of electricity produced onsite in the chemicals industry comes from cogenerating units, which also produce almost 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.



* Steam or gas turbines not producing steam for process use

Figure 3-4 Onsite Power Generation Profile for Chemicals

End-Use Profile

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

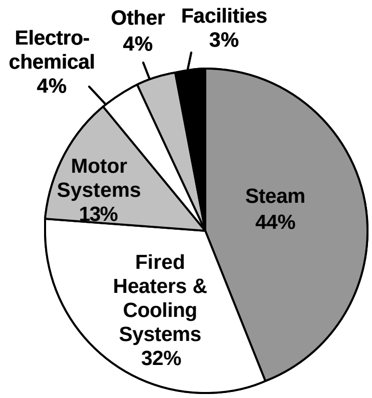


Figure 3-5 Energy End-Use in the Chemicals Industry: Total Delivered Fuel and Electricity - 3729 Trillion Btu

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 systems 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 approximately 3% of energy use.

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

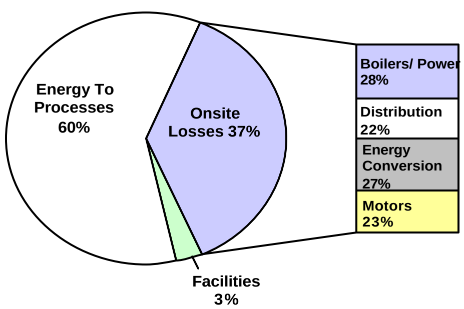


Figure 3-6 Onsite Energy Loss Profile for the Chemical Industry (NAICS 325) Total Onsite Losses – 1363 Trillion Btu

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 supplying energy to process operations or converting energy to usable work (see Chapter 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" in Figure 3-6 includes a significant amount of energy that is lost at the end of the process in exhaust gases, waste steam, hot water, and other waste sources. These potential losses are approximated in Figure 3-7.

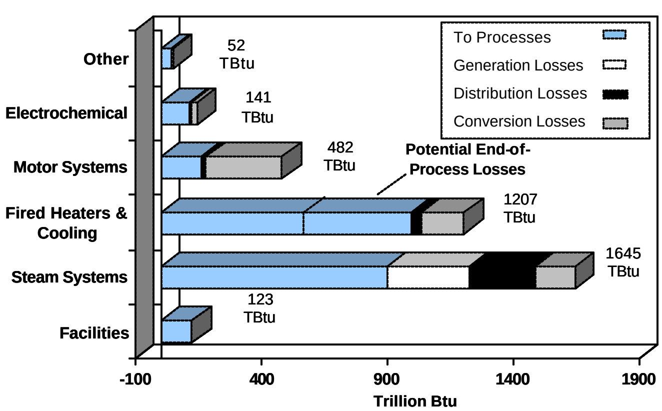


Figure 3-7 Energy End-Use and Loss Distributions in Chemicals (NAICS 325)

System-Specific Losses

Detailed energy use and losses for component systems are summarized in Figure 3-7 and Table 3-2. Total onsite losses are nearly 1.4 quads; associated carbon emissions are 23 million metric tons of carbon equivalent (MMTCE).

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 systems and cooling or refrigeration units. In terms of trillion Btus, steam system losses are the highest and represent 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.

Table 3-2 Chemicals Energy Use and Losses (Trillion Btus)

	To Process/ End-use	Generation Losses	Distribution Losses	Conversion Losses	TOTAL Onsite Losses	Associated Carbon (MMTCE)**	Total Energy
Facilities	123	na	na	na	na	0	123
Steam Systems	897	328	262	158	748	12.8	1645
Fired Systems & Cooling	997	na	38	172	210	3.0	1207
Motor Systems	163	na	18	301	319	5.9	482
Electrochemical	117	na	4	20	24	0.5	141
Other Uses	44	na	na	28	28	0.1	52
Onsite Power	(156)*	54	na	na	54	0.8	54
Export of Power	25	na	na	na		-	25
TOTALS	**2366**	**382**	**322**	**659**	**1363**	**23.0**	**3729**

*Onsite-generated power has been distributed among end-uses and is not included in the totals.
**Carbon emissions associated with total energy losses, in million metric tons of carbon equivalent (MMTCE).

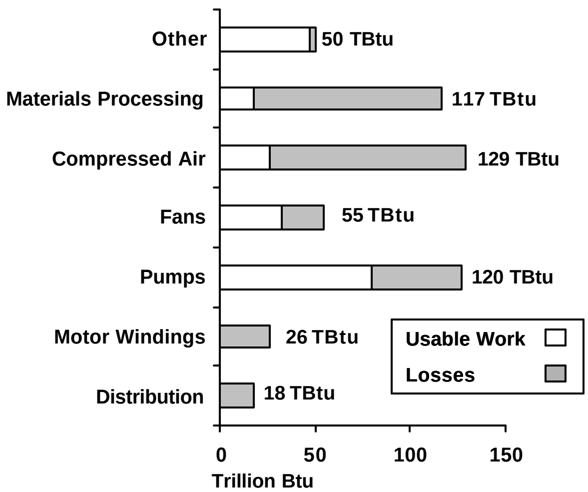


Figure 3-8 Chemical Industry Motor System Energy Use and Loss Profile

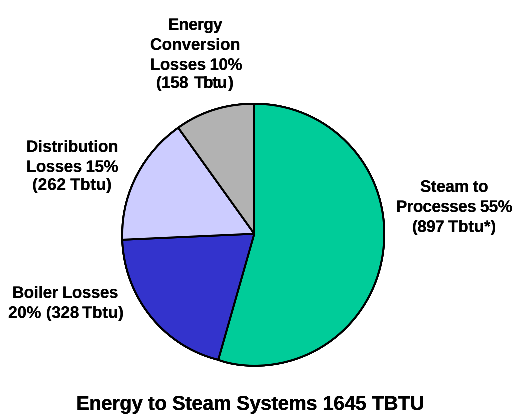


Figure 3-9 Steam System Use and Loss Profile for the Chemical Industry

A **motor use** profile for chemicals is shown in Figure 3-8. The losses, indicated in gray, illustrate the substantial amount of energy that is 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 total about 319 trillion Btu. Most motor systems are powered by 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. A large percentage of losses occur in the boiler, where thermal efficiencies range between 55-85%, depending upon the age of the boiler and type of fuel burned. Waste heat boilers, for example, have lower overall thermal efficiency than natural gas-fired boilers. A little less than half of the package boiler population in the chemical industry is larger capacity (250->1500 MMBtu/hr). Waste heat boilers comprise a significant share of the population – about one-third [ADL 2000].

In **fired systems**, the bulk of losses occur in energy conversion prior to the process. As noted earlier, additional downstream losses could be substantial, but are not estimated here.

3.3 Opportunities Analysis

Energy losses in steam and fired systems in chemicals manufacture total nearly one quad and are a prime target for efficiency improvements. However, steam and fired systems are often linked integrally in many chemical processes, making it difficult to separate thermal requirements and efficiencies. The opportunities presented here are therefore shown as a combination of both steam and fired systems. The chemical chains chosen for study are shown in Table 3-3, and all rank among the top 100 chemicals (ranked by annual production volume). Table 3-4 illustrates the total use of thermal energy and associated end-of-process losses for the selected chemicals, by chemical chain. Tables C-1 and C-2 in Appendix C provide details on equipment, assumed efficiencies, sources of energy losses, references, and other data relative to the opportunities analysis.

Table 3-3 Chemical Chains Selected for Study
Ethylene
Polyethylene
Ethylene Dichloride
Poly Vinyl Chloride
Ethylene Oxide
Ethylene Glycol
Polystyrene
Propylene
Polypropylene
Propylene Oxide
Acrylonitrile
Acrylic Fiber
Benzene-Toluene-Xylene
Ethylbenzene
Styrene
Cumene
Phenol/Acetone
Terephthalic Acid
Cyclohexene
Adipic Acid
Caprolactam]
Nylon 6.6, Nylon 6
Agricultural Chemicals
Ammonia
Urea
Nitric Acid
Ammonia Nitrate
Ammonia Sulfate
Sulfuric Acid
Ammonia Phosphate
Superphosphates
Chlor-Alkali
Caustic Soda
Soda Ash

Organic chemicals production is the largest consumer of thermal energy. The most energy-intensive chemicals include ethylene, polyethylene, propylene, polypropylene, propylene oxide, BTX (benzene-toluene-xylene), ethylbenzene/ styrene, and polystyrene. Steam energy is used in preheaters, reactors, superheaters, evaporators, vacuum and distillation columns, and various other types of equipment. It is also charged directly with feeds or products for dilution or stripping. In these cases the steam may be contaminated and more difficult to recycle. The bulk of the steam use in ethylene production, for example, occurs in dilution processes, followed by fractionation, and acetylene removal. Fired systems for organics include reboilers, furnaces, dryers, evaporators, reformers, and other equipment. The ethylene direct-fired pyrolysis furnace is one of the most energy-intensive fired systems used in chemicals production.

The largest sources of energy losses are exit gases (flared gases, waste gases, vent gases, flue gases) and waste steam or water. Waste heat reduction and recovery thus represents the greatest opportunity for reducing losses in the chemical industry, including the use of waste energy streams for cogeneration. In organic chemicals, the manufacture of olefins (ethylene, polyethylene) and their polymers and derivatives (such as ethylbenzene and styrene) represent significant sources of waste gases and flared gases with potential for heat recovery. Successful technology options would require the capability for recovery of waste energy streams with a wide temperature range and quality, as well as that for potential contaminants and corrosive agents.

The production of inorganic chemicals is relatively low in energy-intensity compared to that of organic chemicals, with the exception of ammonia and chlorine/sodium hydroxide (chlor-alkali) production. Ammonia is produced by steam reforming of methane, and consumes large quantities of steam for both reforming and stripping. Chlor-alkali production consumes steam energy in multiple evaporators, brine heaters, and strippers. Many inorganic chemical production processes also use fired systems for drying and calcining operations. Within inorganic chemicals, the steam reformer is a significant source of waste heat with increased recovery potential. There are also opportunities for recovering heat from dryers and kilns used in the manufacture of fertilizers, many of which are relatively inefficient.

The chemicals studied represent about 40% of the process energy used in the chemical industry, and in most cases highly conservative estimates of energy recovery were applied (5-10% of waste heat). As a result, the estimated loss reduction of 114 TBtu shown in Table 3-3 significantly under-reports the potential for energy recovery in chemicals manufacture. To make a preliminary evaluation of the remaining energy use in the industry, the end result for heat recovery for the selected chemicals was extrapolated to the remaining energy used for boilers and fired systems in the industry to obtain an order of magnitude estimate of additional possible energy savings. The assumption is that an average of 10% of total fuel inputs can be recovered in waste heat throughout the industry. This brings total potentially recoverable energy up to 294 TBtu, which is still a strongly conservative result. A recent study looking at recoverable "exergy" in 18 major chemical products estimated that as much as 900 TBtu could be recoverable, primarily as waste heat [Bandwidth 2004].

The estimated energy savings shown in Table 3-4 were applied to the development of the Top Twenty Opportunities. These are outlined in more detail in Chapter 11 and Appendix C.

Table 3-4 CHEMICALS: COMBINED STEAM AND FIRED SYSTEMS Roll-Up Opportunities Analysis

Chemical Process	Fired Heaters/ Boilers Used	Total Energy From Fuels 10^12 Btu/yr	Average % Waste Heat To Be Recovered	Nature of Waste Heat	Energy Loss Recovery or Reduction Category: Waste heat reduction	Waste heat recovery	Energy Source Flexibility	Controls, Automation, Robotics	CHP (fired and other)	Motors & Drives	*Savings Tbtu/year*
The Ethylene Chain											
Ethylene	Yes	186.3	10.00	Waste gases		X		X	X		*18.63*
Polyethlene	Yes	8.2	5.00	Waste gases		X		X	X		*0.41*
Ethylene Dichloride		56		Waste gases		X		X	X		*0.00*
Poly Vinyl Chloride	Yes	14	5.00	Waste gases		X		X	X		*0.70*
Ethylene Oxide	Yes	8.8	5.00	Waste gases		X		X	X		*0.44*
Ethylene Glycol	Yes	8.6	5.00	Waste gases		X		X	X		*0.43*
Polystyrene	Yes	65	7.50	Waste gases		X		X	X		*4.88*
TOTAL		**346.9**									***25.49***
The Propylene Chain											
Propylene	Yes	31.9	10.00								*3.19*
Polypropylene - 1997		4.2	3.00	Flared gases		X			X		*0.13*
Propylene Oxide - 1997	Yes	8.1	5.00								*0.41*
Acrylonitrile	Yes	3	10.00	Flared waste gases - Hydrogen Cyanide		X			X		*0.27*
Acrylic Acid	Yes	8.4	10.00	Waste Gases		X					*0.84*
Acrylic Fiber		9	5.00	Gases from polymerization reactor, solvent vapors			X				*0.43*
TOTAL		**56**									***5.27***

Table 3-4 CHEMICALS: COMBINED STEAM AND FIRED SYSTEMS Roll-Up Opportunities Analysis (continued)

Chemical Process	Fired Heaters/ Boilers Used	Total Energy From Fuels 10^12 Btu/yr	Average % Waste Heat To Be Recovered	Nature of Waste Heat	Energy Loss Recovery or Reduction Category: Waste heat reduction	Waste heat recovery	Energy Source Flexibility	Controls, Automation, Robotics	CHP (fired and other)	Motors & Drives	*Savings Tbtu/year*
The BTX Chain (Benzene, Toluene, Xylene)											
BTX	Yes	34.2	10.00			X			X		*3.42*
Benzene	Yes	3.1	10.00			X			X		*0.31*
Ethylbenzene		19	5.00	Vent gases, boiler waste heat recovery		X			X		*0.95*
Styrene	Yes	109.8	7.50	Heater flue gases		X			X		*8.24*
Polystyrene	Yes	13.7	7.50			X			X		*1.03*
Cumene		4	5.00			X			X		*0.20*
Phenol/Acetone		54.3	-								*0.00*
Terephthalic Acid	Yes	11.7	5.00	Oxidation process			X				*0.59*
Cyclohexene		3.6									*0.00*
Adipic Acid		31.7									*0.00*
Caprolactam		20.8									*0.00*
Nylon 6.6	Yes	11.1	5.00				X				*0.56*
Nylon 6	Yes	4	5.00								*0.20*
TOTAL		**521**									***15.3***

Table 3-4 CHEMICALS: COMBINED STEAM AND FIRED SYSTEMS Roll-Up Opportunities Analysis (continued)

Chemical Process	Fired systems/ Boilers Used	Total Energy From Fuels 10^12 Btu/yr	Average % Waste Heat To Be Recovered	Nature of Waste Heat	Energy Loss Recovery or Reduction Category: Waste heat reduction	Waste heat recovery	Energy Source Flexibility	Controls, Automation, Robotics	CHP (fired and other)	Motors & Drives	*Savings Tbtu/year*
Agricultural Chemicals - Fertilizers											
Ammonia	Yes	319	10.00	Reformer waste heat		X		X	X		*31.90*
Urea		8.8	2.50			X		X	X		*0.22*
Nitric Acid	Yes	3.6	5.00	Process modification using CHP system		X	X	X	X		*0.18*
Ammonia Nitrate		2.8	-			X		X	X		*0.00*
Ammonia Sulfate		13.4	2.50	Steam replacement		X	X	X	X		*0.34*
Sulfuric Acid		2.2	-			X		X	X		*0.00*
Phosphoric Acid (Furnace Process)	Yes	9.6	5.00	Waste heat		X		X	X		*0.48*
Ammonia Phosphate	Yes	4.6	5.00	Drying system heat	X	X		X	X		*0.23*
Superphosphates	Yes	1.2	5.00	Drying system heat	X	X		X	X		*0.06*
TOTAL		**379.3**									***33.41***
The Chlor-Alkali Industry											
Caustics (Chlorine/Sodium Hydroxide)	Yes	75.8	10.00	Use of CHP, heater flue gases	X	X		X	X		*7.58*
Soda Ash (Sodium Carbonate)	Yes	77.3	10.00	Use of CHP, heater flue gases	X	X		X	X		*7.73*
TOTAL		**153.1**									***15.31***
INDUSTRY SUBTOTAL		**1456**									***94***
Industry Remaining		**1995***									***200***
INDUSTRY TOTAL		**3451**									***294***

* The end result for waste heat recovery for the top chemicals was extrapolated to the remaining energy used for boilers and fired systems in the industry to obtain an order of magnitude estimate of additional possible energy savings. The assumption is that an average of 10% of total fuel inputs can be recovered in waste heat.

4.0 Petroleum Refining Industry (NAICS 324110)

4.1 Overview of the Petroleum Refining Industry

Petroleum is the largest energy resource used in the United States. Petroleum consumption is four times higher than that of nuclear power or renewable energy, and even two times higher than that of coal or natural gas. In the United States, 155 refineries 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 United States is the largest producer of petroleum products, with almost 30% of the global market and an annual production of six billion barrels of refined products [EIA 2003].

Petroleum and Coal Products Manufacturing Sub-sectors
Petroleum Refineries (NAICS 324110)
Asphalt Paving, Roofing, and Saturated Materials
Asphalt Paving Mixture and Block
Other Petroleum and Coal Products
Petroleum Lubricating Oil and Grease
All Other Petroleum and Coal Products
Crude Petroleum and Natural Gas Extraction
Natural Gas Liquid Extraction

Petroleum refineries are the second largest process 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 annually in pollution abatement practices, 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 discussion refers only to petroleum refining (NAICS 324110), which accounts for 90% of the petroleum and coal products industry shipments. NAICS descriptions are provided in Appendix D.

4.2 Energy Use and Loss Analysis for Petroleum Refining

Overview

A snapshot of how the petroleum refining industry ranks in terms of process energy use and losses within manufacturing and mining is shown in Table 4-1. Petroleum refining ranks among the top third in a number of categories, and is the largest user of fired systems and fuels. The industry's main source of fuels consists of byproducts from petroleum refining (66%) which consist mostly of refinery or 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 feedstock energy to produce non-energy products such as ethane, propane, naphtha, ethylene, butane, butylene, propylene, toluene, and xylene. Energy feedstocks used to produce energy products (e.g., gasoline) are not considered in this report.

Table 4-1 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

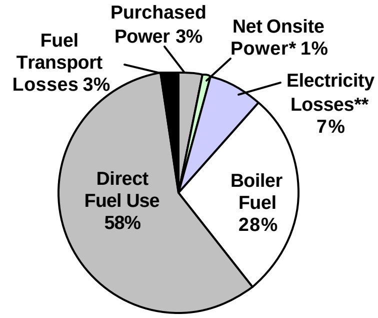
Total feedstock use for petroleum and coal products (NAICS 324) is 3.7 quads [MECS 1998]. When feedstock is combined with fuels and electricity, total energy use is 7.2 quads. Feedstocks are mainly petroleum-based, and contribute directly to our use of imported oil. LPG, a primary feedstock, is comprised of gases derived from refinery processes or natural gas processing plants that fractionate new natural gas plant liquids. LPG consists of a mixture of gases such as ethane, ethylene, propane, propylene, normal butane, butylenes, and isobutene. Heavy liquids and tars from distillation towers, thermal cracking, and other operations are also used to produce products such as wax, asphalt, and roofing tar.

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 provides a more complete perspective on the total energy use associated with the industry, and includes purchased fuels, electricity, byproduct fuels, and the energy losses associated with offsite power generation.

As shown in Figure 4-1, offsite energy losses occurring during electricity generation and transport constitute about 10% of primary energy. Most of these energy losses (7%) occur during the generation of electricity at offsite utilities, where the efficiency of generating systems can be as low as 28-30%.

Direct fuel use constitutes a major source of energy consumption in refining. Direct fuel is used to fire furnaces, reboilers in distillation columns, thermal and catalytic crackers and cokers, reactors and other equipment. Steam is the second largest use of fuels, and is used for steam stripping and other purposes, with the steam often in direct contact with products.



*Excludes losses

**Includes both offsite and onsite losses.

Figure 4-1 Primary Energy Use in the U.S. Petroleum Refining Industry – 3838 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 in refineries is fuels. Petroleum refineries supply a variety of fuel and non-fuel products, and energy use patterns depend on product slate, which can change regularly along with market demand. Figure 4-2 compares fuel and electricity consumption patterns for the petroleum refining and coal products industry sectors.

Fuels production dominates the energy use, with gasoline, jet fuel, and fuel oils representing 90% of product output from refineries. The remaining 10% of products include road oil, asphalt, lubricants, non-fuel coke, waxes, and petrochemicals [EIA 2002].

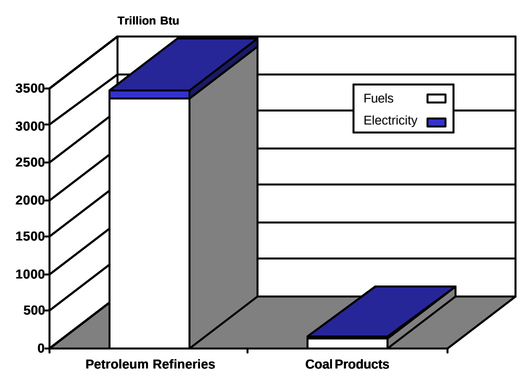
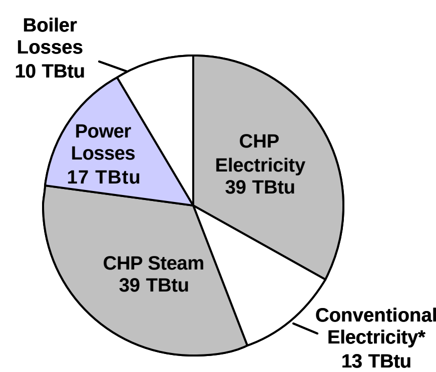


Figure 4-2 Fuel and Electricity Use in Petroleum and Coal Products (NAICS 324)

Onsite Generation and Electricity Demand

The petroleum refining industry is a relatively low user of power and ranks eleventh in demand for electricity, at 174 TBtu in 1998. Electricity use accounts for only 4% of the total energy consumption in refineries.

Petroleum refineries, however, are the third largest cogenerators 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 significant demand for steam, and produces enough waste heat and byproduct fuels to make cogeneration an attractive and economic option. Since 1985, cogeneration in the industry has more than tripled. About 108 trillion Btu of its energy use is associated with the production of onsite electricity, as shown in Figure 4-3.



*Onsite power systems producing only electricity.

Figure 4-3 Onsite Power Generation Profile for Petroleum Refining

End-Use Profile

The petroleum refining industry consumes energy to supply 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. The largest use of energy in petroleum refining is for process heating and cooling, which includes fired systems, cooling, and steam systems.

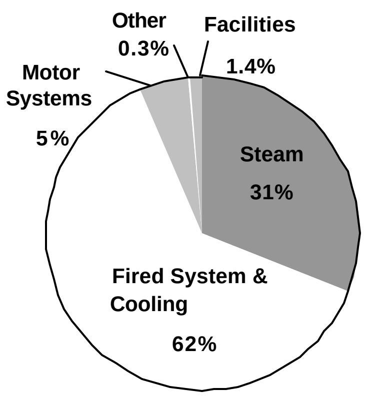


Figure 4-4 Energy Use in Petroleum Refining: Total Delivered Fuel and Electricity – 3478 Trillion Btu

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 petroleum refining energy use. Petroleum refining ranks first in fired systems energy use, accounting for 30% of the total energy use for fired systems 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 opportunities for energy efficiency improvements. The general flow of energy and losses within the average petroleum refinery is illustrated in Figure 4-5, 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 distributed evenly among boilers and power generation, distribution, and motor systems. Energy losses that occur at the end of the process are not included and can be substantial (approximated by dotted line in Figure 4-5).

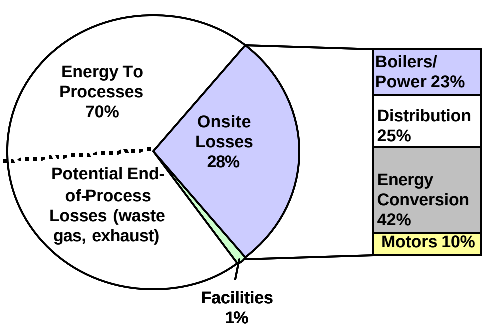


Figure 4-5 Onsite Energy Loss Profile for Petroleum Refining: Total Onsite Losses – 958 Trillion Btu

System-Specific Losses

Figure 4-6 and Table 4-2 shows in detail the energy use and losses for component systems. Onsite losses total about one quad; associated carbon emissions amount to nearly 16 MMTCE.

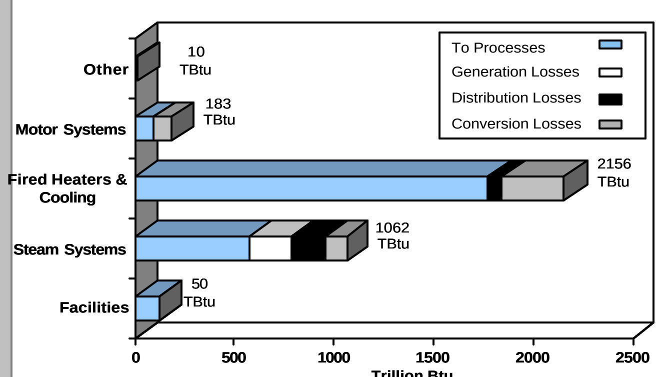


Figure 4-6 Energy End-use and Loss Distributions in Petroleum Refining (NAICS

As shown in Figure 4-6, the largest energy losses occur in fired systems and cooling (includes fired systems and cooling units) and steam 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.

Table 4-2 Petroleum Refining Energy Use and Losses (Trillion Btus)							
	To Process/ End-use	Generation Losses	Distribution Losses	Conversion Losses	TOTAL Onsite Losses	Associated Carbon (MMTCE)**	Total Energy
Facilities	50	na	na	na	na	na	50
Steam Systems	578	212	170	102	484	7.9	1062
Fired Systems & Cooling	1776	na	68	312	380	5.7	2156
Motor Systems	89	na	5	89	94	1.7	183
Electrochemical					0	0.0	0
Other Uses	7	na	na	3	3	0.0	10
Onsite Power	(52)*	17	na	na	17	0.3	17
Export of Power	1	na	na	na		0.0	1
TOTALS	**2501**	**229**	**243**	**506**	**978**	**15.6**	**3479**

*Onsite generated power has been distributed among end-uses and is not included in the totals.
**Carbon emissions associated with total energy losses, in million metric tons of carbon equivalent (MMTCE).

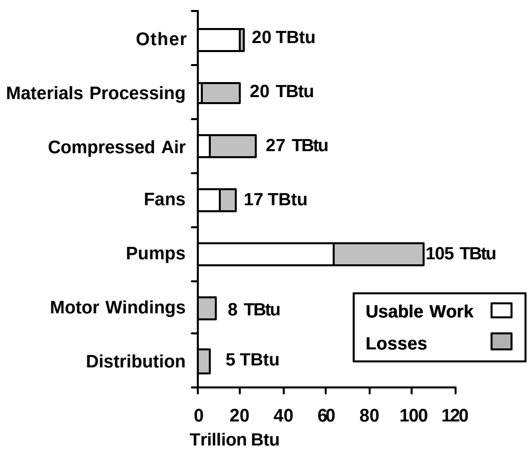
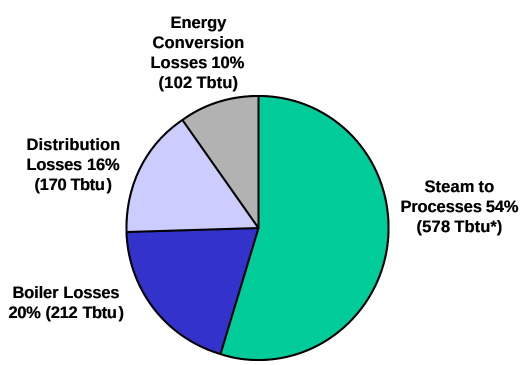


Figure 4-7 Petroleum Refining Motor System Energy Use and Loss Profile



Energy to Steam Systems 1062 TBTU

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

A breakdown of energy use and losses in motor systems 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 energy inputs.

The highest motor system losses occur during energy conversion, and these total 89 TBtu for the industry. Additional conversion losses take place in motor windings (eight TBtu). More than 92% of the energy used for motor systems consists of electricity (146 trillion Btu); fuels comprise the remainder.

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 via system inefficiencies. Boiler inefficiencies account for the largest losses (20%), followed by distribution losses (16%). Throughout industry, boiler efficiencies range between 55-85%, 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.

About 33% of the boiler population in petroleum refining are large, field-erected boilers; the remaining 67% are package boilers in a wide range of capacities. Of the entire population, most boilers are in the 250-500 MMBtu/hr (33%) and 500-1500 MMBtu/hr (29%) capacity range.

4.3 Opportunities Analysis

An analysis to identify opportunities for reducing or recouping energy losses was conducted for both steam and fired systems in petroleum refining. The processes covered in the analysis are shown in Table 4-3. The top energy consuming processes include distillation (atmospheric and vacuum), hydrotreating, alkylation, and reforming. Some processes, such as thermal cracking and fluid catalytic cracking, produce excess heat and steam and are either net energy exporters or produce a good portion of the energy required to fuel the process. However, these processes can still be targets for efficiency improvements or energy loss reduction.

Steam Systems

Table 4-3 Refining Processes Covered by the Analysis
Atmospheric Distillation
Vacuum Distillation
Visbreaking
Coking Operations
Fluid Catalytic Cracking
Catalytic Hydrocracking
Catalytic Hydrotreating
Catalytic Reforming
Alkylation
Isomers

The petroleum refining industry is the third largest steam user in U.S. manufacturing and mining sectors. Table 4-4 illustrates the use of steam in the industry by selected processes and the potential end-of-process energy losses, based on a recent steam assessment study [RDC 2002].

The most steam-intensive processes are atmospheric and vacuum distillation, catalytic hydrotreating, alkylation, and catalytic reforming. For all these processes except vacuum distillation the average thermal efficiency was assumed to be 40%, as most of these processes are stripping or fractionating processes where the steam comes in contact with the hydrocarbon stream, making steam recovery more difficult. The efficiency of vacuum distillation was assumed to be somewhat higher (55%) as a portion of the steam is used for creating a vacuum in the tower, a typically more efficient use of steam. Table C-3 in Appendix C provides the details on the equipment used, the steam efficiencies assumed for each process, the major sources of energy losses, references, and other pertinent data.

Atmospheric and vacuum distillation, followed by alkylation, isomers, and catalytic reforming represent the best areas of opportunity for energy savings through advances or improvements in steam systems. The total potential energy savings through future R&D and new equipment technologies amounts to about 100 trillion Btu. Waste heat reduction and recovery potentially represents a large portion of the opportunities, particularly for lower-quality steam and exit gases.

Fired Systems

The petroleum refining industry ranks first in energy used in fired systems. An analysis of the energy use and losses attributed to fired systems for petroleum refining is shown in Table 4-5. The greatest opportunities for energy savings are found in atmospheric and vacuum distillation, catalytic hydrotreating, catalytic reforming, fluid catalytic cracking, and alkylation. In addition to steam use, energy is used in these processes mostly for fluid heating and to fire reactor systems or cokers. The industry's annual energy savings potential through improved fired systems totals about 325 trillion Btu. Details are provided in Table C-4 in Appendix C.

The primary sources of energy loss include hot flue gases, coolers, and condensers. Potential technology options for reducing losses include recovery of waste heat for fluid heating, steam generation, and absorption cooling. There are also opportunities for power generation and cogeneration by taking greater advantage of waste steam and heat available at a wide temperature range.

Table 4-4 PETROLEUM REFINING: STEAM SYSTEMS Roll-Up Opportunities Analysis

												Improvement Potential (%)						
						Technology Options						Best Practices		Technology				
Process/ Unit Operation	**Equipment Used**	**2002 U.S. Operating Production Capacity billion bbls/year**	**Energy Intensity (10^3 Btu/bbl product)**	**Total Energy Use (Trillion Btu/yr)**	**Average Energy Loss (10^12 Btu/yr)**	**Waste Heat Reduction**	**Waste Heat Recovery**	**Energy Source Flexibility**	**Controls, Automation, Robotics**	**CHP (fired and other)**	**Motors & Drives**	**Existing Potential**	*** *Future** New Potential**	**Commercially Available Technology & Equipment**	**Commercially Available *Alternative* Equipment**	*** *Future** R&D for New Technology & Equipment**	****Future** R&D for Alternative Process**	***Savings Tbtu/year***
Atmospheric Distillation	Fractionating Tower, Stripping (Direct Contact - DC)	6.02	44.0	246.1	148		X		X	X			X			40		60
Vacuum Distillation	Reboiler, Steam Ejection for Pressure Control (indirect contact), Stripping, Fractionating Tower (DC)	2.76	48.0	123.3	55		X		X	X			X			20		11
Visbreaking	Stripping (DC)	0.03	net export	-1.3	(1)													0
Coking Operations	Fractionating Tower (DC)	0.82	net export	-9.4	(6)													0
Fluid Catalytic Cracking	Stripping (DC)	2.18	0.3	0.5	0		X						X			20		0
Catalytic Hydrocracking	Stripping, Quenching (DC)	0.58	71.0	33.6	20		X		X				X			20		4
Catalytic Hydrotreating	Stripping (DC)	4.26	54.0	212.0	127		X		X	X			X			20		25
Catalytic Reforming	Stripping (DC)	1.34	89.0	117.2	70		X		X	X			X			20		14
Alkylation	Stripping (DC)	0.42	348.0	139.5	84		X		X				X			20		17
Isomers	Stripping (DC)	0.24	226.6	38.3	23		X		X				X			20		5
TOTAL				**900**	**521**													**136**

Assumptions: Efficiency improvements are based on cost-effective recovery of low level waste steam and contaminated waste steam that is not recovered currently. Energy totals for steam come within 18% of 1998 MECS steam use. The remainder is used for power generation, mechanical drive (direct drive systems for pumps, compressors), and other process operations.

Table 4-5 PETROLEUM REFINING: FIRED SYSTEMS Roll-Up Opportunities Analysis

Process/ Unit Operation	Equipment Used	Energy Intensity (10^3 Btu/barrel)	Thermal Energy use 10^3 Btu/barrel	Total Energy Use (Trillion Btu/yr)	Average Efficiency (Energy Loss)	Improvement Potential (%): Best Practices: Existing Potential	Improvement Potential (%): Best Practices: * *Future** New Potential	Improvement Potential (%): Technology: Commercially Available Technology & Equipment	Improvement Potential (%): Technology: Commercially Available *Alternative* Equipment	Improvement Potential (%): Technology: * *Future** R&D for New Technology & Equipment	Improvement Potential (%): Technology: **Future** R&D for Alternative Process	*Savings Tbtu/year*
Atmospheric Distillation	Charge Heating With Fired Heater.	113.8	89.00	641.6	**75.00**	5	5			10	10	96.2
Vacuum Distillation	Charge Heating With Fired Heater.	91.5	63.00	238.8	**75.00**	5	5			5	10	29.9
Delayed Coking	Crude (charge) Heating With Fired Coker Heater.	166	230.00	114.6	**80.00**	5	5			5	10	14.3
Fluid Coking	Combustion of Coke in "Burner".	258		7.1		5	10			10	15	1.4
Flexcoking	Oxidation of Coke in Gasifier. Steam addition to gasifier.	167		6.7		5	10			10	15	1.3
Visbreaking	Fired Heater/reactor, Steam Addition	99.5	145.00	2.07	**78.00**	5	5			5	10	0.26
Fluid Catalytic Cracking	Cat feed Fired Heater, Catalyst Regenerator.	100	100.00	190.6	**75.00**	5	10			15	15	42.9
Catalytic Hydrocracking	Fired Charge Heater and Exothermic Catalytic Reaction	240	195.00	109.7	**75.00**	5	10			15	15	-
Alkylation	Reactor (Heat of Reaction)	368	377.00	149	**75.00**	5	10			10	15	29.8
Catalytic Reforming	Fired Heater	284	270.00	376.3	**80.00**	5	5			5	10	47.4
Isomerization	Indirect Heating With Heat Exchangers.	359	Indirect Heating	40	**80.00**		5			5	10	4.0
Ethers Manufacture		403		33.4		5	5			10		3.3
Catalytic Hydrotreating/Hydroprocessing	Fired Heater	120		468.3	**80.00**	5	5			10	10	70.3
Lube Oil		1506	0.00	109.5	**75.00**	5	10			10	10	19.2
TOTALS				**2,487.67**								**359.9**

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 communication, packaging, consumer goods, and construction.

Forest Products Industry Sectors
NAICS 321 = Wood Products **<u>Wood Product Sectors</u>** Sawmills Wood Preservation Veneer, Plywood, and Engineered Woods Other Wood Products
NAICS 322 = Paper **<u>Paper Sectors</u>** 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

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

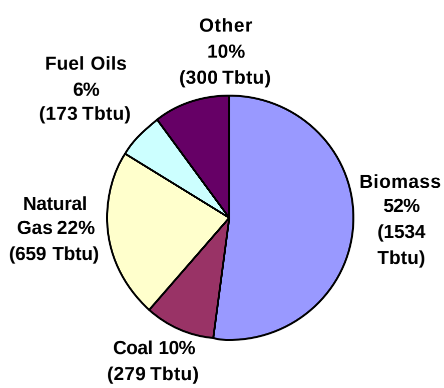


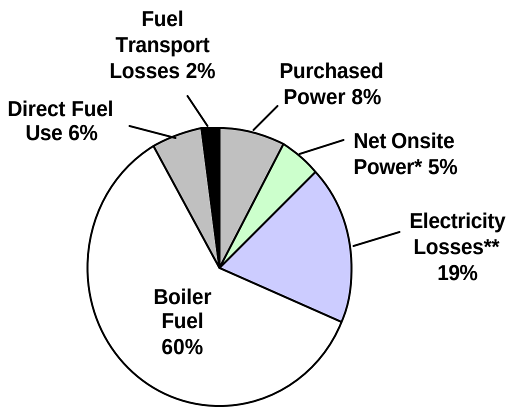
Figure 5-1 Fuel Use in the Forest Products Industry – 2936 Trillion Btu

Overview

A snapshot of where the forest products industry ranks in terms of energy use and losses within manufacturing and mining is shown in Table 5-1. Forest products 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 only to chemicals in primary energy use.

Figure 5-1 shows fuel distribution in forest products. Biomass (black liquor and wood residues) is the primary fuel (52%), followed by natural gas (22%). Forest products constitute the largest industrial use of biomass. Biomass resources utilized by the industry include 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. Coal, fuel oils, and other petroleum-based fuels make up the remainder of fuel use.

Improvements in the efficiency of energy systems impact fuel use distribution directly in forest products. The forest products industry is steam-intensive, so increasing boiler and process heat transfer efficiencies can have a significant impact. Much of boiler fuel, however, comes fromprocess byproducts. There is subsequently a trade-off between increased yield and process efficiency (producing less byproducts), the biomass available for boiler fuel, and the use of more costly fossil fuels.



*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

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. Primary energy inputs to the industry are shown in Figure 5-2. Fuels for boilers comprise 60% and power demand 13%, of the industry's primary energy use.

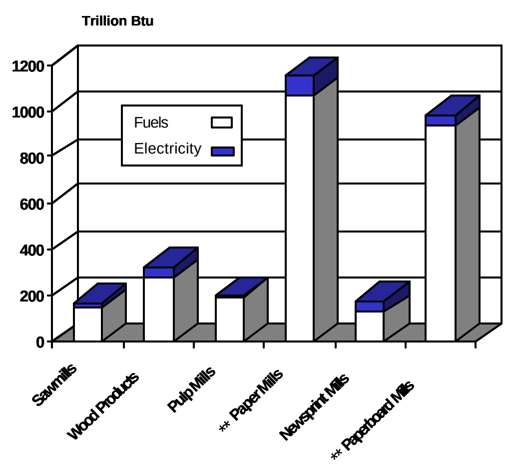
Electricity generation and fuel transport losses represent 21% of the primary energy consumed by the forest products industry. The bulk of energy losses occur during the generation of electricity at offsite utilities, where the efficiency of generating systems can be as low as 28-30%. Thermal efficiency of onsite power is greatly improved through the use of cogeneration. The forest products industry is the largest cogenerating industry, meeting 39% of electricity demand with onsite power systems.

Fuel and Electricity Use

Over 3.2 quads of fuel and electricity were consumed by the forest products industry in 1998. On average, fuels comprise 90% of the industry's primary energy use; about 10% is electricity. The industry creates a diversity of products with many different production processes, so energy use patterns vary across sectors. Figure 5-3 illustrates energy use among the major product sectors of the industry [MECS 1998].

Within the same product sector processes can also differ depending upon the technology used. For example, pulp can be made by chemical pulping, mechanical pulping, or a combination of the two pulping processes. Energy demand among these pulping processes can be quite different.

It should be noted that the data reported in Figure 5-3 may be somewhat misleading due to how sectors are categorized by NAICS. Paper and Paperboard Mills, for example, include operations where pulping is done at the same facility (integrated pulp/paper mills). Subsequently, in those cases, energy reported includes energy for pulping as well as papermaking. Energy shown for pulp mills only includes mills that do not make paper.



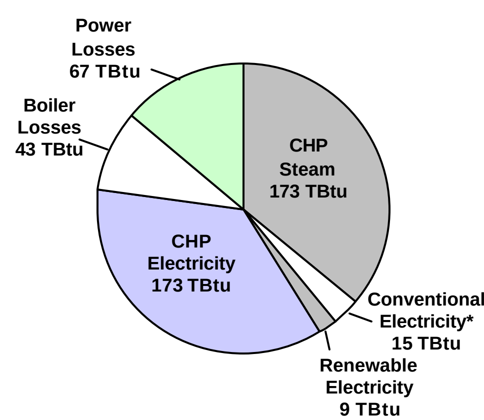
**Includes integrated pulp/paper mills.

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 electricity demand 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.

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. Nearly 430 TBtu of energy is associated with the production of onsite electricity. Approximately 88% of this electricity comes from cogenerating units, which also yield about 173 TBtu of steam.



*Steam or gas turbines not producing steam for process use

Figure 5-4 Onsite Power Generation Profile for Forest Products

End-Use Profile

Energy is consumed in forest products manufacturing to provide 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 mill and sector differences.

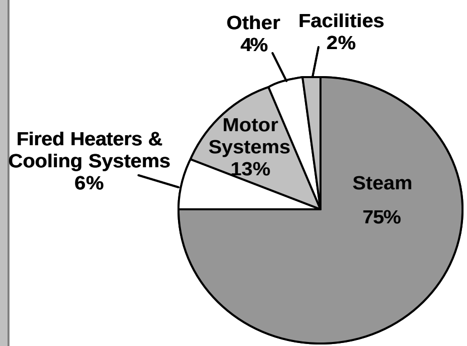


Figure 5-5 Energy End-Use in the Forest Products Industry: Total Delivered Fuel and Electricity – 3272 Trillion Btu

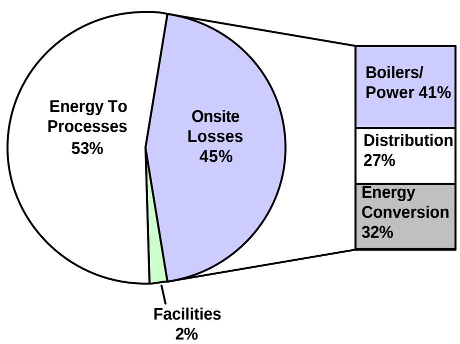


Figure 5-6 Onsite Energy Loss Profile for the Forest products Industry (NAICS 325) Total Onsite Losses – 1474 TBtu

Process heating and cooling systems, particularly those used for drying or evaporation, represent the bulk of energy use (81%) in forest products manufacture. These systems include steam systems, fired systems 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 accounts for only about 2% of energy use.

The forest products industry ranks first in steam, and ranks 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, 45% of the energy that enters the mill is lost prior to use in process units. These losses occur in equipment and distribution systems 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 TBtu of total onsite losses. Energy distribution and conversion systems account for the remaining offsite energy losses.

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 to the source of energy losses and identify targets for energy-saving opportunities. As shown in Figure 5-7, most energy losses occur in steam systems. In terms of TBtus, steam system losses are the highest of all energy systems, about 1.1 quads, 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. Downstream losses (e.g., flue gas, exhaust, stack) have not been estimated, but could be substantial (as much as 30-50% of delivered energy).

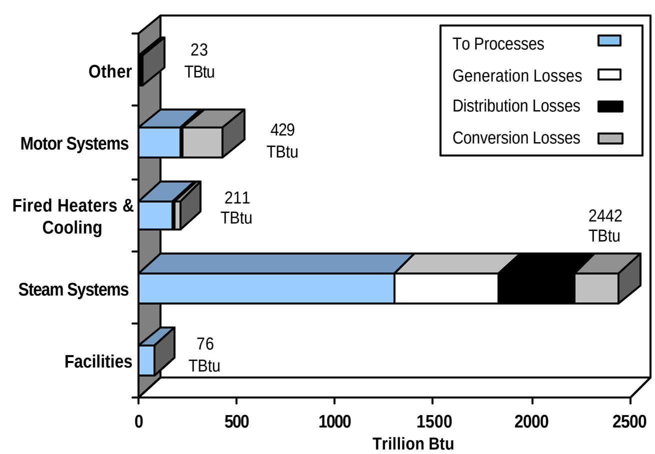


Figure 5-7 Energy End-Use and Loss Distributions in Forest Products NAICS 321 & 322)

Table 5-2 Forest Products Energy Use and Losses (Trillion Btus)							
	To Process/ End-use	Generation Losses	Distribution Losses	Conversion Losses	TOTAL Onsite Losses	Associated Carbon (MMTCE)**	Total Energy
Facilities	76	na	na	na	-	-	76
Steam Systems	1299	535	379	229	1143	9.4	2442
Fired systems & Cooling	174	na	7	30	37	0.6	211
Motor Systems	211	na	16	202	218	3.2	429
Electrochemical	2	na	0	0	0	0.0	2
Other Uses	12	na	na	9	9	0.1	21
Onsite Power	(197)*	67	na	na	67	0.6	67
Export of Power	24	na	na	na	na	na	24
TOTALS	**1798**	**602**	**402**	**470**	**1474**	**13.8**	**3272**

*Onsite generated power is distributed among end-uses and is not included in the totals.
**Carbon emissions associated with total energy losses, in million metric tons of carbon equivalent (MMTCE)

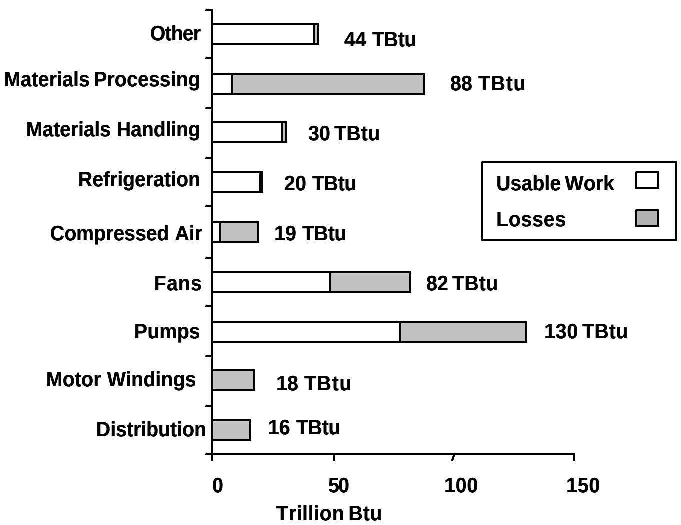


Figure 5-8 Forest Products Industry Motor System Energy Use and Loss Profile

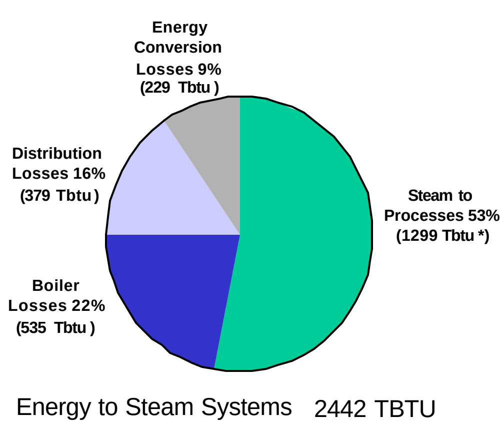


Figure 5-9 Steam Use and Loss Profile for the Forest Products Industry

A motor use profile for forest products is shown in Figure 5-8. The losses, indicated in gray, illustrate the sizeable amount of energy that is 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 TBtu; conversion losses in motor windings comprise another 18 TBtu. The associated energy distribution losses are 16 TBtu. Combined losses attributed to motor systems (excluding distribution) are about 202 TBtu. Most of the energy used for motor systems is electricity (>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 via system inefficiencies. A majority of these occur in the boiler, where thermal efficiencies range between 55-85%, depending upon the age of the boiler and type of fuel burned. Wood byproduct or hog fuel boilers, for example, will have much lower overall thermal efficiencies than natural gas-fired boilers. Distribution losses for steam systems are also significant. These occur in steam traps, valves, and pipes carrying steam to processes and energy conversion units.

5.3 Opportunities Analysis

Steam Systems

The forest products sector ranks first among U.S. industries in steam use. Table 5-3 illustrates the use of steam and potential end-of-process energy losses in the industry by selected processes. The processes that use the most steam are Kraft pulping, bleaching, chemical recovery, and paper drying. The efficiency of steam use in these processes depends upon steam recovery and the quality of the recovered steam. For this analysis, it was assumed that approximately 50-60% of the steam delivered to the process was lost downstream of the process. For chemical recovery, where considerable amounts of steam are produced, the net steam requirement is provided. Appendix B provides the details on the steam efficiencies assumed for each process, the major sources of energy losses, references, and other data. Assuming improvements to steam systems could recover from 10-30% of lost energy, it is estimated that energy savings would approach 200 TBtu/year.

Chemical pulping, bleaching, chemical recovery, and paper drying represent the largest area of opportunity for improving steam system energy efficiency in the forest products industry. In pulp making, potential steam system improvements can be made via the implementation of more efficient digesters (continuous versus batch), increased recovery of waste steam, implementation of increased CHP, and employment of alternative heat sources such as the replacement of steam heating with indirect heating methods.

Better heat integration to reduce bleaching stages, and increased heat recycling, are options for improving steam use in bleaching. Falling film evaporation and increased steam recycling are potential methods for increased heat recovery in the chemical recovery process.

Paper drying is a highly inefficient process that relies largely on the use of steam, and represents one of the most significant opportunities for improved steam system efficiency. Options to improve paper drying efficiency include the use of direct-fired dryers, utilization of alternative drying systems (impulse drying infrared drying, press drying), recovery of heat from air, and recovery of waste heat using mechanical vapor recompression pumps.

Fired Systems

Lime mud calcining is the only significant use of fired systems in the forest products industry (see Table 5-4). The average efficiency of the lime kiln is very low (30-40%). Improvements could be made by increasing heat transfer between lime mud and combustion gases, using lime product coolers for heating combustion air, and employing flash dryers for mud preheat. The steam energy savings potential from these options is estimated to be about 23 TBtu/year, based on the recovery of approximately 35% of lost process energy. Appendix B provides details on the analysis and the methodology used.

Table 5-3 FOREST PRODUCTS: STEAM SYSTEMS Roll-Up Analysis

												Improvement Potential (%)						
						Technology Option						Best Practices		Technology				
Process/ Unit Operation	Equipment Used	2000 U.S. Production 10^6 short tons/yr	Energy Intensity 10^6 Btu/ ston pulp	Total Energy Use 10^12 Btu/yr	Average Energy Loss 10^12 Btu/yr	Waste Heat Reduction	Waste Heat Recovery	Energy Source Flexibility	Controls, Automation, Robotics	CHP (fired and other)	Motors & Drives	Existing Potential	* *Future** New Potential	Commercially Available Technology & Equipment	Commercially Available *Alternative* Equipment	* *Future** R&D for New Technology & Equipment	**Future** R&D for Alternative Process	*Savings Tbtu/yr*
Kraft Pulping	Steam heated batch/continuous digesters, pre-steamers	52.0	3.8	196	88	X	X		X			X	X	10		15		22
Sulfite Pulping	Steam heated batch digesters	1.2	3.6	4	2	X	X		X			X	X	10		10		0
Thermo-mechanical Pulping	Pre-steamers	3.7	0.8	3	1	X	X		X			X	X			10		0
Semi-chemical Pulping	Digesters or pre-steamers	4.0	4.6	18	8	X	X		X			X	X			20		2
Bleaching	Steam-heated bleaching towers/stages	37.6	3.7	139	56	X	X	X	X			X	X	10		15		14
Chemical Recovery	Recovery boilers, superheaters, stripper, evaporators	57.1	3.8	216	86	X	X		X	X		X	X	5		15		17
Pulp Drying	Dryer, condenser, thermocom-pressor	8.4	3.9	33	16	X	X	X	X	X		X	X	10		10		3
Paperdrying (million tons of paper)	Drum dryers and Yankee dryers	96.3	9.2	886	461	X	X	X	X	X	X	X	X	10		20		138
TOTAL				**1495**	**719**													**197**

Table 5-4 FOREST PRODUCTS: FIRED SYSTEMS Roll-Up Analysis

						Energy Loss Recovery or Reduction Category						Improvement Potential (%) Best Practices		Improvement Potential (%) Technology				
Process/ Unit Operation	**Equipment Used**	**2001 U.S. Production 10^6 Short Tons/year**	**Energy Intensity (10^6 Btu/ston pulp)**	**Total Energy Use (10^12 Btu/yr)**	**Average Energy Loss (10^12 Btu/yr)**	**Waste Heat Reduction**	**Waste Heat Recovery**	**Energy Source Flexibility**	**Controls, Automation, Robotics**	**CHP (fired and other)**	**Motors & Drives**	**Existing Potential**	*** *Future** New Potential**	**Commercially Available Technology & Equipment**	**Commercially Available *Alternative* Equipment**	*** *Future** R&D for New Technology & Equipment**	****Future** R&D for Alternative Process**	***Savings Tbtu/year***
Lime Mud Calcining	Lime Kiln	52	2.00	103	65		X	X	X				X	15		20		23
TOTAL				**103**	**65**													**23**

Assumptions: Efficiency improvements are based on recovery of kiln waste heat, reduction of kiln heat losses, and reduction of heat needed for lime mud dissociation. Energy use is consistent with 1998 MECS fuels used in fired systems (166 TBtu), and with the LBL study, which indicates about 3-4% of energy use is attributed to lime burning (115 TBtu).

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 via 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 onsite or purchased. This iron is used as a charge to produce steel in a basic oxygen furnace (BOF). An electric arc furnace (EAF) steel producer, also known as a mini-mill, uses EAFs to produce steel from steel scrap and other iron-bearing materials.

Steel is the fourth largest consumer of fuels and power in manufacturing. The efficiency of the processes and equipment used to produce iron and steel is constrained by thermodynamic, kinetic, or transport limitations, and operating conditions are severe (high temperatures, corrosive environments). These factors contribute collectively to proportionally high energy use per ton of product.

6.2 Energy Use and Loss Analysis for Iron and Steel

Overview

A snapshot of where 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 systems 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 byproduct fuels are coke oven gas and blast furnace gas (coal-based in origin).

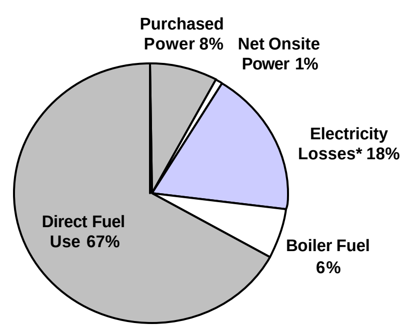
Table 6-1 Snapshot of the Iron and Steel Industry: Energy Use and Rank Within U.S. Manufacturing and Mining

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

Primary Energy

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%.



*Includes both offsite and onsite losses.

Figure 6-1 Primary Energy Use in the U.S. Iron and Steel Industry - 2056 Trillion Btu

A considerable portion of the primary energy associated with the manufacture of iron and steel (18%) 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.

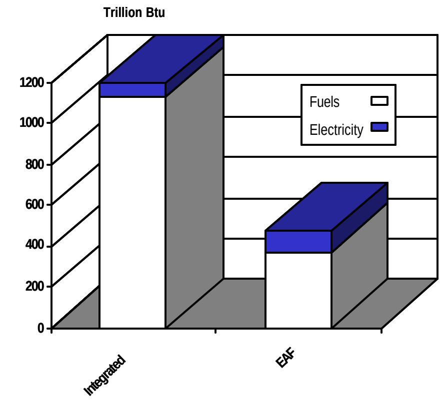


Figure 6-2 Fuel and Electricity Use in the Integrated and EAF Sub-sectors

Fuel and Electricity Use

About 1.7 quads of fuels and electricity were consumed by the iron and steel industry in 1998. On average, around 90% of its 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 (electricity 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.

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 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 TBtu 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 to supply 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.

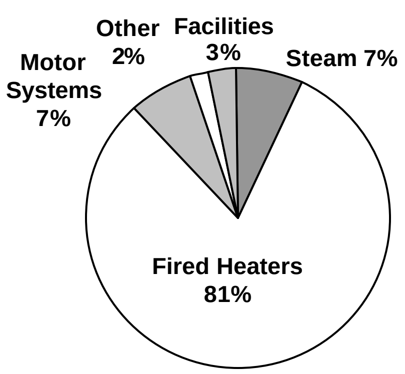


Figure 6-3 Energy End-Use in the Iron and Steel Industry: Total Delivered Fuel and Electricity - 1672 Trillion Btu

Fired systems (excluding boilers), particularly ironmaking blast 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, consume another 7% of steel industry energy use. Heating, cooling, and lighting of facilities accounts for just 3% of its energy use.

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

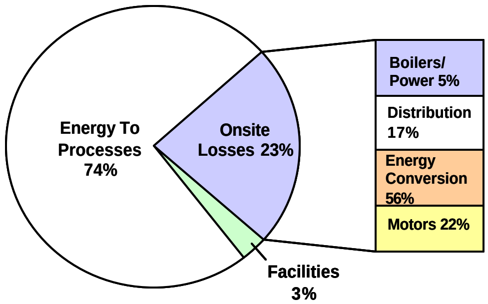


Figure 6-4 Onsite Energy Loss Profile for the Iron and Steel Industry:
Total Onsite Losses - 378 Trillion Btu

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, nearly one-quarter of the energy that enters the plant (23%) is lost prior to use in process units. These losses occur in equipment and distribution systems supplying energy to process operations or converting energy to usable work. 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. As shown in Figure 6-5, the bulk of energy losses occur in fired systems and cooling. In terms of TBtus, these heating and cooling losses total about 241 TBtu, which represents approximately 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	Associated Carbon Emissions (MMTCE)**	Total Energy
Facilities	56	na	na	na	na	na	56
Steam Systems	56	19	15	10	44	0.7	100
Fired Systems & Cooling	1131	na	42	199	241	4.0	1372
Motor Systems	36	na	5	80	85	1.6	121
Electrochemical	4	na	na	1	1	0.0	5
Other Uses	11	na	na	1	1	0.0	12
Onsite Power	(18)*	6	na	na	6	0.0	6
Export of Power	0	na	na	na	na	na	0
TOTALS	**1294**	**25**	**62**	**291**	**378**	**6.3**	**1672**

*Onsite generated power is distributed among end-uses and is not included in the totals.
** Carbon emissions associated with total energy losses, in million metric tons of carbon equivalent (MMTCE).

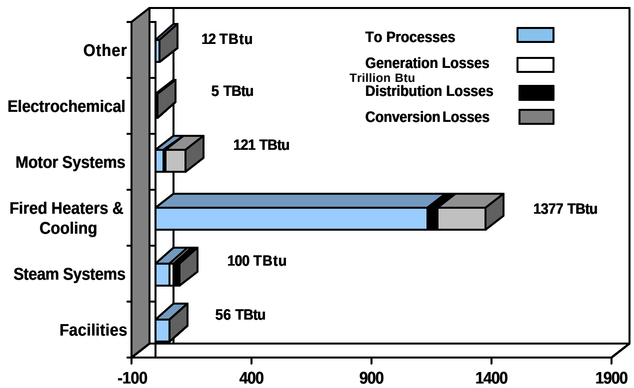


Figure 6-5 Energy End-Use and Loss Distributions in the Iron and Steel Industry

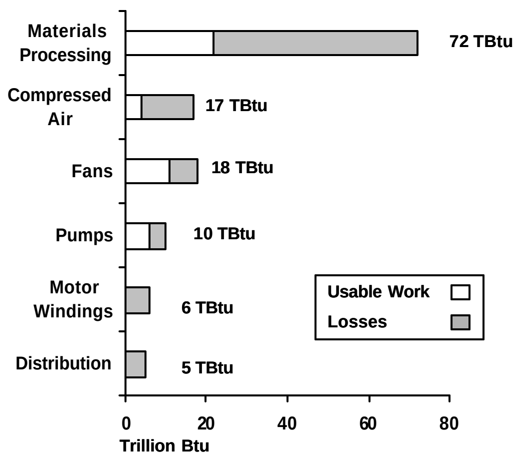
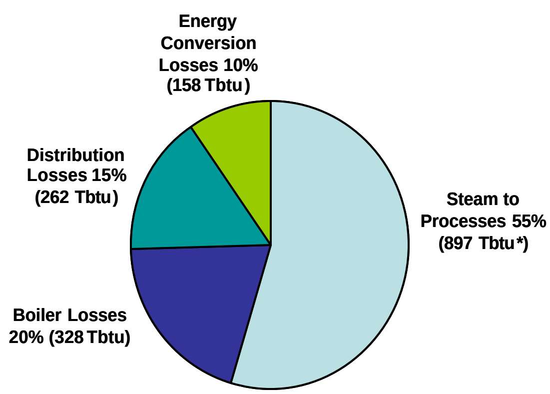


Figure 6-6 Iron and Steel Industry Motor System Use and Loss Profile



Energy to Steam Systems 1645 TBtu
Figure 6-7 Steam Use and Loss Profile for the Iron and Steel Industry

A motor use profile for the iron and steel industry is shown in Figure 6-6. The losses, indicated in gray, illustrate the significant amount of energy that is 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 TBtu; conversion losses in motor windings comprise another 6 TBtu. The associated energy distribution losses are 5 TBtu. Combined losses attributed to motor systems (excluding distribution) are about 80 TBtu iron and steel making. More than 90% of the energy used for motor systems in the industry is electricity.

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. Most of these losses occur in the boiler, where thermal efficiencies range between 55-85%, depending upon the age of the boiler and fuel type 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 highly dependent on plant configurations, how effectively heat sources and sinks are integrated, and operating and maintenance practices.

6.3 Opportunities Analysis

Combined Steam and Fired Systems

The iron and steel industry ranks second in the use of fired systems, and ranks seventh in the use of steam within the U.S. industrial sector. Table 6-3 illustrates the use of fired systems in the industry by selected processes and the potential end-of-process energy losses. Major areas of loss for fired systems include hot gases (both contaminated and clean), warm water (120-150 ^{o}F), and hot products that require cooling or quenching (coke, annealed metal, molten iron, hot slabs, process gases). The total energy savings potential for the iron and steel industry (based on the efficiencies shown in Table 6-3) is approximately 270 TBtu. The largest opportunity area is ironmaking in basic furnaces, which accounts for 36% of potential energy savings. More than 29% of the savings opportunities are concentrated in EAFs. Other savings opportunities are found in slab reheating furnaces (19%) and annealing (~7%).

Steam is used extensively in integrated steel plants to generate power and to supply steam to several low-to-medium temperature heating systems. Traditionally byproduct fuels (coke oven gas, blast furnace gas) have been used to supply heat to steam generators and furnaces. With structural changes in the steel industry, many integrated plants have eliminated or restricted severely the use of processes that generate byproduct fuels such as blast furnace gas, coke ovens, and so forth. This has adversely affected the cost of heating in the plants.

A significant amount of steam use in integrated mills can be replaced by direct-fired systems. In many cases, a large quantity of steam is generated using primary fuels such as natural gas and fuel oil where byproduct fuels (coke oven gas, blast furnace gas) have been used historically; using primary fuels has a significant cost “penalty” for the plants.

Gas-turbine-based CHP systems can be utilized for supplying heat to steam generators and to fluid heating processes used in the plant. Waste heat from combustion products, or flue gases from reheat furnaces, coke oven batteries, continuous annealing furnaces, etc., can be supplied to combustion air preheating, to charge preheating, or to adjoining lower-temperature processes. Thermo-electric systems are a viable option for utilizing medium-temperature, clean flue products or cooling air.

For mini-mills, major energy sources include electricity and natural gas. Electricity is the primary source of energy for EAFs, while natural gas is the principal source of heat for reheating operations. Modern installations utilize oxy-fuel burners and other sources of chemical heat to supplement heat supply to EAF, which helps to reduce energy consumption. EAFs represent a major source of waste heat discharged as gases that include chemical and sensible heat. However, the gases are highly contaminated and recovering their energy presents several technical challenges. Flue products from reheat furnaces are relatively clean and can be used in steam generation or other heating operations located close to the furnaces, if the plant has a downstream process plant. Although steam is not used extensively in mini-mills, its use is increasing and could be promoted through the use of steam as a supplement to electricity.

Table 6-3 IRON AND STEEL: COMBINED STEAM AND FIRED SYSTEMS Roll-Up Analysis

ID #	Process/Unit Operation	Equipment Used	Pro-duction 10^6 Short Tons/yr	Energy Intensity (10^6 BTU/ston Product)	Total Energy Use (10^12 Btu/yr)	Average Efficiency %	Technology Options						Improvement Potential (%)						Savings Tbtu/year
													Best Practices		Technology				
							Waste Heat Reduction	Waste Heat Recovery	Energy Source Flexibility	Controls, Automation, Robotics	CHP (fired and other)	Motors and Drives	Existing Potential	* *Future** New Potential	Commercially Available Technology & Equipment	Commercially Available *Alternative* Equipment	* *Future** R&D for New Technology & Equipment	**Future** R&D for Alternative Process	
1	Coke Making	Coke Ovens	23	3.4	77			X			X						5		4
2	Sintering		12	1.5	18														0
3	BF Ironmaking (MM tons/yr)	Blast Furnace	60	16.1	966												10		97
4	BOF Steelmaking	Basic Oxygen Furnace	60	0.9	54														0
5	EAF Steelmaking	Electric Arc Furnace	49	6.5	316	56									25				79
6	Ingot (4%)	Soaking pits	4	2.8	12											90			11
7	Continuous (96%)	Caster	104	0.3	30		X	X					X		25				8
8	Slab Reheat Furnace	Various Reheat Furnaces	98	1.5	146	36	X	X		X	X	X	X	X	10	15	35		51
9	Tunnel furnace	Tunnel - equalizing Furnaces	10	0.7	7	36	X	X			X		X	X			25		2
10	Hot Rolling	Hot Rolling Mills	109	0.8	87						X								0
11	Acid pickling	Pickle baths		1.2	0		X	X	X				X	X			20		0
12	Cold rolling	Cold Rolling Mills	71	0.7	49						X								0
13	Cleaning/Annealing	Annealing Furnaces	71	1.0	71	32	X	X		X			X	X			25		18
	TOTAL				**1833**														**269**

Assumptions: Efficiency improvements are based on heat reduction and recovery, and application of CHP. Values are within 10% of 1998 MECS energy use.

7.0 Food and Beverage Industry (NAICS 311 and 312)

7.1 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. Food and beverage is one of the largest U.S. manufacturing sectors, accounting for $570 billion in annual shipments, or about 14% of total U.S. manufacturing shipments. Increasing globalization of agriculture markets and companies has led to increased trade for food and beverage products; exports in 2002 were about $29 billion, along 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
Beverages
Tobacco Products

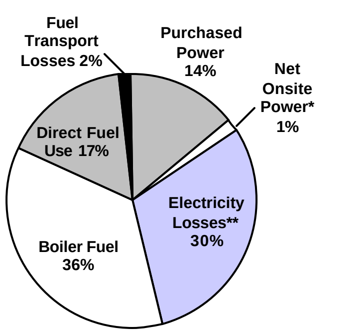
The food and beverage industry is highly diversified, and produces thousands of different products. Processing facilities range from small plants to large industrial units, and most plants produce more than one product. The industry is divided into sectors that reflect major product categories.

The food and beverage industry is one of the top five 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 high temperature or pressure operating conditions. All these factors contribute to high energy use per pound of product.

7.2 Energy Use and Loss Analysis for Food and Beverage

Table 7-1 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 7-1 Primary Energy Use in the U.S. Food and Beverage Industry - 1685 Trillion Btu

Overview

A snapshot of where the food and beverage industry ranks in terms of energy use and losses is shown in Table 7-1. The food and beverage industry ranks among the top six in U.S. manufacturing and mining in nearly every energy end-use category.

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.

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 7-1. Fuels for boilers and direct-fired systems comprise about 53% of total primary energy; power demand is about 15%.

About 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 an array of different products and uses many different processes in their manufacture. As a result, energy use patterns can vary significantly across sectors.

Figure 7-2 illustrates the energy purchase patterns across major sectors of the industry [ASM/DOC 2001]. Overall, grain milling, fruit and vegetable processing, meat product output, and beverage production are responsible for the majority of its energy purchases. Processing of meat products consumes the most electricity.

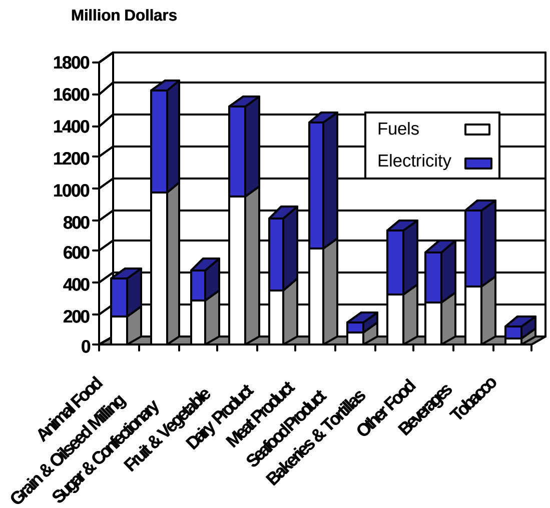


Figure 7-2 Fuel and Electricity Purchases in Selected Food and Beverage Industry Sectors, 2001

Onsite Generation and Electricity Demand

The food and beverage industry is ranked fourth among the U.S. manufacturing and mining sector in demand for electricity at 258 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 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 7-3. About 52 TBtu of annual energy use is associated with the production of onsite electricity. Approximately 95% of electricity produced onsite in the food and beverage industry comes from cogenerating units, which also generate about 24 TBtu in steam. A small amount of electricity is produced in conventional steam and gas turbines or other systems that are not generating steam for process use.

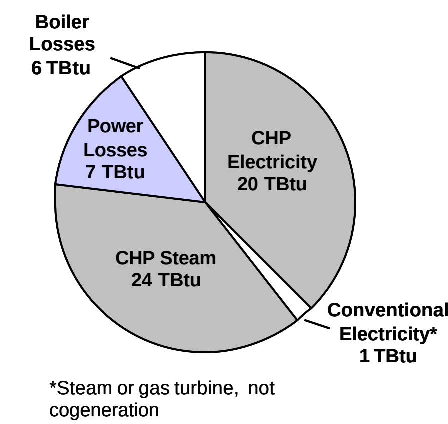


Figure 7-3 Onsite Power Generation Profile for Food and Beverage

End-Use Profile

Energy is consumed in food and beverage manufacture to provide process heating and cooling, to power motor-driven systems, and for various other purposes. A breakdown of energy end-use is shown in Figure 7-4. It should be noted that the energy trends shown here are an average for the industry and may not reflect sector differences.

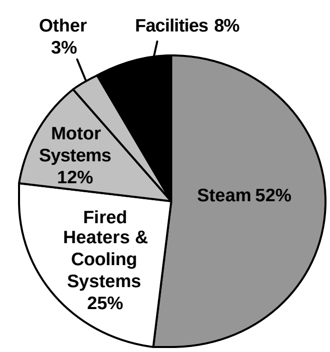


Figure 7-4 Energy End-Use in the Food and Beverage Industry: Total Delivered Fuel and Electricity - 1156 Trillion Btu

Process heating and cooling systems represent the bulk of energy use (77%) in food and beverage manufacture. These include steam systems, fired systems 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. The food and beverage industry ranks fourth in steam use within manufacturing and mining, and also fourth in the use of fired systems. It is also the fifth largest user of motor-driven systems in the U. S. industrial sector.

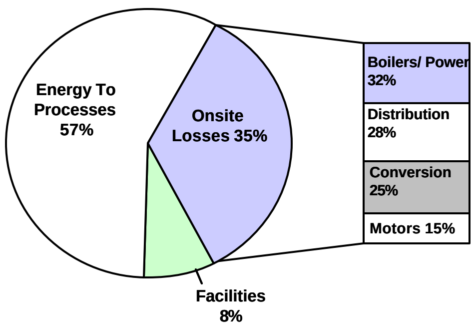


Figure 7-5 Onsite Energy Loss Profile for the Food and Beverage Industry (NAICS 311 and 312) Total Onsite Losses - 407 Trillion Btu

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 7-5, which is based on the energy footprint, illustrates the general flow of energy and losses within the average food and beverage plant.

As Figure 7-5 shows, a substantial share (35%) of the energy that enters the plant is lost prior to use in process units. These losses occur in equipment and distribution systems 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% 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. Downstream, end-of-process losses (exhaust, stack) have not been estimated, but could be substantial (as much as 30-50% of delivered energy).

System-Specific Losses

Detailed energy use and losses for component systems are summarized in Figure 7-6 and Table 7-2. As shown in Figure 7-6, most energy losses occur in process heating and cooling, which includes steam systems as well as fired systems and cooling or refrigeration units. In terms of trillion Btus, steam system losses are the highest of all energy systems, (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.

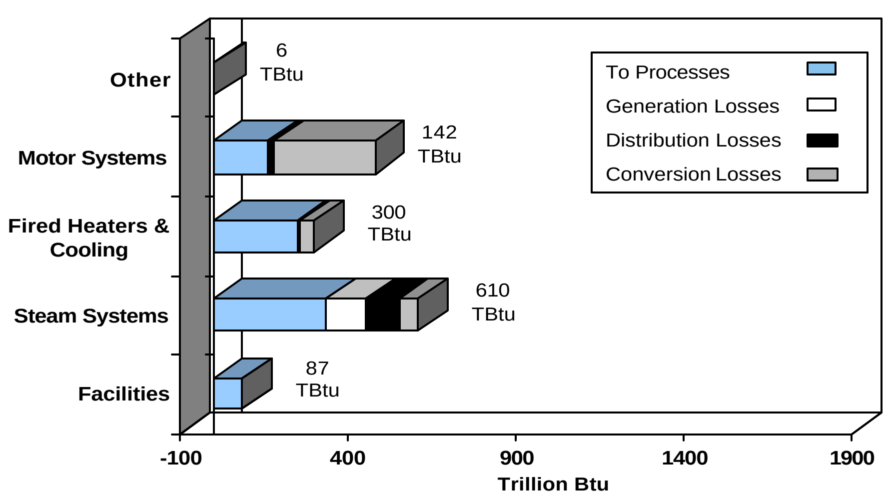


Figure 7-6 Energy End-Use and Loss Distribution in Foods and Beverages (NAICS 311 and 312)

Table 7-2 Food and Beverage Energy Use and Losses (Trillion Btus)							
	To Process/ End-use	Generation Losses	Distribution Losses	Conversion Losses	TOTAL Onsite Losses	Associated Carbon Emissions (MMTCE)**	Total Energy
Facilities	87	na	na	na	na	na	87
Steam Systems	333	121	97	59	277	4.9	610
Fired Systems & Cooling	250	na	10	40	50	0.7	300
Motor Systems	73	na	6	63	69	1.3	142
Other Uses	2	na	na	4	4	0.1	6
Onsite Power	(21)*	7	na	na	7	0.1	7
Export of Power	4	na	na	na		0.0	4
TOTALS	**749**	**128**	**113**	**166**	**407**	**7.1**	**1156**

*Onsite power generation is distributed among end-uses and is not included in the totals.
**Carbon emissions associated with total energy losses, in million metric tons of carbon equivalent (MMTCE).

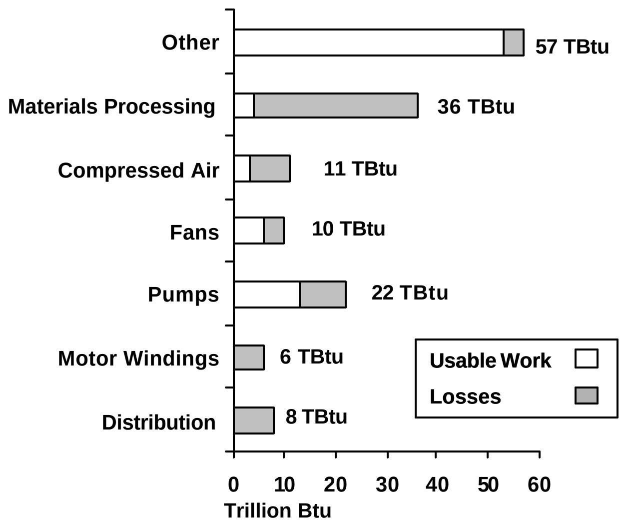


Figure 7-7 Food and Beverage Industry Motor System Energy Use and Loss Profile

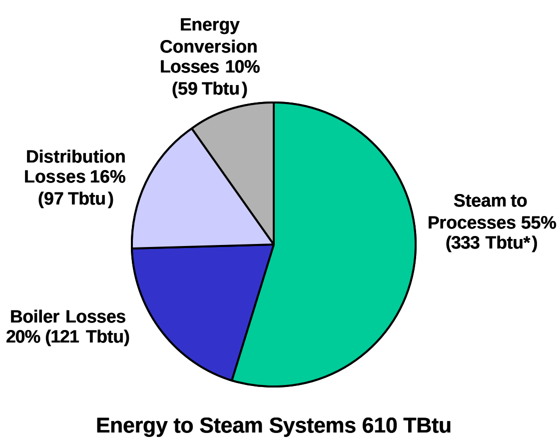


Figure 7-8 Steam Use and Loss Profile for the Food and Beverage Industry

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

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

A profile of food and beverage industry steam use and associated losses is shown in Figure 7-8. About 45% of steam system energy inputs are lost due to system inefficiencies. The bulk of these occur in the boiler, where thermal efficiencies range between 55-85%, depending upon the age of the boiler and type of fuel burned. Waste heat boilers, for example, will have much lower overall thermal efficiency than natural gas-fired boilers. Distribution losses in steam systems are also significant. These occur in steam traps, valves, and pipes carrying steam to processes and to energy conversion units.

7.3 Opportunities Analysis

Steam Systems

The food processing industry is the fourth largest steam user in the U.S. manufacturing and mining sector. Table 7-3 illustrates the use of steam in the industry by selected processes and the potential end-of-process energy losses.

The most steam intensive processes are found in wet corn milling (steeping, steepwater evaporation, germ drying), and cane sugar and beet sugar processing (solution, refining). Lesser amounts of steam are used for meat evisceration, cheese processing (whey drying), and fats and oils processing (meal drying). The numerous drying and evaporative processes of the food processing industry are considerably inefficient and use large amounts of steam. For this analysis it was assumed that steam system efficiencies for these processes ranged between 45-50%. Appendix B provides details about the efficiencies assumed for each process, the major sources of energy losses, references, and other pertinent data.

The best areas of opportunity for efficiency improvements in food and beverage manufacture are in wet corn milling and sugar processing and refining. Technology options include the use of direct-fired drying systems (impulse drying, infrared drying, press drying) and waste heat recovery. Replacing steam-heated systems with direct firing could also increase efficiency in food drying. Another option is the use of CHP and secondary heat recovery from boiler flue gases.

Assuming improvements to steam systems could enable the recovery of 10-30% of energy wasted currently, potential energy savings for the industry as a whole are estimated at more than 80 TBtu/year.

Fired Systems

The food processing industry is the fourth largest user of fired systems. Meat products, cheese processing, dry condensed and evaporated products, wet corn milling, bread cake and related products, and fats and oil processing are the major sub-sectors that employ fired systems, mostly for drying, evaporation, cooking, and baking.

Not enough data was available to conduct a detailed analysis of fired systems used in food processing. However, if the basic assumption is made that these processes lose considerable waste heat and are relatively inefficient (40-50% energy lost), this would amount to about 135 TBtu annually. Recouping even a small percentage of that energy (e.g., 20%) would provide energy savings of about 30 TBtu annually, which is significant. In addition, because steam and electricity use are high in this sector, it is an ideal candidate for increasing the use of cogeneration as well as other waste heat recovery technologies.

Table 7-3 FOOD PROCESSING: STEAM SYSTEMS Roll-Up Analysis

						Technology Options						Improvement Potential (%) Best Practices		Improvement Potential (%) Technology				
Process/ Unit Operation	**Equipment Used**	**U.S. Production 10^6 lbs/year**	**Energy Intensity (10^6 Btu/lb)**	**Total Energy Use (10^12 Btu/yr)**	**Average Energy Loss (10^12 Btu/yr)**	**Waste heat reduction**	**Waste heat recovery**	**Energy Source Flexibility**	**Controls, Automation, Robotics**	**CHP (fired and other)**	**Motors & Drives**	**Existing Potential**	***Future* New Potential**	**Commercially Available Technology & Equipment**	**Commercially Available *Alternative* Equipment**	***Future* R&D for New Technology & Equipment**	***Future* R&D for Alternative Process**	***Savings Tbtu/year***
Wet Corn Milling	Rotary steam tube dryers, flash dryers		2625.0	115	63		X	X	X	X		X	X	10		15		16
Sugar Processing/ Refining	Evaporators, dryers, vacuum pans			169	93		X	X	X	X		X	X	10		15		23
Meat Products	Steam Vacuum, Steam Pasteurization	19000.0	333.0	6	3		X		X			X	X	10		15		1
Cheese	Feed System, Drying Chamber, Fluid Bed	6900.0	1020.0	7	4		X		X			X	X	10		15		1
Fats and Oils	Dryers	72515.0	93.0	7	3		X		X			X	X	10		15		1
Miscellaneous (baking, dairy, others)	Steam Pasteurization, Ovens, Dryers			272	136		X		X	X		X	X	10		15		34
TOTAL				**576**	**302**													**76**

Assumptions: Efficiency improvements are based on cost-effective waste steam recovery, waste heat reduction, and other options such as reducing excess air and flue gas, improving process control, and using CHP. Energy totals for steam cover all of 1998 MECS steam use.

8.0 Mining Industry (NAICS 212)

8.1 Overview of the Mining Industry

The mining industry plays an important role in the U.S. economy and its energy supply. In 2000, mined materials such as uranium and coal represented 72% of energy inputs for electric power production in the United States, and process materials of mineral origin accounted for 5% of the nation's GDP. The U.S. mining industry also directly employs more than 320,000 people. On average, 47,000 pounds of material are mined per person each year, making the industry indispensable to our quality of life. In 2000, 35% of the 1.1 billion tons of coal produced were mined from underground; the remainder was obtained from the surface. That same year, mining of crude industrial and metal ores totaled 3.1 billion pounds and 1.3 billion pounds respectively.

Mining Industry Sub-sectors
Oil and Gas Extraction
Mining Except Oil and Gas • Coal Mining • Metal Ore Mining • Nonmetallic Mineral Mining and Quarrying
Support Activities for Mining

Some mining operations are highly energy intensive. For example, rock crushing, drilling, and grinding require considerable mechanical forces and subsequently large amounts of energy. Substantial amounts of energy are also expended to transport massive quantities of ore and rock from mining to milling operations.

The mining industry (NAICS 21) includes several sub-sectors. Metal and minerals mining account for a large portion (50%) of mining industry shipments, and are the focus of this analysis. Oil and gas extraction are excluded.

8.2 Energy Use and Loss Analysis for the Mining Industry

Table 8-1 Snapshot of the Mining Industry: Energy Use and Rank Within U.S. Manufacturing & 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

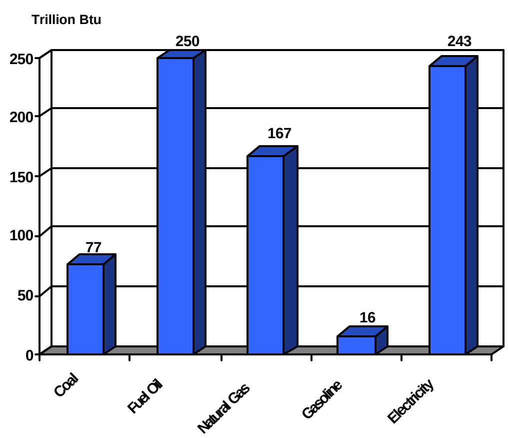


Figure 8-1 Mining Industry Energy Supply By Energy Source (NAICS 212) – 753 Trillion Btu

Overview

A snapshot of where the mining industry ranks in terms of energy use and losses within manufacturing and mining is shown in Table 8-1. The industry ranks sixth in primary energy use, fuel and electricity use, and onsite losses. The mining sector also ranks fourth in offsite losses and fifth in energy conversion losses.

Fuel oil (diesel, residual) 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 8-1 shows the breakdown of the mining industry's energy supply by energy source. The mining industry 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.

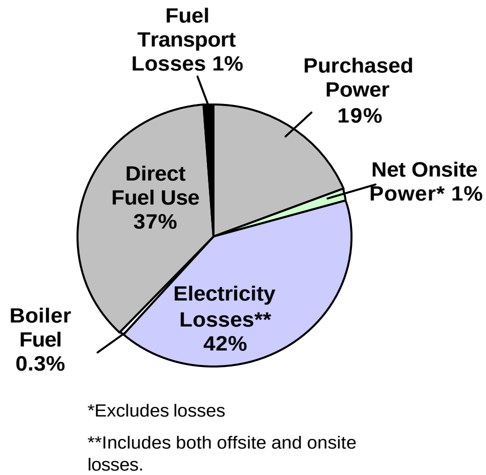


Figure 8-2 Primary Energy Use in the U.S. Mining Industry – 1273 Trillion Btu

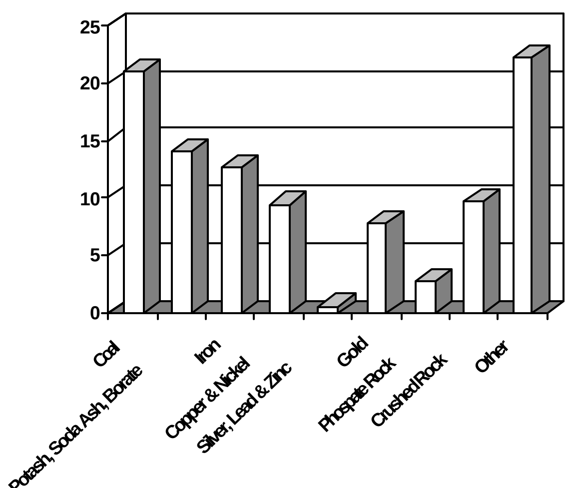


Figure 8-3 Fuel and Electricity Use in Selected Mining Sectors

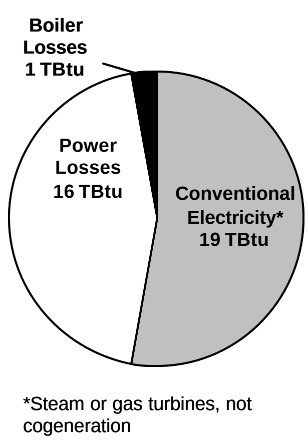


Figure 8-4 Onsite Power Generation Profile for the Mining Industry (NAICS 212)

Primary Energy Use

Figure 8-2 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 total mining industry energy use.

On average, 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%.

Fuel and Electricity Use

Total fuel and electricity supplied to the mining industry has been estimated at 750 TBtu of energy per year. 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 versus surface mining), in the nature and location of ore or mineral deposits, and in 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 solely from surface mines.

Figure 8-3 illustrates the percent of energy use consumed by major mining industry sectors. Due to the large volume of coal production, mining it accounts for the most energy use. However, mineral mining is significantly more energy intensive on a Btu/per ton basis.

Onsite Generation and Electricity Demand

The mining industry ranks third among U.S. industrial sectors in electricity demand, topped only by the chemical and forest product industries. Diesel- and coal-fired power systems are used onsite to produce electricity as needed for mining equipment.

Current data is not readily available on electricity cogeneration in the mining sector, although it is expected to be moderate. The values shown in Figure 8-4 have been extrapolated from an older source and applied to current projected energy use [EIA 1978, ORNL 1980]. With this approach, conventional electricity generating systems are estimated to supply about 19 TBtu per year. Power generation losses from onsite generation are approximately 16 TBtu. Total energy associated with onsite power production in mining is around 36 TBtu.

End-Use Profile

The mining industry consumes energy to supply direct heating, to power motor-driven machinery, and for other purposes. A breakdown of energy end-use is shown in Figure 8-5.

The mining industry's largest use of energy for heat and power is classified under "other" uses. This includes drilling, materials transport and other energy-intensive operations. Limited data are available on the exact breakdown of energy use among these processes, as the mining industry is not part of the MECS conducted by the U.S. Department of Energy. According to older studies [EIA 1978, ORNL 1980], over 61% of the industry's energy end-use is reflected in the "other" category. Motor systems (pumps, material handling equipment) rank second with 25% of the total energy end-use. Direct-heating represents 13% of the industry's energy end-use.

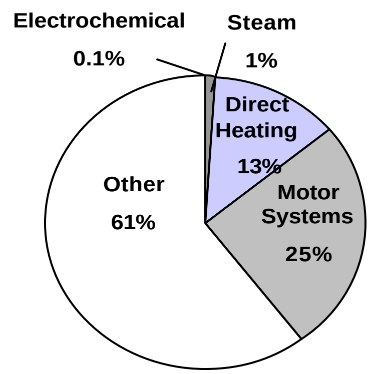


Figure 8-5 Onsite Energy Loss Profile for the Mining Industry (NAICS 312) Total Onsite Losses – 311 Trillion Btu

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 improvement. Based on the energy footprint, Figure 8-6 shows a breakdown of the mining industry's onsite losses and general energy flow. As illustrated 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 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 most 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 in energy distribution.

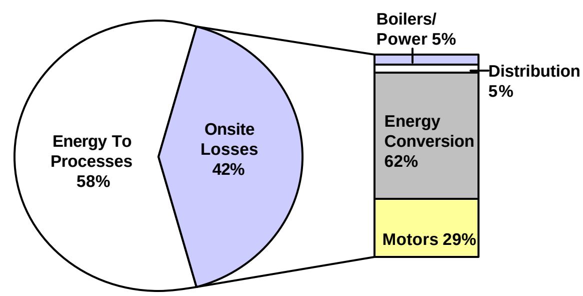


Figure 8-6 Energy End-use and Loss Distributions in Mining (NAICS 212)

System-Specific Losses

Figure 8-7 and Table 8-2 show in detail the energy use and losses for component systems. As shown, the largest energy losses occur in the "Other" category. However, because the mining sector is not part of the DOE MECS, little data are available on end-uses and losses within the "other" category. Losses are assumed to be mostly due to the 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.

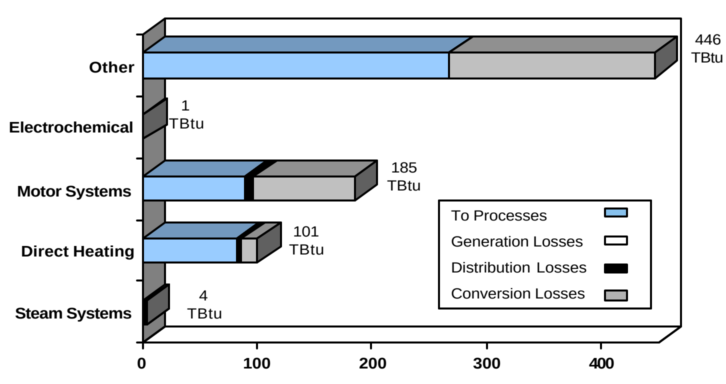


Figure 8-7 Energy End-use and Loss Distribution in Mining (NAICS 212)

Table 8-2 Mining Energy Use and Losses (Trillion Btus)							
	To Process/ End-use	Generation Losses	Distribution Losses	Conversion Losses	TOTAL Onsite Losses	Associated Carbon Emissions (MMTCE)**	Total Energy
Facilities	0	na	na	na		Na	0
Steam Systems	3	1	0.3	0.3	1.6	0	4
Direct Heating	82	na	5	14	19	0.3	101
Motor Systems	89	na	8	88	96	1.8	185
Electrochemical	1	na	na	na	0	0	1
Other Uses	268	na	na	178	178	3.2	446
Onsite Power	(19)*	16	na	na	16	0.3	16
Export of Power	0.01	na	na	na		0	0.01
TOTALS	**442**	**17**	**13**	**281**	**311**	**5.8**	**753**

*Onsite generated power is distributed among end-uses and is not included in the totals.
**Carbon emissions associated with total energy losses, in million metric tons of carbon equivalent (MMTCE).

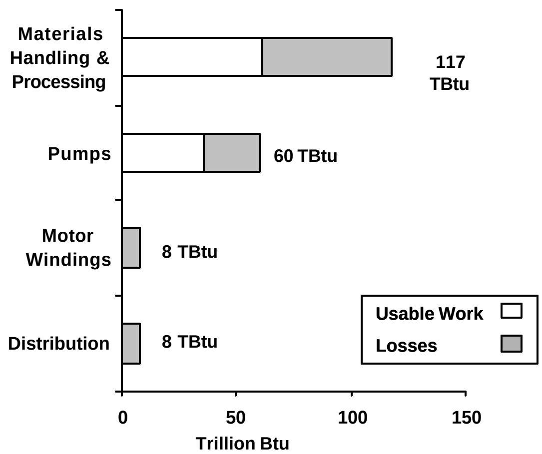


Figure 8-8 Mining Industry Motor System Energy Use and Loss Profile

Figure 8-8 shows a breakdown of energy use and losses 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 (40%) are also considerable.

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 was estimated to be 82% electricity and 18% fuel.

9.0 Cement Industry (NAICS 327310)

The cement industry is energy systems (fired systems, steam systems, motor drives), consuming about 347 TBtu in 1998 ranking them sixth among U.S. industries. Most cement industry energy is used in fired systems (305 TBtu) and in motor driven equipment (41 TBtu). Energy utilized in its steam systems accounts for only about one TBtu. The industry generates a minute amount of electricity and steam from waste fuels and byproducts to meet onsite energy demand. In 1998, onsite power generation in the cement industry totaled to approximately 2 TBtu of electricity.

The energy footprint analysis estimates pre-process energy losses attributed to energy systems in the cement industry (within the plant boundary) at around 71 TBtu. These include losses incurred in steam and power generation (0.1 TBtu), in distribution systems (11 TBtu), and in conversion to useful work (60 TBtu). About 91 TBtu of energy losses are associated with offsite utilities providing electricity, gas, and other fuels to the cement industry.

An individual energy use and loss chapter was not developed for this industry because it ranks thirteenth on the list of primary U. S. industrial energy users. However, cement ranks fifth in its use of fired systems, and the calcining process used in cement making is similar to that used in other energy-intensive sectors, such as forest products, mining, alumina, petroleum coke calcining, and chemicals manufacture (materials production, catalyst regeneration). Accordingly, the cement industry was included in the opportunities analysis to capture potential synergies from reducing energy losses in calcining across several industries.

9.1 Opportunities Analysis

Fired Systems

Table 9-1 illustrates the use of fired systems and potential end-of-process energy losses in the industry for calcining, which is the top energy consumer in cement. The efficiency of energy use in this process rests largely on the kiln type used, fuel type employed, and heat recovery and integration schemes in place. Appendix B provides details on the efficiencies assumed for each process, the major sources of energy loss, references, and other pertinent data.

The wet kiln process is the least efficient calcining technology in use and represents the principal opportunity for improving energy efficiency in the cement industry fired systems. Sources of loss from the wet kiln include water evaporation, inefficient combustion, unrecovered exhaust gases, and uncaptured radiative and convective heat. Potential efficiency improvements could be made through the implementation of preheat systems, combustion system optimization, adaptation to semi-wet conversion, enhanced heat recovery in the clinker cooler, and improvements to the grate cooler.

While dry kilns are more efficient, they can also benefit from the addition of preheaters and precalcining units, as shown in Table 9-1. Many of the older kilns in use are currently not retrofitted with effective preheat systems. Dry kilns could also benefit from increased heat recovery in the clinker cooler and better grate coolers. Heat recovery via cogeneration is also possible, but uses for the steam generated would need to be explored.

Assuming improvements to fired systems could reduce energy losses as shown in Table 9-1 (ranging from 11-50%, depending on the process), energy savings are estimated at about 80 TBtu/year.

Table 9-1 CEMENT MANUFACTURING: FIRED SYSTEMS Roll-Up Analysis

Process/ Unit Operation	Equipment Used	2002 U.S. Production Short Tons/year	Energy Intensity (10^6 Btu/ton clinker)	Total Energy Use (10^12 Btu/yr)	Average Energy Loss (10^12 Btu/yr)	Improvement Potential (%): Energy Loss Recovery or Reduction Category: Waste heat reduction	Waste heat recovery	Energy Source Flexibility	Controls, Automation, Robotics	CHP (fired and other)	Motors & Drives	Best Practices: Existing Potential	* *Future** New Potential	Technology: Commercially Available Technology & Equipment	Commercially Available *Alternative* Equipment	* *Future** R&D for New Technology & Equipment	**Future** R&D for Alternative Process	*Savings Tbtu/year*
Wet Process Long Kiln	Rotary kiln	24,647,428	6.00	148	104	X	X	X	X		X	X	X	25		25		52
Dry Process Long Kiln	Rotary kiln with heat recovery	46,450,922	4.50	209	100	X	X	X	X	X	X	X	X	10		15		25
Dry Process Preheater Kiln	Rotary kiln with preheat towers	11,849,725	3.80	45	14			X	X	X	X		X	11				2
Dry Process Precalciner Kiln	Rotary kiln with precalciner units	11,849,725	3.30	39	11			X	X	X	X		X	11				1
TOTAL				**441**	**230**													**80**

Assumptions: Efficiency improvements are based on reduction of kiln heat loss, conversion of wet kilns to semi-wet kilns, superior clinker cooling, higher efficiency motors, optimized combustion, heat recovery for cogeneration, increased use of preheaters and precalciners, and other heat recovery schemes. Energy totals come within 15% of 1998 MECS, adjusted for increased production by 2% per year.

10.0 Energy Systems

10.1 Fired Systems and Cooling

Overview

Fired systems and cooling systems play a crucial role in today's manufacturing processes. Fired systems supply heat to produce basic materials and commodities, and cooling systems chill and refrigerate processes in which achieving lower temperatures is essential. Almost 39% of the total energy used in manufacturing and mining is consumed in fired systems. Natural gas accounts for 44% of the energy used in fired systems. Electricity and coal are also important energy sources, and represent 13% of total fired system energy end-use, as shown in Figure 10-1.

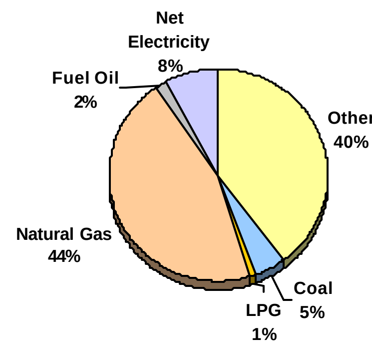


Figure 10-1 Fuel Consumption in Fired Systems and Cooling

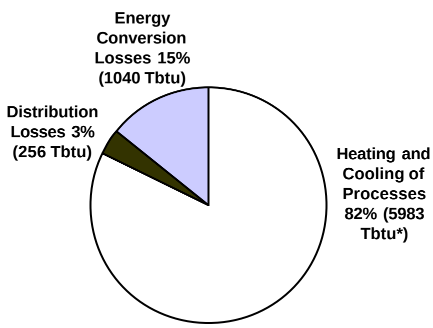


Figure 10-2 Fired Systems Energy Use and Losses in U. S. Manufacturing and Mining

Energy Use and Loss Analysis: Fired Systems

As shown in Figure 10-2, annual U.S. manufacturing and mining fired systems energy use totals 7.3 quads (including onsite losses). Only about 3.5% of this energy is consumed by cooling systems; fired systems account for a majority of the use. Fired heating equipment includes furnaces, dryers, calciners, evaporators, condensers, and other direct- or indirect-fueled heating systems. Cooling systems include cooling towers and ponds, heat exchangers, cryogenic equipment, chillers, and refrigeration equipment. Figure 10-2 does not incorporate energy that is lost downstream via flue and stack gases, and other waste heat sources, equal up to one-half of the energy delivered for heating and cooling.

Table 10-1 ranks industries by fired systems and cooling energy use. Petroleum refining is the largest fired systems energy consumer, accounting for 31% of the total. The iron and steel and chemicals industries rank second and third with 20% and 17% of total energy use, respectively. These three industries consume approximately two-thirds of all energy used for fired systems in manufacturing and mining. All three of these industries operate under severe processing conditions (high temperatures, high pressures, corrosive environments) to convert raw materials to usable products.

Table 10-1 Ranking Industry by Fired Systems Energy Use

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

Figure 10-3 shows fired system energy use as a percentage of total energy use for each industry. More than 81% of the iron and steel industry's energy use is consumed in fired systems, mostly in ironmaking and blast furnaces. Fired systems are a major portion of energy use in petroleum refining (62%), and include the use of thermal cracking processes for fuels and chemicals production. The petroleum refining industry is also a large producer of ethylene, which is accomplished primarily in a pyrolysis furnace. Chemicals and forest products industries are also significant users of fired systems, mostly for separations and drying operations. However, these industries both rely more heavily on steam for process heating than direct-fired systems.

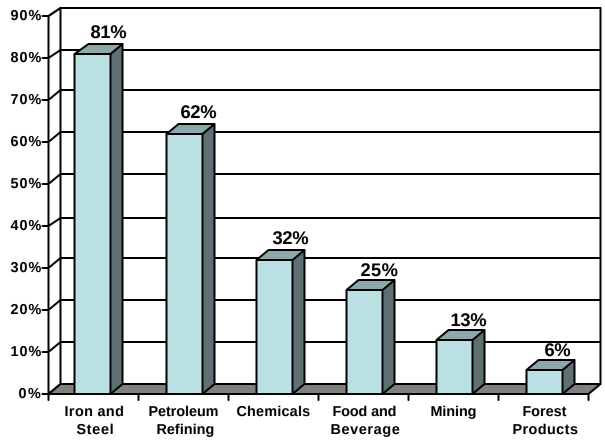


Figure 10-3 Energy Use of Fired Systems and Cooling Systems as a Percentage of Total Energy End-use

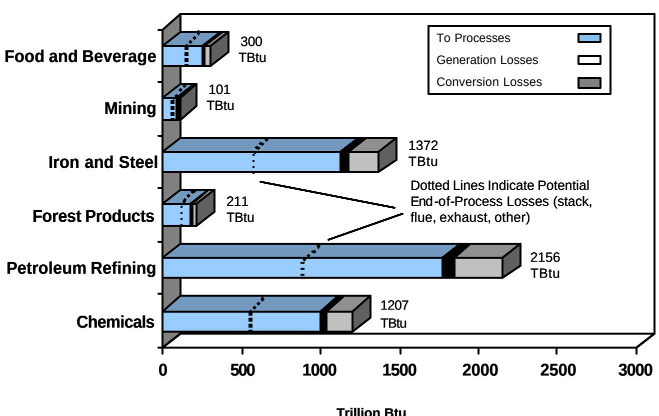


Figure 10-4 Fired Systems Energy Use and Losses by Industry

Figure 10-4 shows the energy use and losses in fired systems for the six largest energy consuming industries. Petroleum refining is the largest consumer and exhibits the largest losses. In all six industries, energy conversion to useful work comprises most losses in fired systems.

Note that the energy delivered to processes shown in Figure 10-4 does not reflect downstream energy losses exiting the process in flue and exhaust gases, in waste water, and in other waste heat sources. These losses have not been estimated for this study, and can be considerable (as much as 30-50% of the energy delivered). The dotted lines shown in Figure 10-4 illustrate the potential magnitude of these losses for some of the larger energy consuming industries. Though much of the waste heat exiting fired systems is recovered, thermodynamic and economic equipment limitations often restrict the amount of waste heat that can be recuperated feasibly.

Table 10-2 shows in greater detail the fired systems losses for each industry. The total losses attributed to these end-users in manufacturing and mining total 1.3 quads. The six largest users shown in Table 10-2 account for 77% of the total losses in this category (937 TBtu).

Table 10-2 Energy Delivery and Associated Losses in Fired Systems

	Chemicals	Petroleum Refining	Forest Products	Iron and Steel	Mining	Food and Beverage
Delivered 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**

10.2 Steam Systems

Overview

Steam is used to heat raw materials, to generate electricity, to provide heat for buildings, and to power equipment. In the United States, the total cost of fuels used for steam generation is estimated at $18 billion (1997 dollars). Overall, more than 70% of U. S. manufacturing boiler population is concentrated in four industries – chemicals, petroleum refining, forest products, and food processing.

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 total steam system fuel use [MECS 1998]. Figure 10-5 shows the boiler fuel mix for steam generation used in manufacturing and mining.

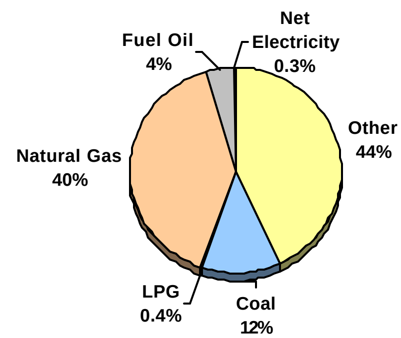
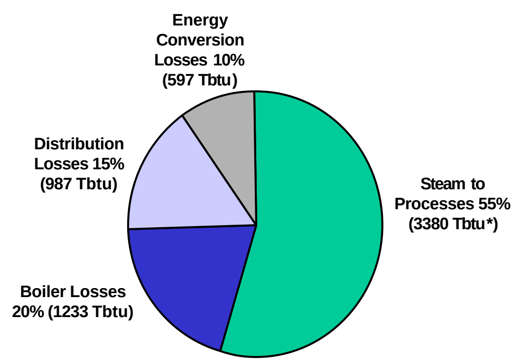


Figure 10-5 Fuel Consumption in Boilers



Energy to Steam Systems: 6201 Tbtu

Figure 10-6 Steam Use and Losses in U.S. Manufacturing and Mining

Table 10-3 Industry Ranked by Steam Energy Use

Sector	Steam Use Tbtu	Steam Use 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

Energy Use and Loss Analysis: Steam Systems

Steam systems represent 35% of total energy use in U. S. manufacturing and mining, or 6.2 quads. Only 55% of this energy is delivered to processes; the remaining 45% is lost due to inefficiencies in boilers, in energy distribution, and in energy conversion systems. Steam generation in boilers, with efficiencies ranging from 55-85%, accounts for the largest losses. Boiler efficiency varies widely, and depends both on equipment age and configuration as well as the fuel combusted. In the top six energy intensive industries alone, steam system inefficiencies are responsible for 2.7 quads of energy losses.

Distribution losses are also significant, 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 10-6 shows a breakdown of U.S. manufacturing and mining steam use and losses.

Table 10-3 shows U. S. industries ranked by steam energy use. Forest products is the largest steam user, consuming more than 38% of total industry steam use. Steam is used during pulp and paper making in digesters, in wood chip preparation, in black liquor recovery, in bleaching, and in paper drying. 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, and is used for fractionation, for steam injection, for drying, and for other purposes. In petroleum refining, steam is often in direct contact with the product (steam stripping). The food and beverage industry is another major steam user (10%), relying heavily on steam for processing, for sterilization, and for cleaning. In textiles steam is used for dyeing and bleaching. Together, these five industries account for about 95% of the total energy used by U. S. industrial steam systems.

Figure 10-7 shows the energy used for steam systems as a percentage of the total energy end-use for each industry. The forest products industry has the largest relative steam use of any U.S. industry, with steam accounting for 75% of the industry's energy end-use. Food and beverage, chemicals, and petroleum refining also depends heavily on steam energy.

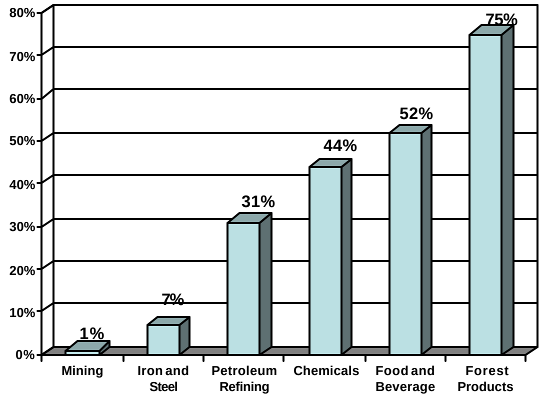


Figure 10-7 Steam Energy Use as a Percentage of Total Energy Use

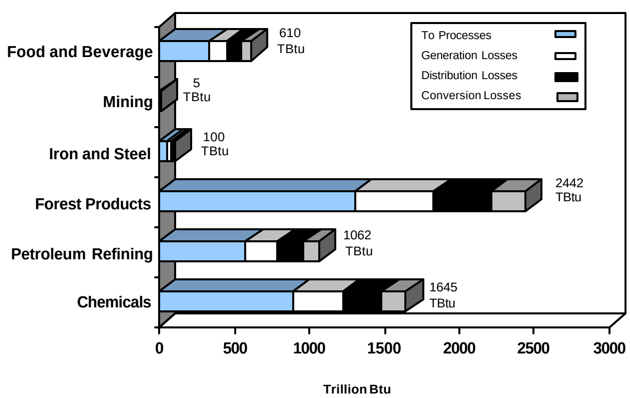


Figure 10-8 Steam Energy Use and Losses by Industry

Figure 10-8 shows the energy use and losses in steam systems for the six largest energy consuming industries. The forest products industry, specifically pulp and paper, exhibits the greatest energy losses in all categories. In all six industries, boiler inefficiencies are responsible for nearly one-half of industrial steam system losses.

Table 10-4 shows in detail the components of steam system losses for each of the six energy intensive U. S. industries. This industry grouping incurs 96% (2.7 out of 2.8 quads) of total industrial steam system losses is a significant target for potential steam-system improvements in manufacturing and mining. Steam generation represents 45% of these losses, followed by energy conversion (34%), and lastly distribution (21%). As the most prolific user of steam, the forest products industry accounts for 42% of all steam losses in U. S. manufacturing and mining.

Table 10-4 Energy Delivered and Losses in Steam Systems

	Chemicals	Petroleum Refining	Forest Products	Iron and Steel	Mining	Food and Beverage
Delivered 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**

10.3 Onsite Power Generation

Overview

Onsite power generation systems allow industries to satisfy power demand while reducing energy costs and reducing electricity purchases. Combined heat and power (CHP) systems are used to produce power onsite and then recover waste heat for use in processes. This recovered heat can be used to produce mechanical energy, to heat or cool water, to make steam, or to control humidity in buildings. CHP accounts for 92% of the total U. S. manufacturing and mining power generated onsite. The remaining power generation is obtained from gas turbines, combustion turbines, and renewable electricity generating technologies (solar, geothermal, bioenergy, ocean, wind).

Power generation systems at utilities often exhibit low efficiencies ranging from 25-44%. At these efficiencies, as much as two thirds of the fuel used for electricity generation is lost during the process. CHP systems help reduce these losses by recovering waste heat, by creating steam, and by 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 represents only 12% of the total industrial power demand and 8% of total industrial steam demand. Given that power systems require large capital investments and have significant permitting and site issues, 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.

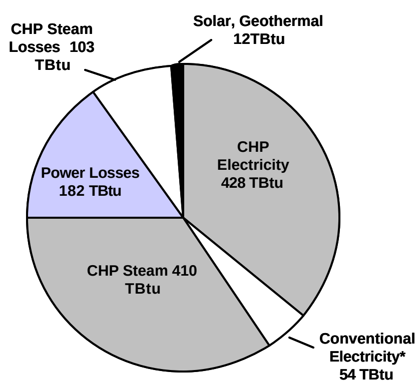


Figure 10-9 Onsite Power Generation and Loss Profile for U. S. Manufacturing and Mining

Table 10-5 Industry Rankings By CHP-Produced Electricity*		
	CHP Use	
Sector	**Tbtu**	**Rank**
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	<0.5	12
Glass & Glass Products	0	-

* Net electricity (losses not included)

Energy Use and Loss Analysis: Onsite Power Generation

Onsite electricity generation currently meets 13% of total manufacturing and mining electricity demand, with CHP accounting for the largest share. The proportionally large use of CHP can be attributed to the high thermal efficiencies of these systems, which are up to 30% greater than conventional power systems. Figure 10-9 shows an onsite power generation and loss profile for U.S. manufacturing and mining.

The forest products industry is the largest user of CHP, followed closely by the chemicals industry. These two industries alone represent 77% of total manufacturing and mining CHP energy use. Petroleum refining, food and beverage, and iron and steel are much smaller users, but are still significant when compared to other U. S. manufacturing and mining sectors. These three industries are large consumers of byproduct fuels and of steam and/or electricity thus logically can take significant advantage of the benefits of cogeneration. Table 10-5 shows industry rankings based on electricity produced onsite via CHP.

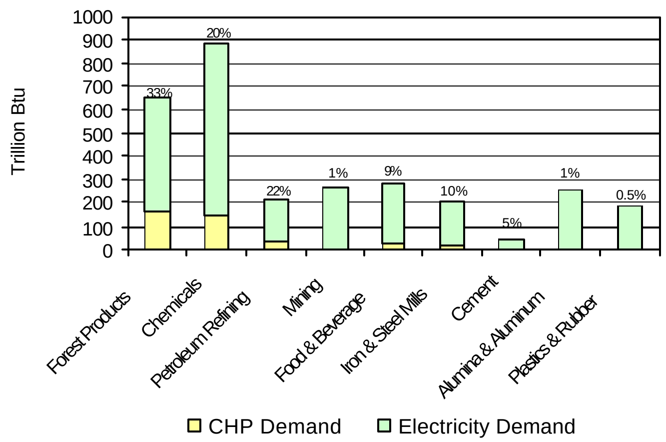


Figure 10-10 shows total electricity and CHP demand by industry. Forest products are not only the largest CHP user, but also satisfies the largest amount of its electricity needs with CHP (32%). CHP is attractive economically and technically to pulp and paper mills because their processes generate large quantities of waste fuels that can be used for power generation and are also notably steam reliant.

The petroleum refining and chemicals industries also meet a considerable portion of their electricity requirements with CHP (22% and 20%, respectively).

Figure 10-10 CHP as a Percentage of Total Electricity Demand

Figure 10-11 shows the energy use and losses in CHP systems for each industry. Losses occur primarily during both power generation (conversion of fuels to electricity) and boiler and auxiliary system operation. However, because cogeneration also produces steam for process use, the overall thermal efficiency of its electricity production is significantly greater than that of purchased electricity.

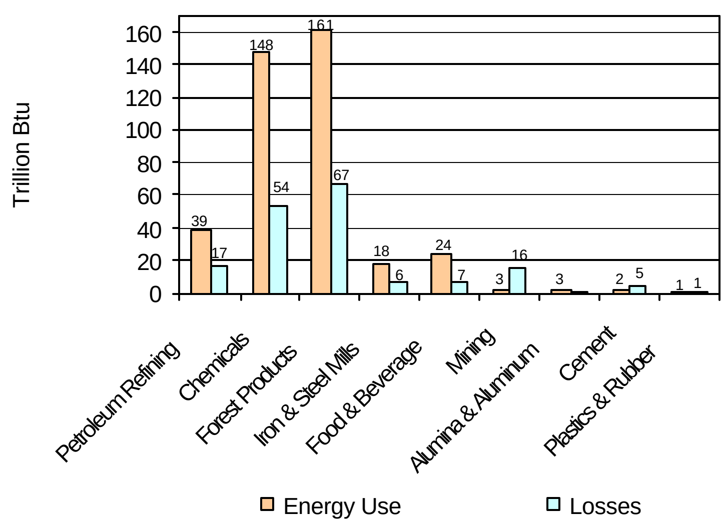


Figure 10-11 CHP Energy Use and Losses in Selected Industries

10.4 Motor Systems

Overview

Motor-driven systems (sometimes referred to alternatively as machine-driven systems) include pumps, fans, compressors, conveyor belts, mixers, grinders, refrigerators, and materials handling and processing equipment. Motor systems consume a significant portion of the total energy used by the most energy intensive industries in the U. S. manufacturing and mining sectors. Total energy consumption attributed to motor systems exceeds 2.3 quads annually.

Motor systems are powered largely by electricity (>89%), as shown in Figure 10-12. Natural gas is the second most used energy source, but only represents about 5% of motor-driven industrial energy use [MECS 1998].

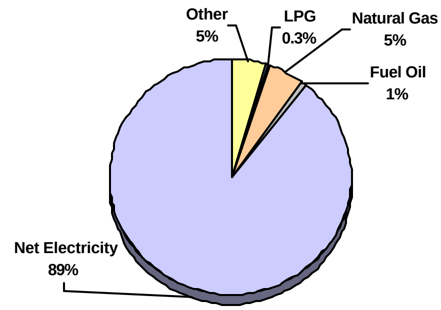
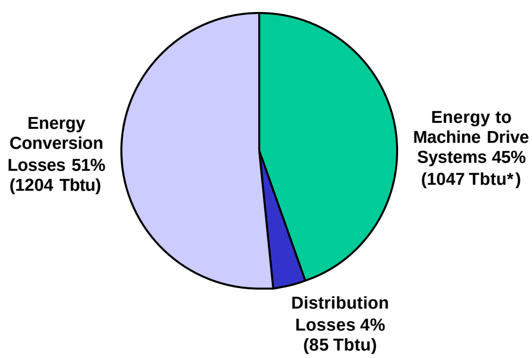


Figure 10-12 End-use Fuel Consumption for Machine Drive Systems



Energy to Motor Systems: 2336 Tbtu

Figure 10-13 Motor Systems Use and Losses in Manufacturing and Mining

Energy Use and Loss Analysis: Motor Systems

In the top six energy-intensive U. S. industries covered in this report, motor systems account for over 1.5 quads of energy use with losses of nearly one quad. Motor systems represent 13% of total energy end-use in U. S. manufacturing and mining. Only 45% of this energy is delivered to processes; the remaining 55% is lost due to inefficiencies in motor-driven equipment, in motor windings, and in distribution systems. Energy conversion losses occurring during the conversion of motor energy to useful work represent the largest motor losses (51% of total energy supply to motor systems). Figure 10-13 outlines motor systems use and losses.

Table 10-6 ranks industry based on motor systems energy consumption. The chemicals industry is the largest consumer of energy for motor systems, accounting for over 21% of total motor systems energy use in U. S. manufacturing and mining. The forest products industry ranks second utilizing another 18% of the total. Both of these industries are large users of motor-driven pumps, fans, compressed air systems, and materials processing and handling 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 U. S. manufacturing and mining.

Table 10-6 Industry Rankings by Motor Systems Energy 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
Fabricated Metals	104	7
Heavy Machinery	99	8
Transportation Equipment	99	9
Plastics & Rubber	98	10
Textiles	85	11
Computers, Electronics	56	12
Cement	40	13
Alumina & Aluminum	33	14
Glass & Glass Products	22	15
Foundries	19	16

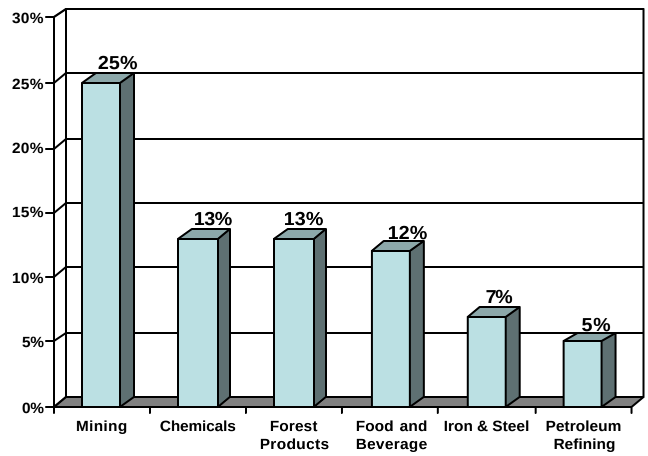


Figure 10-14 Motor Energy Use as a Percentage of Total Energy End-use

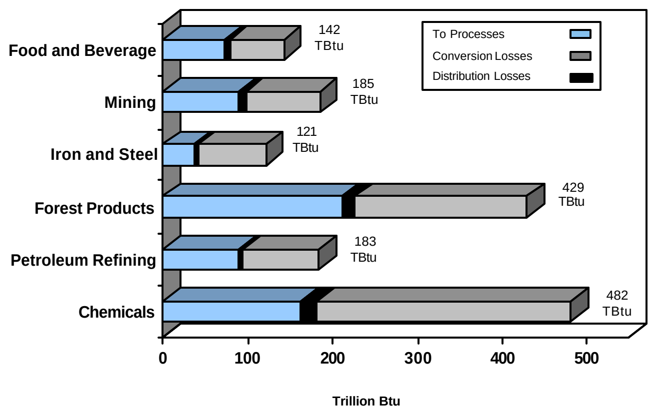


Figure 10-15 Motor Systems Use and Losses by Industry

Figure 10-14 shows the energy used for motor systems as a percentage of the total energy end-use for each industry. While mining is only the third largest energy user for machine-driven systems, motors represent 25% of mining's total energy end-use, almost twice as much as higher-ranked chemicals and forest products. This reflects the mining industry's dependence on motor-driven drills, grinders, fans, and crushers, many of which are exceedingly inefficient in converting energy to useful work. While the chemicals and petroleum refining industries are the first and second largest energy users for motor systems, motors only represent about 13% of their total energy use.

Figure 10-15 shows the energy use and losses in motor systems for the six largest energy consuming industries. The chemicals industry is the top user and accounts for the largest losses. In all six industries, energy conversion losses represent the bulk of total motor system losses. The substantial energy conversion losses in chemicals and other industries are due to the 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 10-15. Energy losses associated with electricity generated offsite and used to power motor systems are not included.

Table 10-7 shows more specifically 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% of losses. Chemical industry motor losses represent 25% of the total motor system losses in U. S. manufacturing and mining, followed by forest products at 17%.

Table 10-7 Energy Delivered and Losses of Motor Systems

	Chemicals	Petroleum Refining	Forest Products	Iron and Steel	Mining	Food and Beverage
Energy 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**

10.5 Facilities and Other Systems

Overview

Other energy systems used in industry include onsite transport equipment, electrochemical systems, facilities HVAC and lighting, process controls, and other industry-specific processing or non-processing systems. Onsite transport includes the energy used to fuel equipment (trucks, forklifts, etc.) that carry materials between locations at the plant site. Electrochemical energy use occurs in systems that convert raw inputs to products through an electrochemical reaction. 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.

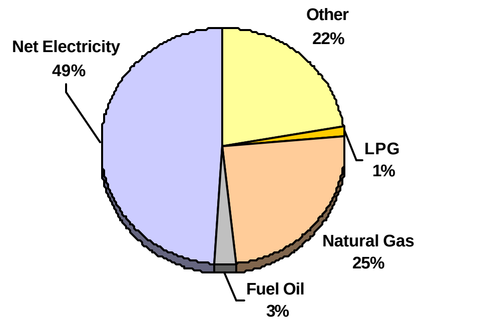


Figure 10-16 Energy Consumption by Source for Facilities HVAC and Lighting, Electrochemical Processes, and Other Uses

As shown in Figure 10-16, almost one-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]. Coal is not included as a fuel source as it represents a very minute percentage of the total energy supply for facilities.

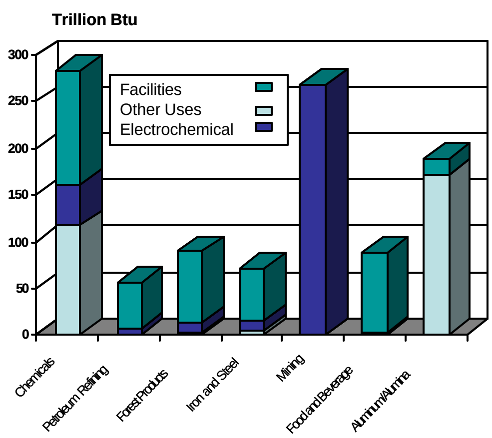


Figure 10-17 Energy Used in Facilities HVAC and Lighting, Electrochemical Processes, and Other Uses

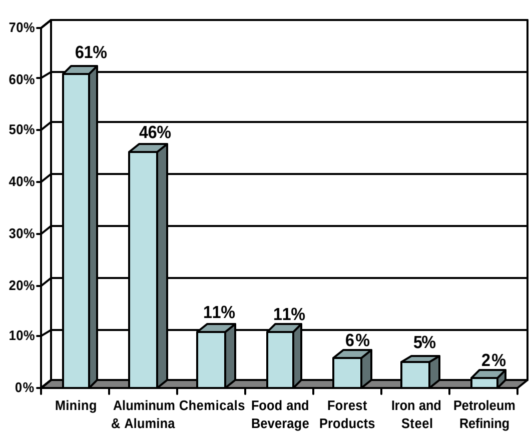


Figure 10-18 Other Systems Energy Use as a Percentage of Total Energy End-use

Energy Use and Loss Analysis: Facilities and Other Systems

Figure 10-17 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. Since mining is not covered by the Manufacturing Energy Consumption Survey [MECS 1998], there are limited data on energy use for its specific equipment categories. However, from information that is available, the "other" category in mining includes onsite transport of mined materials, diesel-fueled equipment for materials handling, and other energy intensive mining equipment. The aluminum industry is the leading energy user of electrochemical processes, totaling 172 TBtu. The chemicals industry is the principal energy user for facilities HVAC and lighting systems (123 TBtu), and the second largest user of electrochemical processes (117 TBtu).

The total energy used for facilities HVAC and lighting, electrochemical processes, and other systems accounts for 14% of total U. S. manufacturing and mining energy end-use. More specifically, facilities account for 8%, electrochemical processes for 2%, and other systems for 4%. Figure 10-18 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 (61%) classified under "other systems". In the aluminum industry, 40% of its total energy end-use is consumed by electrolysis operations.

The mining and chemicals industries are the two largest users of energy for facilities and other systems. The mining industry exhibits the most severe losses in this category, primarily because materials handling and transport systems are highly inefficient. Chemical industry use is attributed predominately to electrochemical reactors and to facilities HVAC and lighting.

The aluminum and alumina industry is the third largest end-user of energy for facilities and other systems, and also exhibits substantial losses. Figure 10-19 and Table 10-8 show the energy use and losses for each industry in facilities HVAC and lighting, in electrochemical processes, and in other uses.

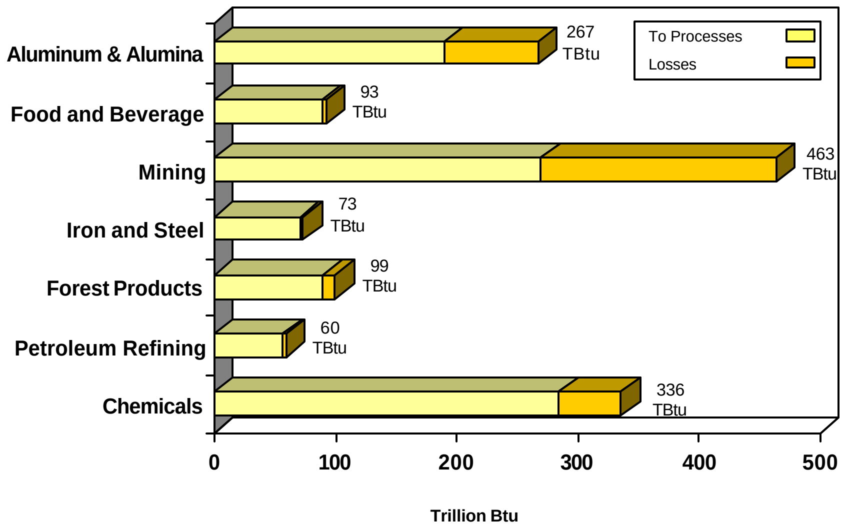


Figure 10-19 Energy Use and Losses in Facilities and Other Uses

Table 10-8 Energy Delivered and Losses in Facilities and 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
Total Energy Use to Process/Facility	284	57	90	71	269	89	189
Total Losses	52	3	9	2	194	4	78
Industry Totals	**336**	**60**	**99**	**73**	**463**	**93**	**267**

11.0 Top Twenty Opportunities

11.1 Opportunity Selection Criteria

Table 11-1 Opportunity Selection Criteria

- Magnitude of potential energy savings for combined individual and multiple-industry applications
- Initial applicability across more than one industry
- Potential for extending results to industries not included in the detailed study
- Identified in existing visions and roadmaps as a priority for industry
- High potential for reducing costs and increasing efficiency
- Feasibility and industry acceptance of possible technology options
- Environmental soundness or potential for reduced environmental impact

A set of criteria was developed and applied to aid in identifying potential targets for energy loss reduction and recovery. These criteria, which cover a range of energy, economic, environmental, and technical aspects, are shown in Table 11-1. The first two criteria represent the greatest potential for energy benefits.

Opportunities were developed in two primary categories: 1) those that could be achieved through research and development opportunities (whether near-, mid-, or long-term), and 2) those that could be achieved without R&D through adoption or implementation of existing or newly emerging technology, tools, or best practices. These two approaches are outlined below.

11.2 Research, Development, and Demonstration Opportunities

Individual results of the opportunity analysis for each of the energy-intensive industries profiled in this study were used to compile a list of potential targets in key functional categories. The functional categories correspond to some of the major technology approaches for improving efficiency and reducing energy losses – waste heat recovery, energy recovery, alternative energy sources – and the major industrial sources of losses. While technology options do exist in some cases to capture these opportunities, most are not currently feasible, technically or economically, and will require some degree of research and development to move toward industry adoption. Some options are near-term (0-3 years), while others will require moderate (4-10 years) or extended R&D (greater than 10 years). In some cases, a combination of research and demonstration will be required. Federal funding might be appropriate for some, but not all, and no judgments are made regarding funding applicability or potential research performers.

The approach was to calculate the potential energy savings based on ***end-of-process energy losses*** for individual industries (see industry-specific chapters and Appendix C). These would include the energy embodied in waste gases and fluids (e.g., stack, flues) heat, in byproducts, in radiative and evaporative heat loss, and in any other sources of energy losses downstream of the process. The energy savings for industries were then grouped into common technology options, all requiring some degree of research, development and demonstration (RD&D). These opportunities are illustrated in Table 11-2, highlighted by shading. Potential reduction in end-of-process losses achieved through RD&D amounts to about 2.1 quads.

In addition, a conservative estimate of the potential energy savings that could be attained by recovering a percentage of ***pre-process energy losses*** (identified via the energy footprints) was also calculated. The pre-process loss contributions for RD&D amounted to 960 TBtu and were taken from 8 industries: chemicals, petroleum refining, forest products, iron and steel, food and beverage, cement, aluminum, and foundries. These are shown in Table 11-2. The basic assumptions behind each opportunity are described in detail by opportunity number in Appendix C.

Potential energy savings are summarized in Table 11-3 according to broader categories that group similar approaches across different industries. Some of the most worthwhile opportunities exist in the recovery of waste energy from fluids and gases in a diversity of industries from petroleum refining to metals manufacture. Technology R&D areas include innovative energy recovery cycles, waste heat pumping, thermally activated technologies, new heat recovery techniques, and improved energy transport and storage. Supporting technologies such as hot gas cleanup and corrosion-resistant materials would be needed to realize these opportunities.

Drying is another energy-intensive process that generates substantial amounts of wasted energy, and could benefit from energy recovery as well as the exploration of alternative energy sources. The potential combined impacts from waste heat and energy recovery in drying are over 1.8 quads of energy annually. Most of these opportunities require R&D, and could be achieved in the mid- to long-term time frame.

Table 11-2 Top 20 R&D Opportunities (Trillion Btu) *[Shading indicates opportunity that will require some degree of RD&D; no shading indicates a near-term, best practices opportunity that could be achieved without R&D, with moderate to no federal funding]*					
#	**Opportunity Area**	**Industries Analyzed**	**Pre-Process Energy Savings**	**Post-Process Energy Savings**	**Total Energy & Cost (million $) Savings**
1	**Waste heat recovery** from gases and liquids in chemicals, petroleum, and forest products, including hot gas cleanup and dehydration of liquid waste streams	chemicals, petroleum, forest products	0	851	851 ($2271 MM)
2	**Combined heat and power systems**	forest products, chemicals, food, metals, machinery	634	0	634 ($2000 MM)
3	**Advanced industrial boilers**	chemicals, forest products, petroleum, steel, food processing	400	0	400 ($1090 MM)
4	**Heat recovery from drying processes**	chemicals, forest products, food processing	160	217	377 ($1240 MM)
5	**Steam best practices** (improved generation, distribution and recovery), not including advanced boilers	all manufacturing	310	0	310 ($850 MM)
6	**Pump system optimization** in electric motor-driven systems	all manufacturing	*302 (98)	0	*302 (98) $1370 MM)
7	**Energy system integration**	chemicals, petroleum, forest products, iron and steel, food, aluminum	110	150	260 ($860 MM)
8	**Improved process heating/heat transfer systems for chemicals and petroleum industries** (improved heat exchangers, new materials, improved heat transport)	petroleum, chemicals	121	139	260 ($860 MM)
9	**Energy efficient motors and improved rewind practices**	all manufacturing	*258 (84)	0	*258 (84) ($1175 MM)
10	**Waste heat recovery** from gases in metals and non-metallic minerals manufacture (excluding calcining), including hot gas cleanup	iron and steel, cement	0	235	235 ($1133 MM)
11	**Energy source flexibility** (heat-activated power generation, waste steam for mechanical drives, indirect vs. direct heat vs. steam)	chemicals, petroleum, forest products, iron and steel	119	75	194 ($1100 MM)
12	**Improved sensors, controls, automation, robotics for energy systems**	chemicals, petroleum, forest products, iron and steel, food, cement, aluminum	39	152	191 ($630 MM)
13	**Improved process heating/heat transfer for metals melting, heating, annealing** (cascade heating, batch to continuous, better heat channeling, modular systems)	iron and steel, metal casting, aluminum	63	127	190 ($915 MM)
14	**Compressed air system optimization** in motor-driven systems	all manufacturing	*163 (53)	0	*163 (53) ($740 MM)
15	**Optimized materials processing** (grinding, mixing, crushing)	all manufacturing	*145 (47)	0	*145 (47) ($660 MM)
16	**Energy recovery from byproduct gases**	petroleum, iron and steel	0	132	132 ($750 MM)
17	**Energy export and co-location** (fuels from pulp mills, forest biorefineries, co-location of energy sources/sinks)	forest products	0	105	105 ($580 MM)
18	**Waste heat recovery from calcining** (not flue gases)	cement, forest products	11	63	74 ($159 MM)
19	**Heat recovery from metal quenching/cooling processes**	iron and steel	0	57	57 ($275 MM)
20	**Advanced process cooling and refrigeration**	food processing, chemicals, petroleum and forest products	*57 (15)	0	*57 (15) ($212 MM)
TOTALS			**2892**	**2303**	**5195 ($18,418 MM)**

*Includes losses incurred during offsite generation and transmission of electricity, based on conversion factor of 10500 Btu/kWh. Number in parenthesis does not include losses.

Table 11-3 Opportunity Energy Savings Summarized by Broad Categories	
Category	**Combined Savings (Trillion Btu)**
Waste Heat and Energy Recovery (Opportunities 1,4,10,16-19)	1831
Improvements to Boilers, Fired Systems, Process Heaters and Cooling (Opportunities 3,8,13,20)	907
Energy System Integration and Best Practices (Opportunities 5-7,9,14-15)	1438
Energy Source Flexibility and Combined Heat and Power (Opportunities 2, 11)	828
Sensors, Controls, Automation (Opportunity 12)	191
Total	5195

Research to improve both boiler systems and fired systems (process heaters) represents an important opportunity to reduce energy losses in many industrial applications. While some incremental improvements can be achieved, R&D could lead to innovations that increase the efficiency of process heaters and heat transfer systems substantially. Combined energy savings for these categories are over 900 TBtus annually.

Another important cross-cutting area with significant potential for energy loss reduction is sensors, controls, and automation. Better sensors, for example, can enable more effective control of the combustion process, thereby helping manufacturers meet product specifications while minimizing energy use and cost.

Achieving energy source flexibility is essentially finding new or alternative ways to provide the energy required for manufacturing processes. Technology options range from innovations such as microwaves or heat-activated power to the substitution of steam for direct heat or vice-versa, and new energy sources such as biomass. In some cases, technology is already available and demonstrations may be needed to prove the technical and economic feasibility of the alternative. In others, significant research may be needed to develop and apply the technical concept in an industrial setting.

11.3 Energy Management and Integration

In addition to opportunities achieved through technology RD&D, there are potential energy savings to be gained via the implementation of improved energy management and energy integration strategies. For example, tools to integrate energy sources and sinks, and assist industries in improving operating and maintenance practices, will help to achieve these near-term opportunities.

To capture the more near-term opportunities, estimates were made of potential reductions in energy losses based on various sources. These include the system losses calculated in the energy footprint analysis for individual industries, a motor opportunities study conducted by Oak Ridge National Laboratory [ORNL 1998], and a national roadmap developed for combined heat and power [USCHPA 2001]. The results are opportunities with no shading in Table 11-2. The assumptions and methodology behind these opportunities are provided in more detail by opportunity number in Appendix C. Overall, the combined energy loss reductions for near-term opportunity areas total more three quads annually.

There are also near- to long-term opportunities for increased use of CHP in industrial facilities. CHP represents a means of reducing energy losses both onsite and offsite. By displacing purchased electricity with more efficiently generated onsite energy, industry meets its energy needs more effectively and reduces its bottom line. As shown in Table 11-2, large potential energy savings are possible from the increased use of combined heat and power (CHP) systems in the industrial sector, specifically in the forest products, chemicals, metals, and machinery industries. Savings are based on the potential adoption of 54 GW of new CHP capacity by 2020.

The optimization of motor-driven systems such as pumps, compressors, and materials processors (grinders, mixers, crushers, sizers), as well as upgrading motors and improving rewind practices, represents a unique opportunity to reduce energy losses both within and outside the plant boundary. Potential energy savings are estimated to total around 1.4 quads annually (see Table 11-3). Reducing electricity demand in the plant translates into less electricity generated at utilities, concurrently reducing generation and transmission losses.

Energy system integration involves a diversity of methods for integrating energy sources and sinks, for integration of energy requirements to minimize the cost of operations, and for part-load cycling and load management. Energy savings are based on a reduction in pre- and post-process energy losses in six energy-intensive industries (petroleum, chemicals, forest products, iron and steel, food processing, and aluminum).

11.4 Cross-Industry Opportunities

Using the top 20 opportunities identified, a matrix of cross-cutting application areas was developed for all 16 of the industrial sectors covered in the original energy footprint analysis (see Table 11-4). The matrix illustrates the potential for the widespread extension of new energy systems (steam and fired systems) technology and the capability to replicate energy loss reductions across U.S. industry.

The most industry-wide opportunities exist in a variety of industries in the recovery of waste heat from exit gases, including flue and stack gases, flared gases, vent gases, metal heating, dryer vents, and combustion gases. These are available throughout a range of temperatures, could have substantial energy content, are often contaminated, and may include dilute concentrations of valuable products that are difficult to separate and recover and cannot be vented directly to the atmosphere.

Another important cross-cutting area is improvements to heat transfer systems. This incorporates a wide range of technologies, with the most important being advanced materials (both refractories and materials of construction), innovative heat exchanger designs, improved insulation, new ideas for integration of heat sources and sinks, modular heat transfer systems, oxy-fuel firing, and others.

Table 11-4 Cross-Industry Technology Matrix

	1. Waste heat recovery/ gases and liquids/chemicals, petroleum, forest products	2. Combined heat and power	3. Advanced industrial boilers	4. Heat recovery from drying	5. Steam best practices	6. Pump system optimization	7. Energy system integration	8. Improved process heating/ heat transfer/ chemicals, petroleum	9. Efficient motors/rewind practices	10. Waste heat recovery/ gases/ metals and minerals	11. Energy source flexibility	12. Improved sensors, controls	13. Improved process heating/heat transfer/ metals melting, heating	14. Compressed air optimization	15. Optimized materials processing	16. Energy recovery/ byproduct gas	17. Energy export and co-location	18. Waste heat recovery/calcining	19. Heat recovery/metal quenching/ cooling	20. Advanced process cooling/ refrigeration
Petroleum Refining	■	■	■		■	■	■	■	■		■	■		■	■	■	■			■
Chemicals	■	■	■	■	■	■	■	■	■		■	■		■	■	■	■			■
Forest Products	■	■	■	■	■	■	■	■	■		■	■		■	■	■	■	■		
Iron and Steel		■	■		■	■	■		■	■	■	■	■		■	■	■		■	
Food and Beverage	■	■	■	■	■	■	■	■	■		■	■		■	■		■			■
Cement				■		■	■		■		■	■			■			■		
Heavy Machinery		■	■		■	■	■		■		■	■	■				■		■	
Mining						■	■		■		■	■			■				■	
Textiles	■	■	■		■	■	■	■	■		■	■		■			■			
Transportation Equipment		■	■		■	■	■		■		■	■	■				■		■	
Aluminum & Alumina						■	■		■	■	■	■	■		■				■	
Foundries						■	■		■	■	■	■	■		■				■	
Plastics & Rubbers	■	■	■		■	■	■	■	■		■	■		■			■			
Glass & Glass Products						■	■		■	■	■	■	■		■					
Fabricated Metals						■	■		■	■	■	■	■						■	
Computers, Electronics						■	■		■		■	■								

Note: Shading indicates opportunity is applicable to that industry.

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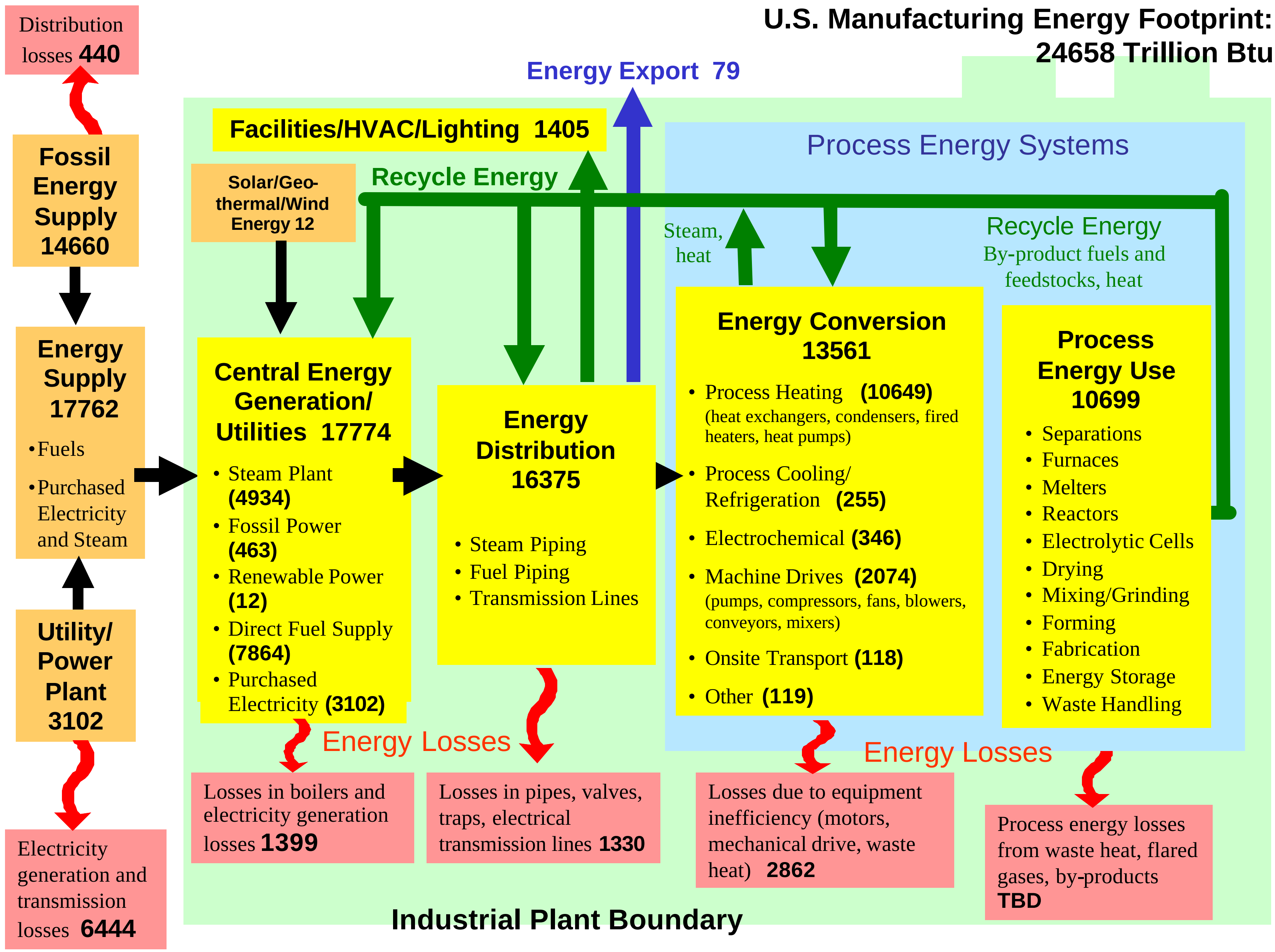
Appendix A

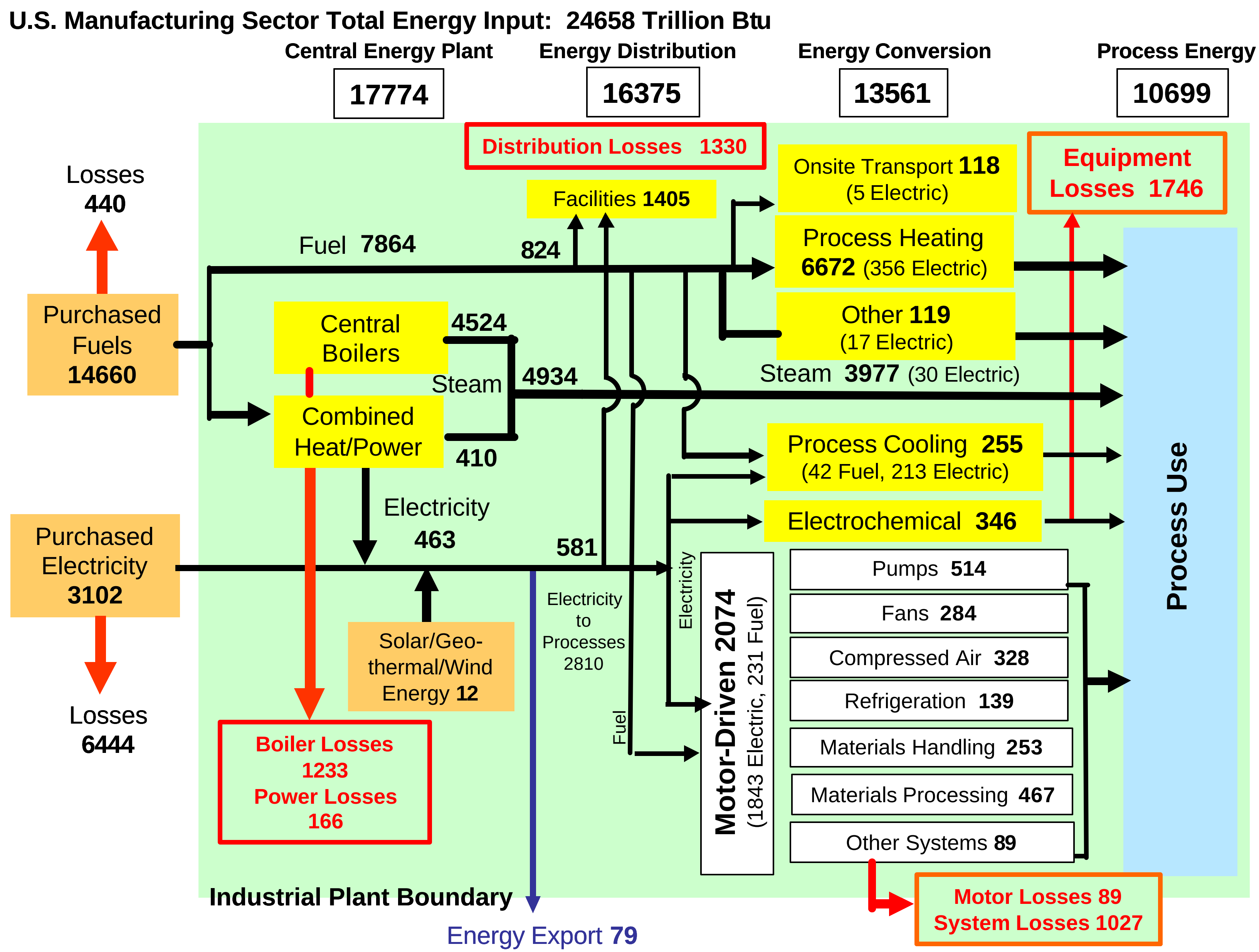
Energy Footprints and Sample Calculations

In alphabetical order, by industry

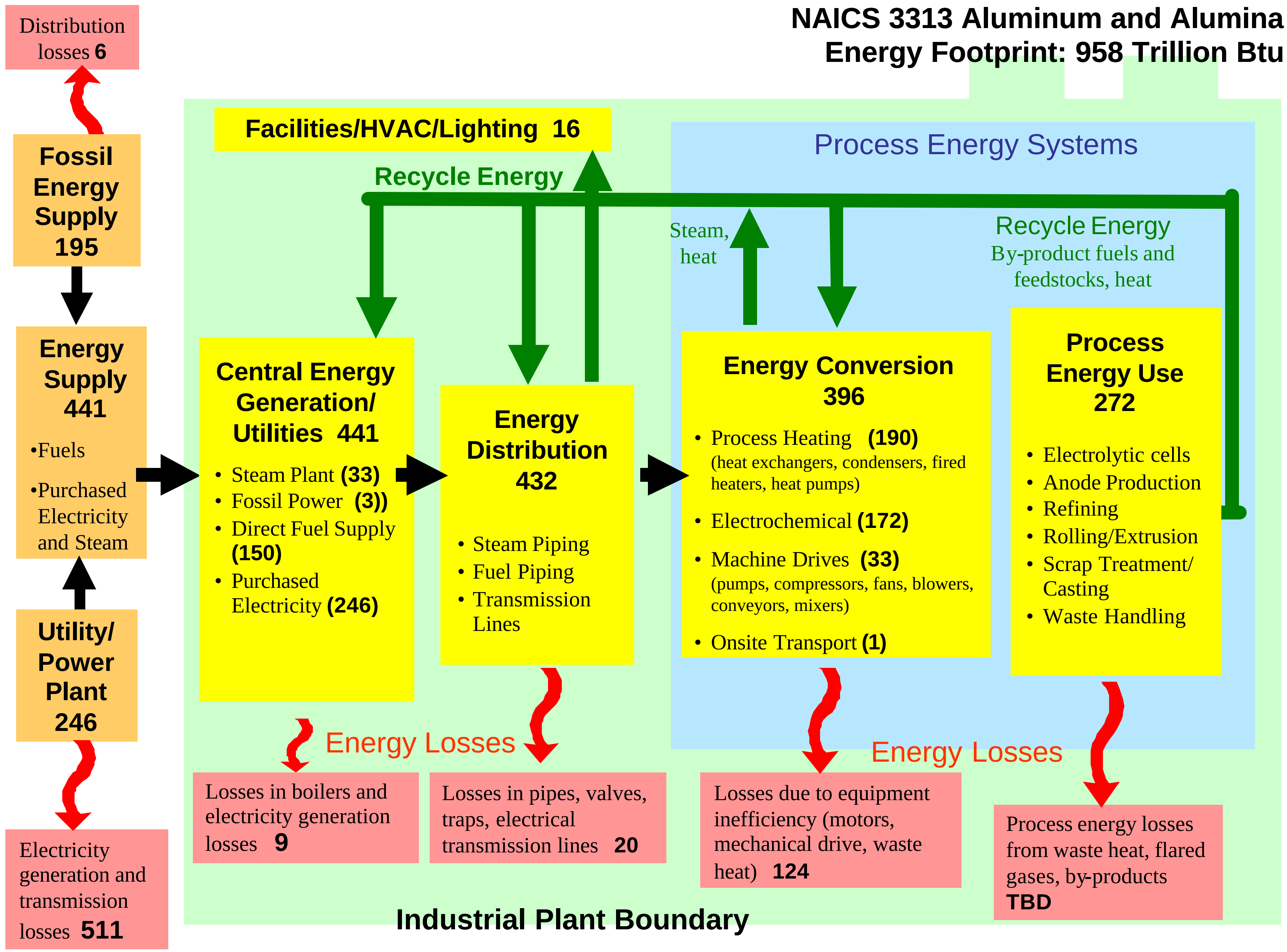
All Manufacturing
Alumina and Aluminum
Cement
Chemicals
Computers, Electronics, and Electrical Equipment
Fabricated Metals
Food and Beverage
Forest Products
Foundries
Glass and Glass Products
Heavy Machinery
Mining
Petroleum Refining
Plastics and Rubber
Steel Industry
Textiles
Transportation Equipment

Sample Calculations: Forest Products

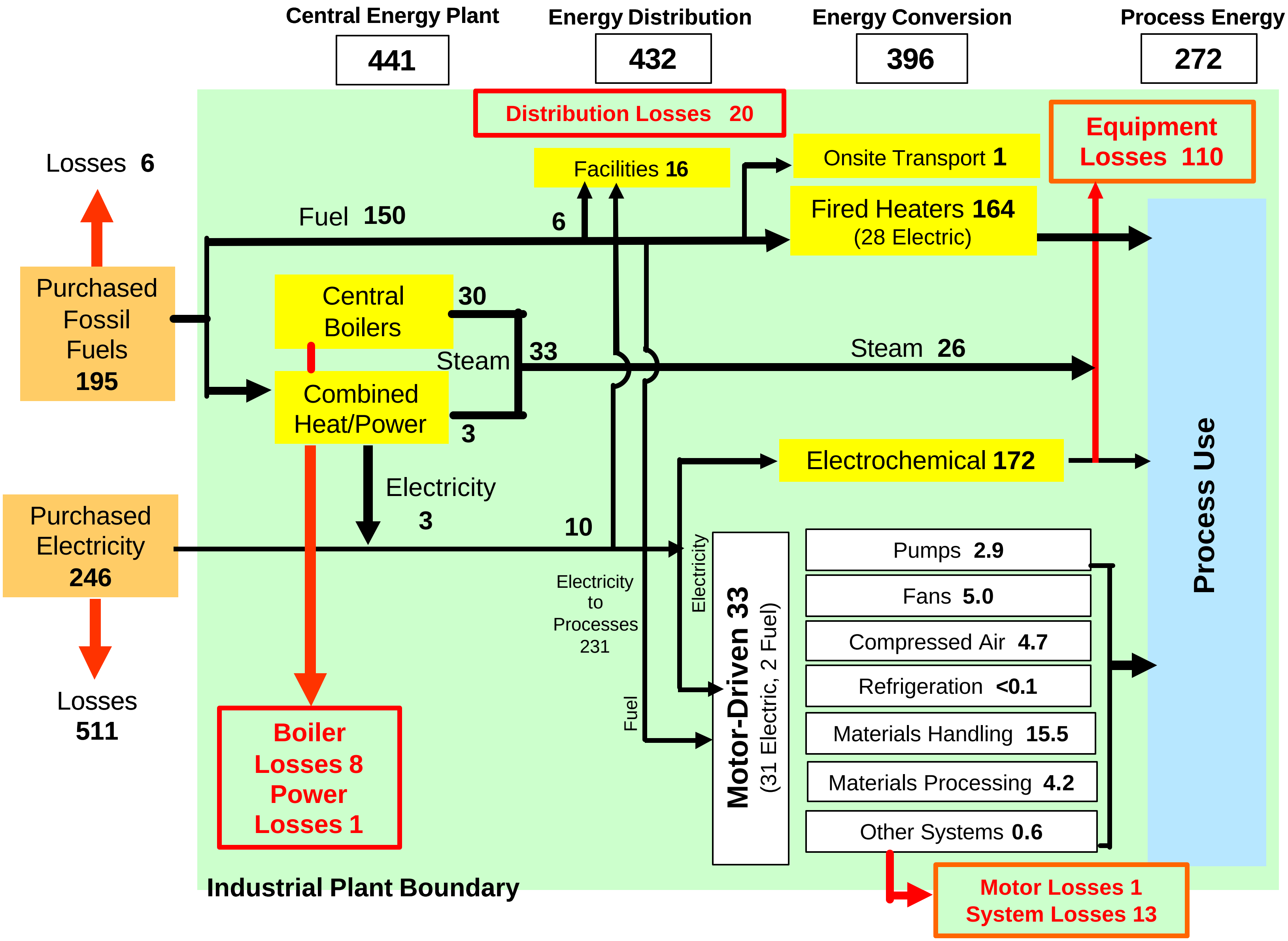

U.S. Manufacturing Energy Footprint:
24658 Trillion Btu
Distribution losses 440
Fossil Energy Supply 14660
Energy Supply 17762
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 3102
Electricity generation and transmission losses 6444
Energy Export 79
Facilities/HVAC/Lighting 1405
Solar/Geo-thermal/Wind 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
Energy Losses
Losses in boilers and electricity generation losses 1399
Losses in pipes, valves, traps, electrical transmission lines 1330
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

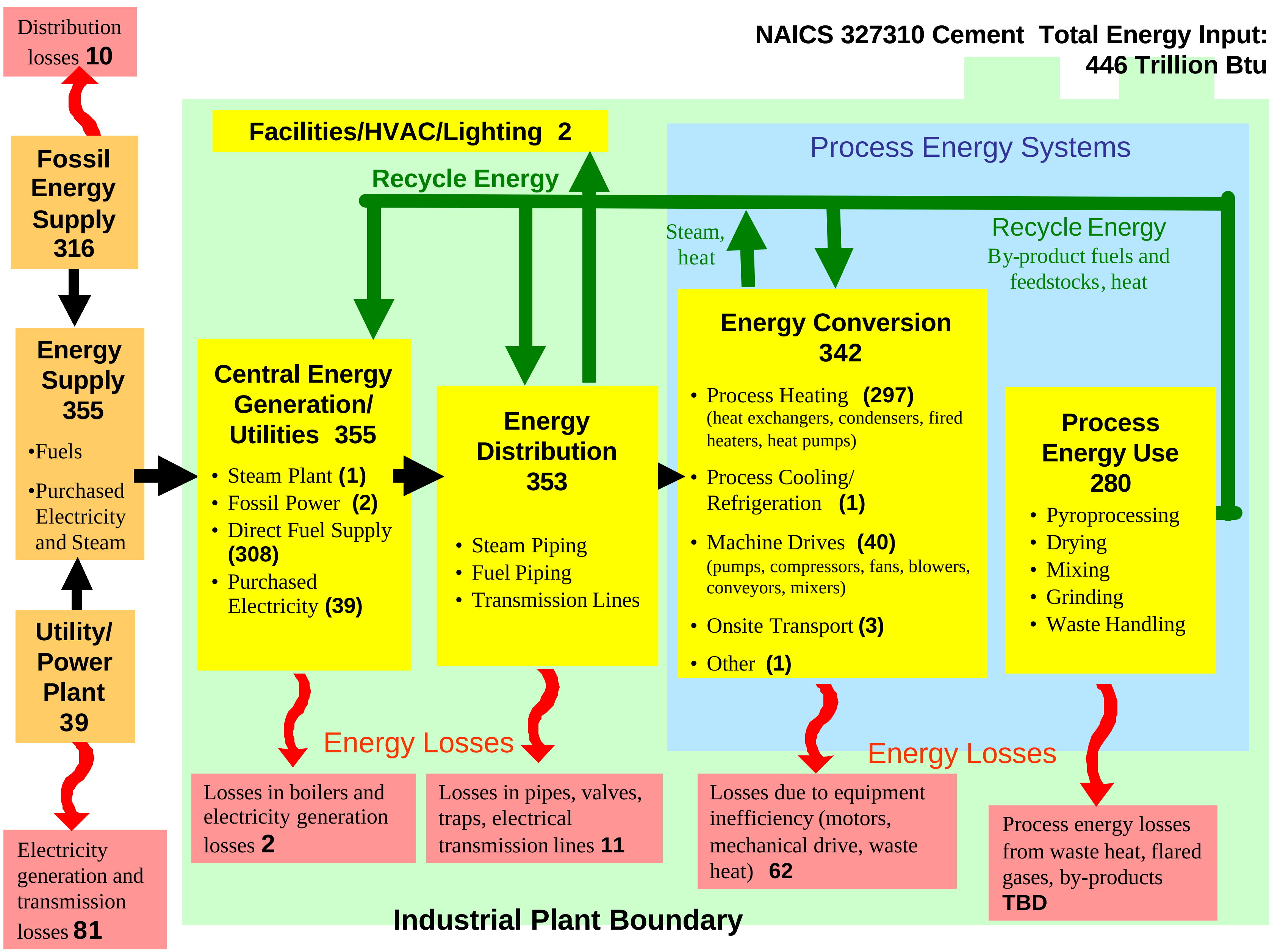

U.S. Manufacturing Sector Total Energy Input: 24658 Trillion Btu
Central Energy Plant
17774
Energy Distribution
16375
Energy Conversion
13561
Process Energy
10699
Losses
440
Purchased Fuels 14660
Distribution Losses 1330
Facilities 1405
Fuel 7864
824
Onsite Transport 118 (5 Electric)
Process Heating 6672 (356 Electric)
Other 119 (17 Electric)
Equipment Losses 1746
Central Boilers
4524
Steam
4934
Steam 3977 (30 Electric)
Combined Heat/Power
410
Process Cooling 255 (42 Fuel, 213 Electric)
Electrochemical 346
Electricity
463
581
Purchased Electricity 3102
Losses
6444
Solar/Geo-thermal/Wind Energy 12
Electricity to Processes 2810
Electricity
Fuel
Motor-Driven 2074 (1843 Electric, 231 Fuel)
Pumps 514
Fans 284
Compressed Air 328
Refrigeration 139
Materials Handling 253
Materials Processing 467
Other Systems 89
Process Use
Boiler Losses 1233
Power Losses 166
Industrial Plant Boundary
Energy Export 79
Motor Losses 89
System Losses 1027

NAICS 3313 Aluminum and Alumina
Energy Footprint: 958 Trillion Btu

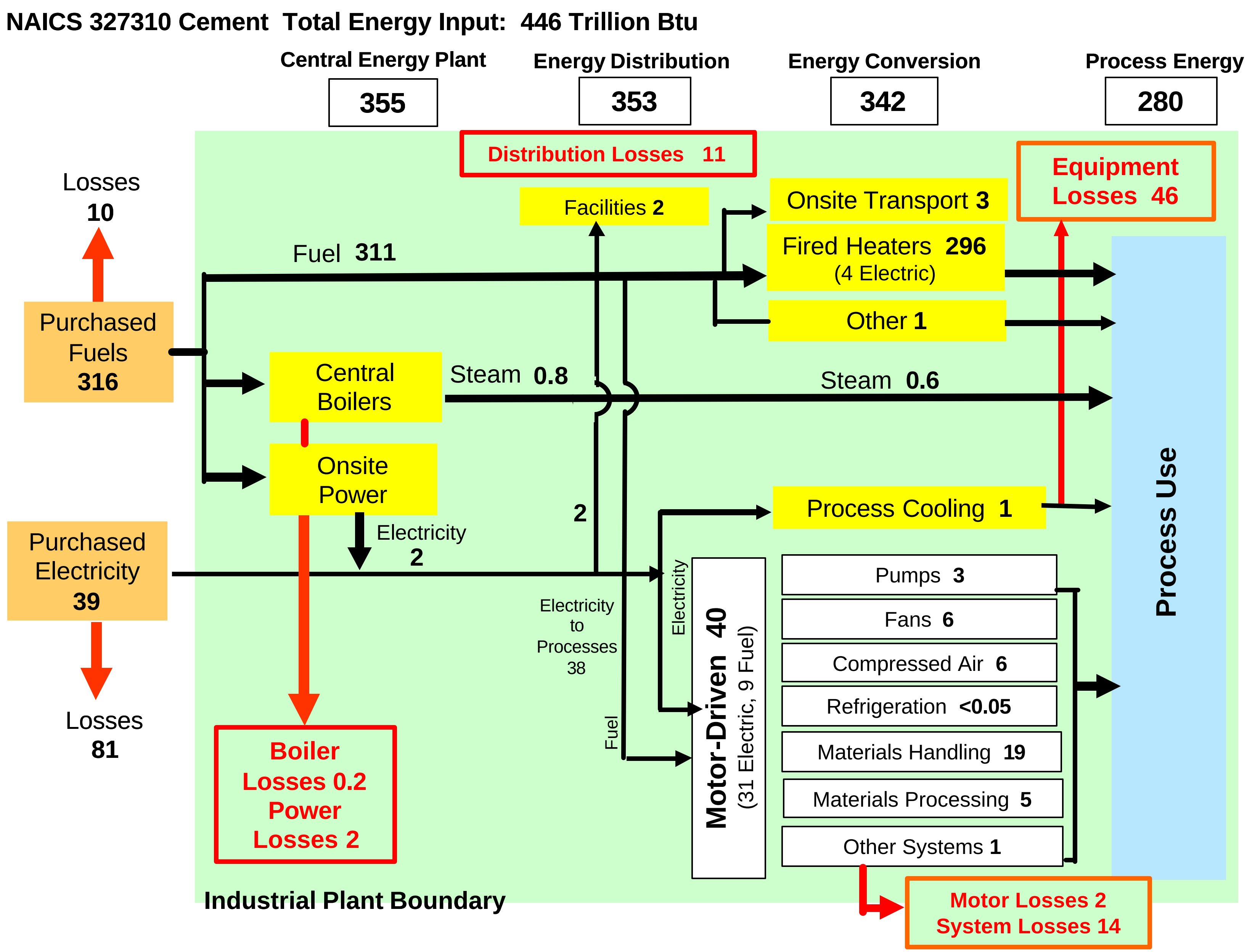


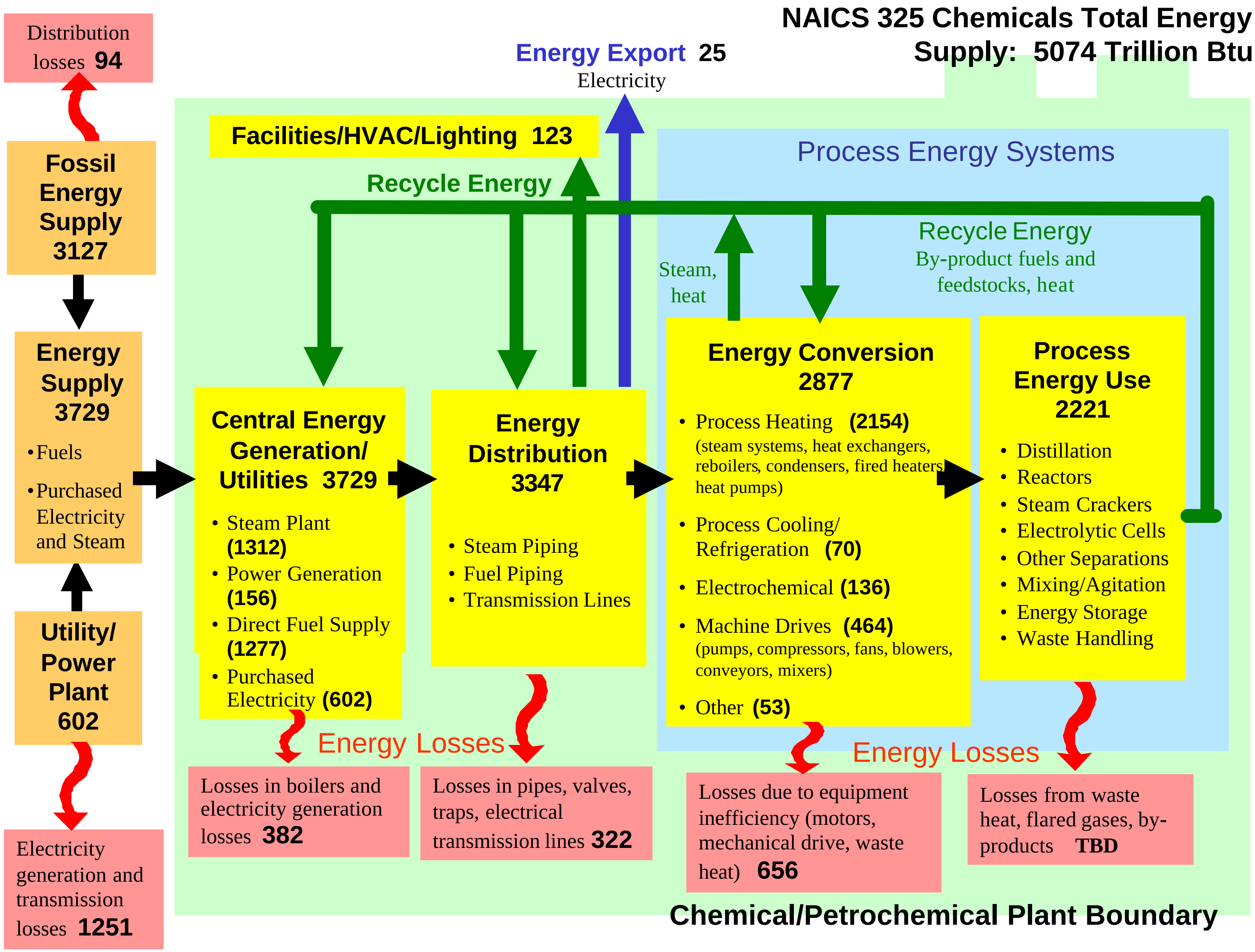
NAICS 3313 Aluminum and Alumina Total Energy Input: 958 Trillion Btu



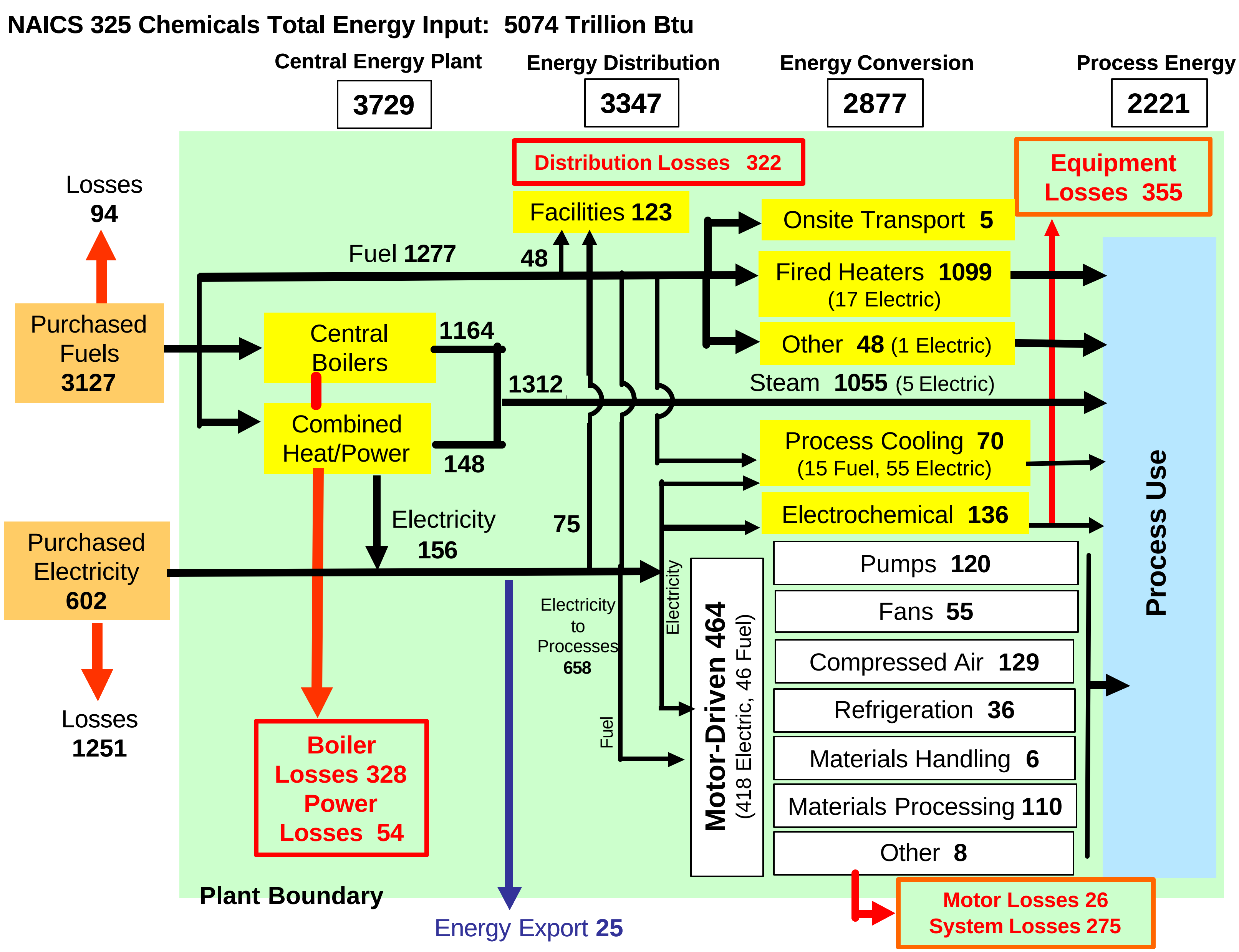


NAICS 327310 Cement Total Energy Input: 446 Trillion Btu
Distribution losses 10
Fossil Energy Supply 316
Energy Supply 355
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 39
Electricity generation and transmission losses 81
Facilities/HVAC/Lighting 2
Recycle Energy
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, heat
Central Energy Generation/ Utilities 355
• Steam Plant (1)
• Fossil Power (2)
• Direct Fuel Supply (308)
• Purchased Electricity (39)
Energy Distribution 353
• Steam Piping
• Fuel Piping
• Transmission Lines
Energy Conversion 342
• Process Heating (297)
(heat exchangers, condensers, fired heaters, heat pumps)
• Process Cooling/ Refrigeration (1)
• Machine Drives (40)
(pumps, compressors, fans, blowers, conveyors, mixers)
• Onsite Transport (3)
• Other (1)
Process Energy Use 280
• Pyroprocessing
• Drying
• Mixing
• Grinding
• Waste Handling
Energy Losses
Energy Losses
Losses in boilers and electricity generation losses 2
Losses in pipes, valves, traps, electrical transmission lines 11
Losses due to equipment inefficiency (motors, mechanical drive, waste heat) 62
Process energy losses from waste heat, flared gases, by-products TBD
Industrial Plant Boundary

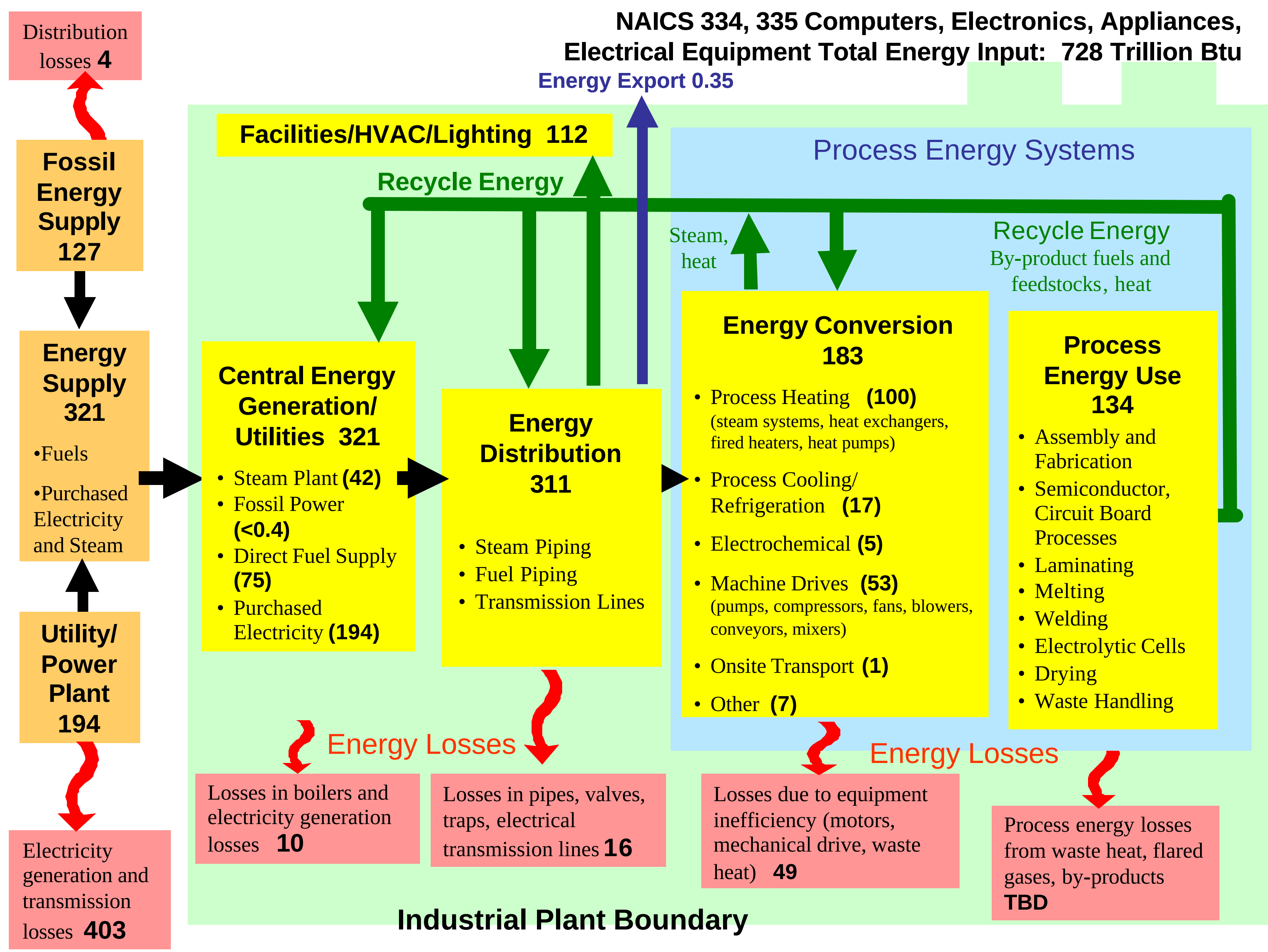

NAICS 327310 Cement Total Energy Input: 446 Trillion Btu
Central Energy Plant
355
Energy Distribution
353
Energy Conversion
342
Process Energy
280
Distribution Losses 11
Equipment Losses 46
Losses 10
Facilities 2
Onsite Transport 3
Fuel 311
Fired Heaters 296
(4 Electric)
Purchased Fuels 316
Other 1
Central Boilers
Steam 0.8
Steam 0.6
Onsite Power
2
Process Cooling 1
Electricity 2
Purchased Electricity 39
Electricity
Pumps 3
Fans 6
Compressed Air 6
Refrigeration <0.05
Materials Handling 19
Materials Processing 5
Other Systems 1
Electricity to Processes 38
Motor-Driven 40
(31 Electric, 9 Fuel)
Fuel
Process Use
Losses 81
Boiler Losses 0.2
Power Losses 2
Industrial Plant Boundary
Motor Losses 2
System Losses 14



NAICS 325 Chemicals Total Energy Supply: 5074 Trillion Btu
Distribution losses 94
Fossil Energy Supply 3127
Energy Supply 3729
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 602
Electricity generation and transmission losses 1251
Energy Export 25
Electricity
Facilities/HVAC/Lighting 123
Recycle Energy
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, heat
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
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

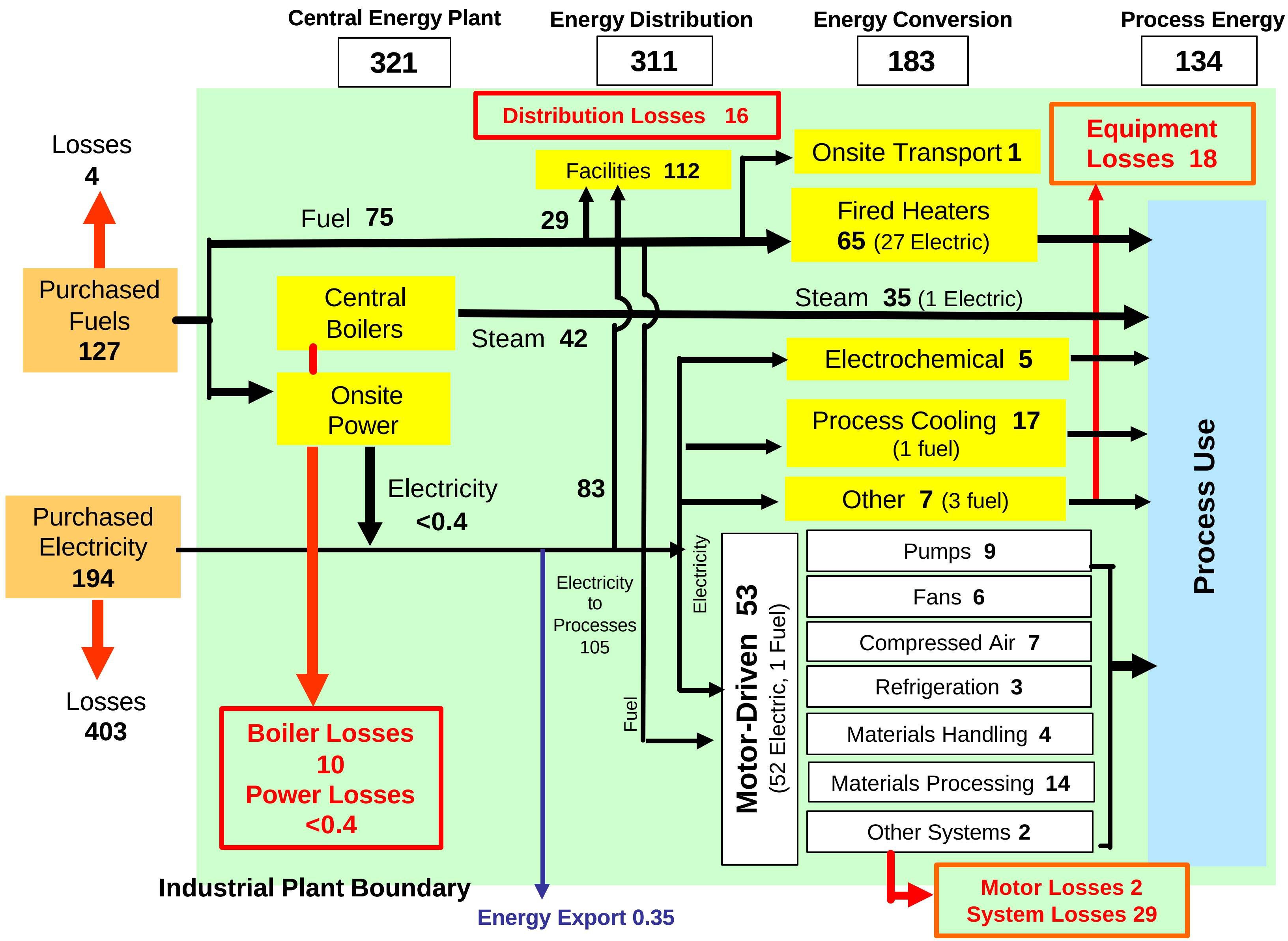


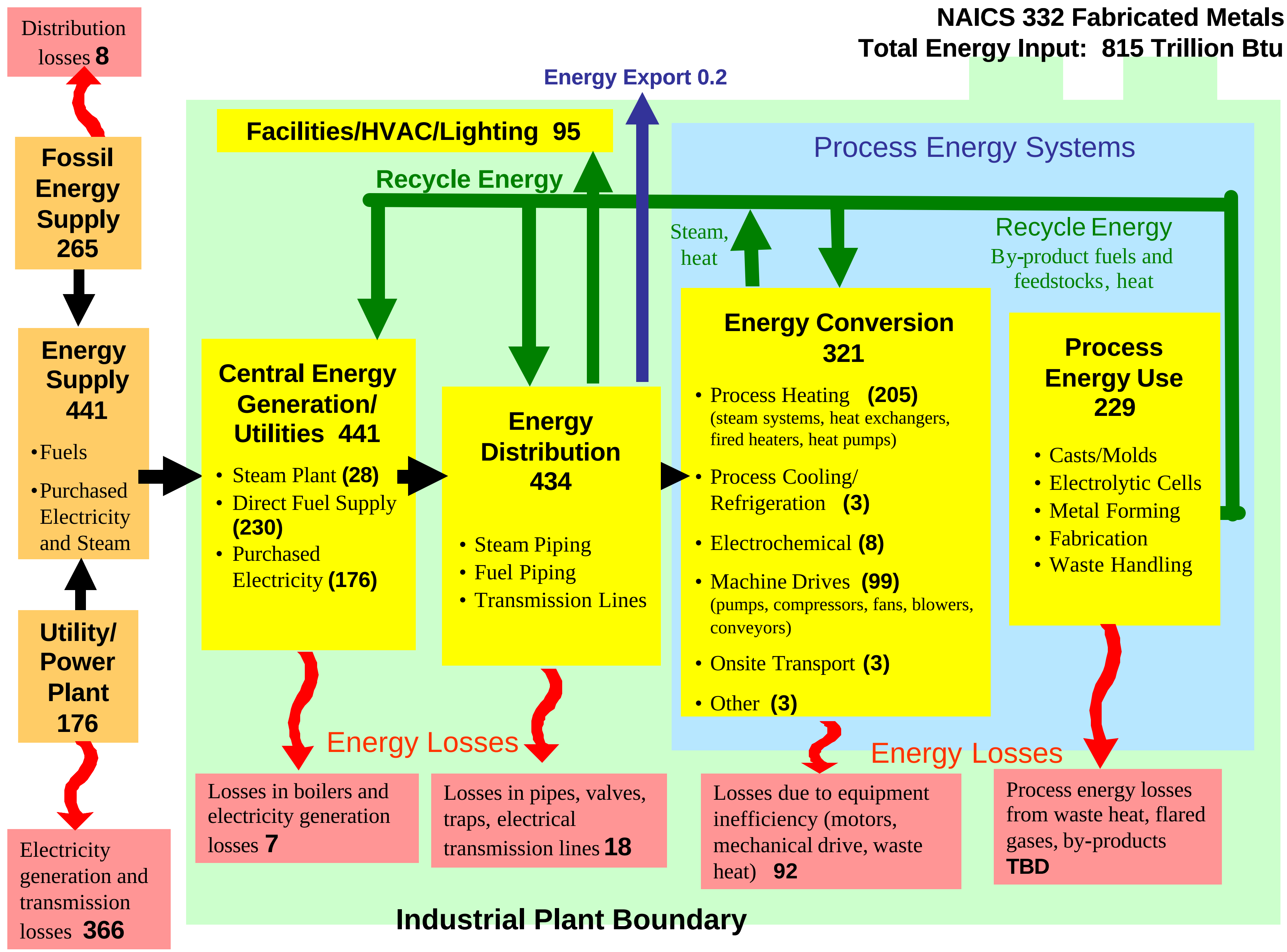
NAICS 325 Chemicals Total Energy Input: 5074 Trillion Btu
Central Energy Plant
3729
Energy Distribution
3347
Energy Conversion
2877
Process Energy
2221
Losses
94
Purchased Fuels
3127
Distribution Losses 322
Facilities 123
Equipment Losses 355
Onsite Transport 5
Fuel 1277
48
Fired Heaters 1099
(17 Electric)
Central Boilers
1164
Other 48 (1 Electric)
1312
Steam 1055 (5 Electric)
Combined Heat/Power
148
Process Cooling 70
(15 Fuel, 55 Electric)
Electricity
156
75
Electrochemical 136
Purchased Electricity
602
Pumps 120
Fans 55
Compressed Air 129
Refrigeration 36
Materials Handling 6
Materials Processing 110
Other 8
Electricity to Processes 658
Electricity
Fuel
Motor-Driven 464
(418 Electric, 46 Fuel)
Process Use
Losses
1251
Boiler Losses 328
Power Losses 54
Plant Boundary
Energy Export 25
Motor Losses 26
System Losses 275



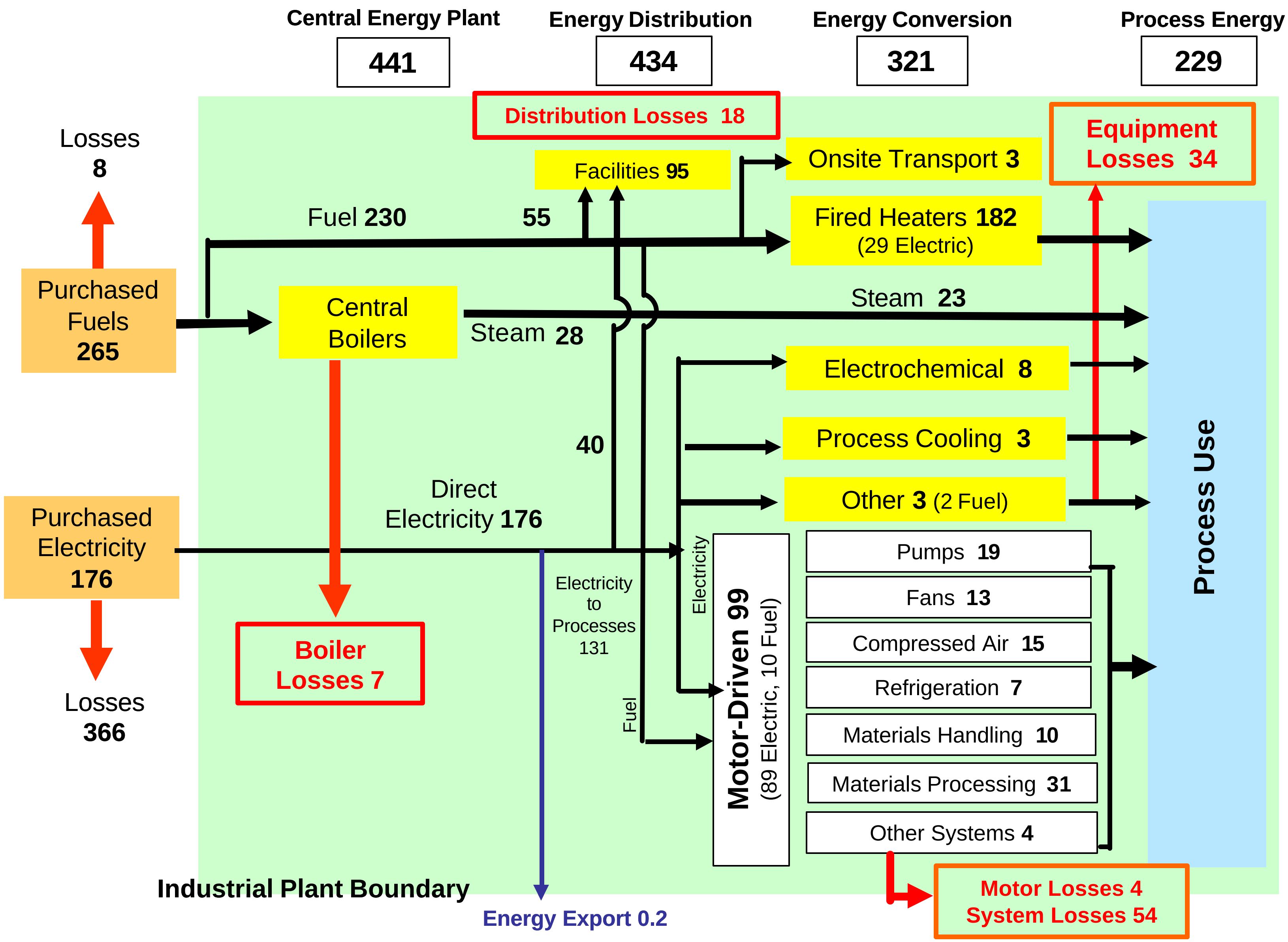
NAICS 334, 335 Computers, Electronics, Appliances,
Electrical Equipment Total Energy Input: 728 Trillion Btu
Energy Export 0.35
Distribution losses 4
Fossil Energy Supply 127
Energy Supply 321
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 194
Electricity generation and transmission losses 403
Facilities/HVAC/Lighting 112
Recycle Energy
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, heat
Central Energy Generation/ Utilities 321
• Steam Plant (42)
• Fossil Power (<0.4)
• Direct Fuel Supply (75)
• Purchased Electricity (194)
Energy Distribution 311
• Steam Piping
• Fuel Piping
• Transmission Lines
Energy Conversion 183
• Process Heating (100)
(steam systems, heat exchangers, fired heaters, heat pumps)
• Process Cooling/ Refrigeration (17)
• Electrochemical (5)
• Machine Drives (53)
(pumps, compressors, fans, blowers, conveyors, mixers)
• Onsite Transport (1)
• Other (7)
Process Energy Use 134
• Assembly and Fabrication
• Semiconductor, Circuit Board Processes
• Laminating
• Melting
• Welding
• Electrolytic Cells
• Drying
• Waste Handling
Energy Losses
Energy Losses
Losses in boilers and electricity generation losses 10
Losses in pipes, valves, traps, electrical transmission lines 16
Losses due to equipment inefficiency (motors, mechanical drive, waste heat) 49
Process energy losses from waste heat, flared gases, by-products TBD
Industrial Plant Boundary

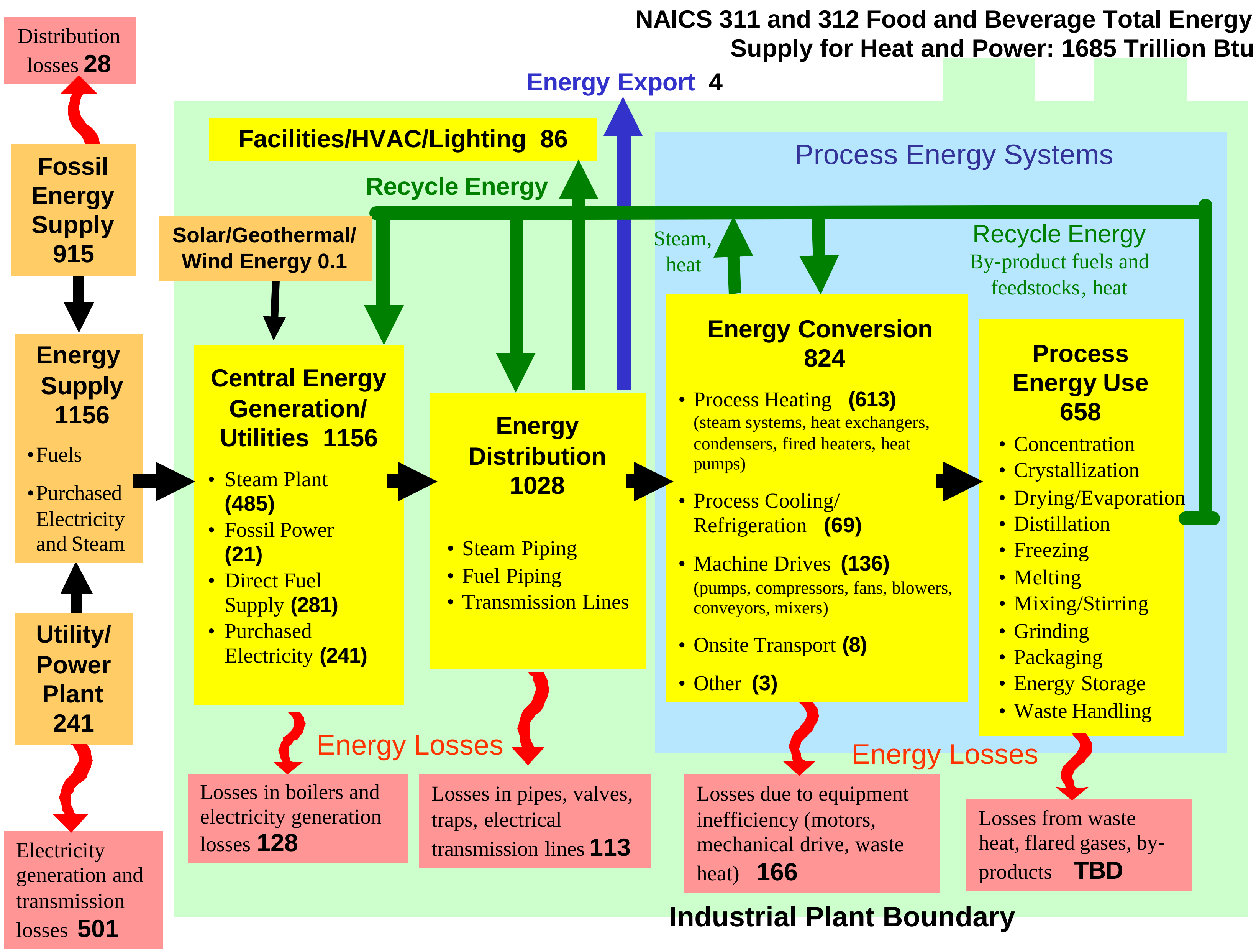
NAICS 334, 335 Computers, Electronics, Appliances, Electrical Equipment Total Energy Input: 728 Trillion Btu



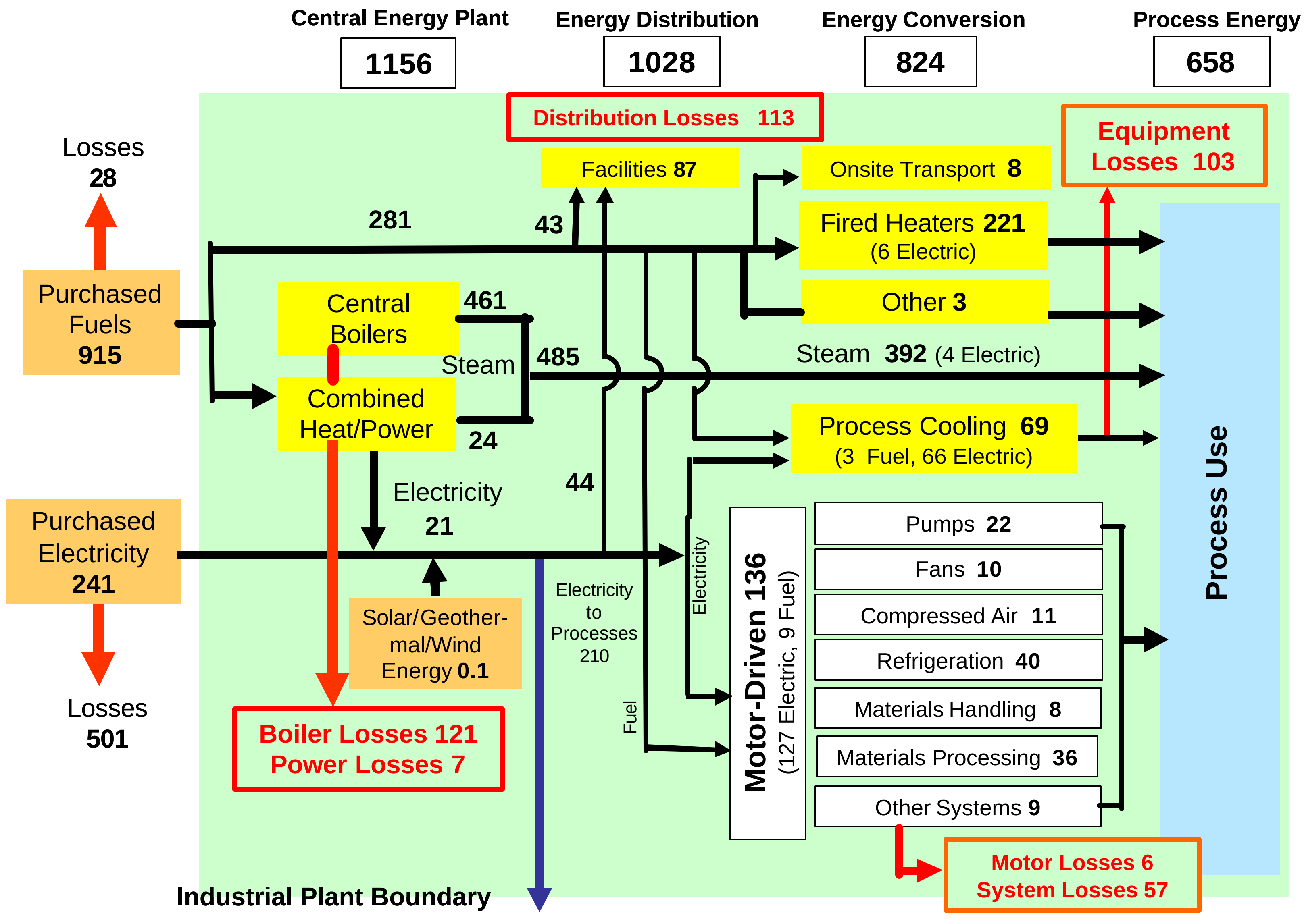

NAICS 332 Fabricated Metals
Total Energy Input: 815 Trillion Btu
Distribution losses 8
Fossil Energy Supply 265
Energy Supply 441
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 176
Electricity generation and transmission losses 366
Energy Export 0.2
Facilities/HVAC/Lighting 95
Recycle Energy
Process Energy Systems
Central Energy Generation/ Utilities 441
• Steam Plant (28)
• Direct Fuel Supply (230)
• Purchased Electricity (176)
Energy Distribution 434
• Steam Piping
• Fuel Piping
• Transmission Lines
Steam, heat
Energy Conversion 321
• Process Heating (205) (steam systems, heat exchangers, fired heaters, heat pumps)
• Process Cooling/ Refrigeration (3)
• Electrochemical (8)
• Machine Drives (99) (pumps, compressors, fans, blowers, conveyors)
• Onsite Transport (3)
• Other (3)
Recycle Energy
By-product fuels and feedstocks, heat
Process Energy Use 229
• Casts/Molds
• Electrolytic Cells
• Metal Forming
• Fabrication
• Waste Handling
Energy Losses
Losses in boilers and electricity generation losses 7
Losses in pipes, valves, traps, electrical transmission lines 18
Energy Losses
Losses due to equipment inefficiency (motors, mechanical drive, waste heat) 92
Process energy losses from waste heat, flared gases, by-products TBD
Industrial Plant Boundary

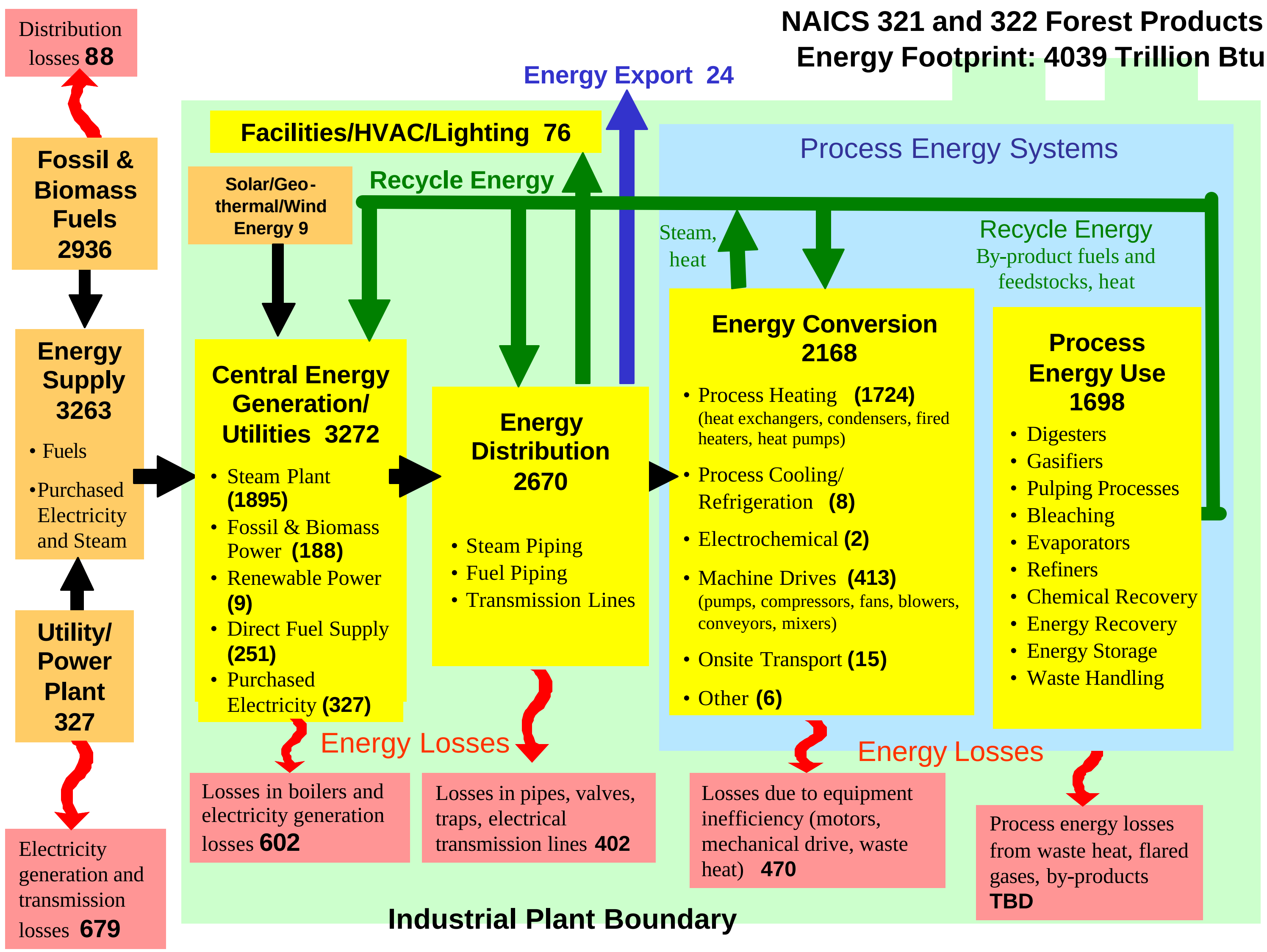
NAICS 332 Fabricated Metals Total Energy Input: 815 Trillion Btu




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
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
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, heat
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

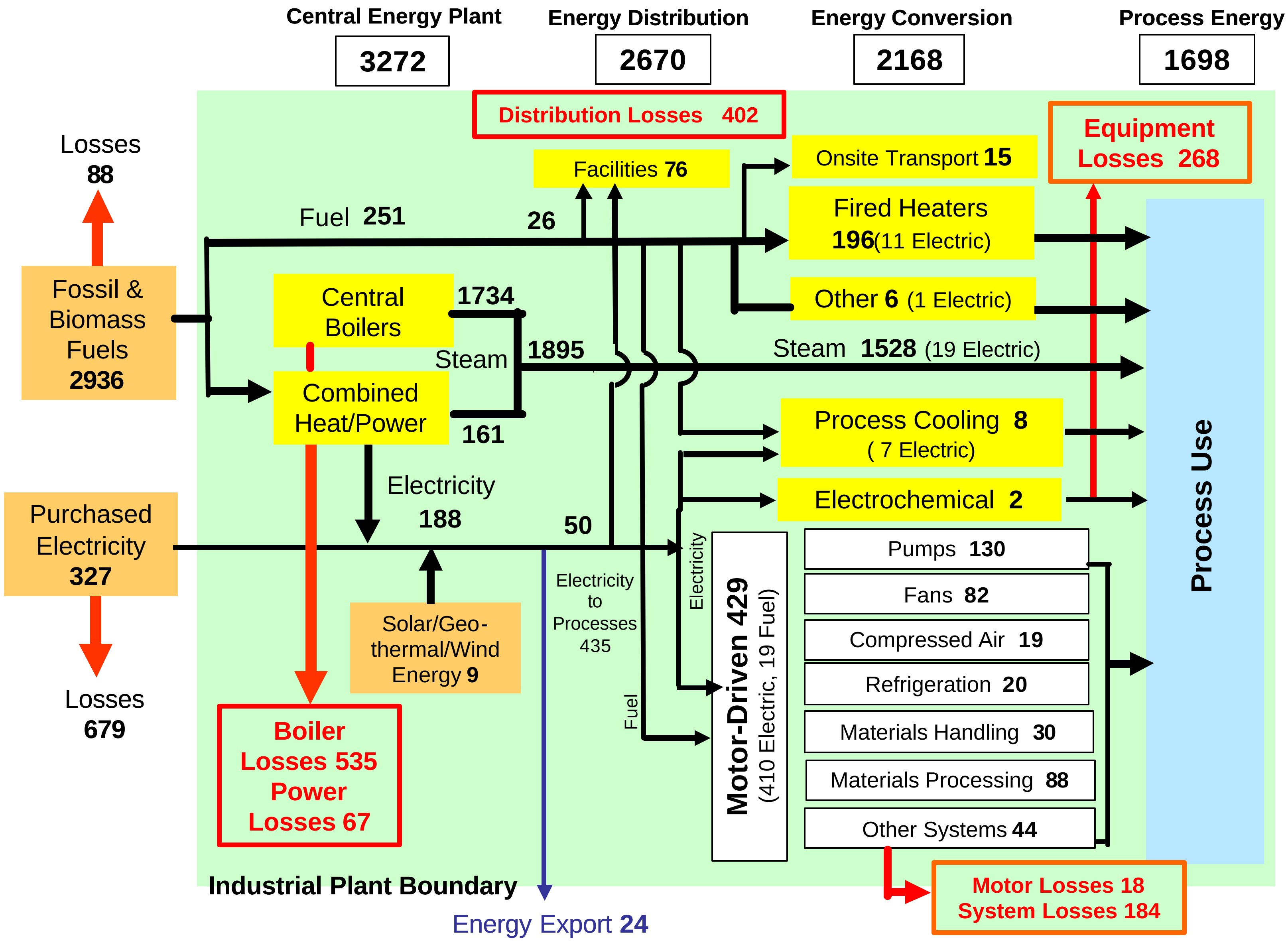
NAICS 311 and 312 Food and Beverage Total Energy Input: 1685 Trillion Btu



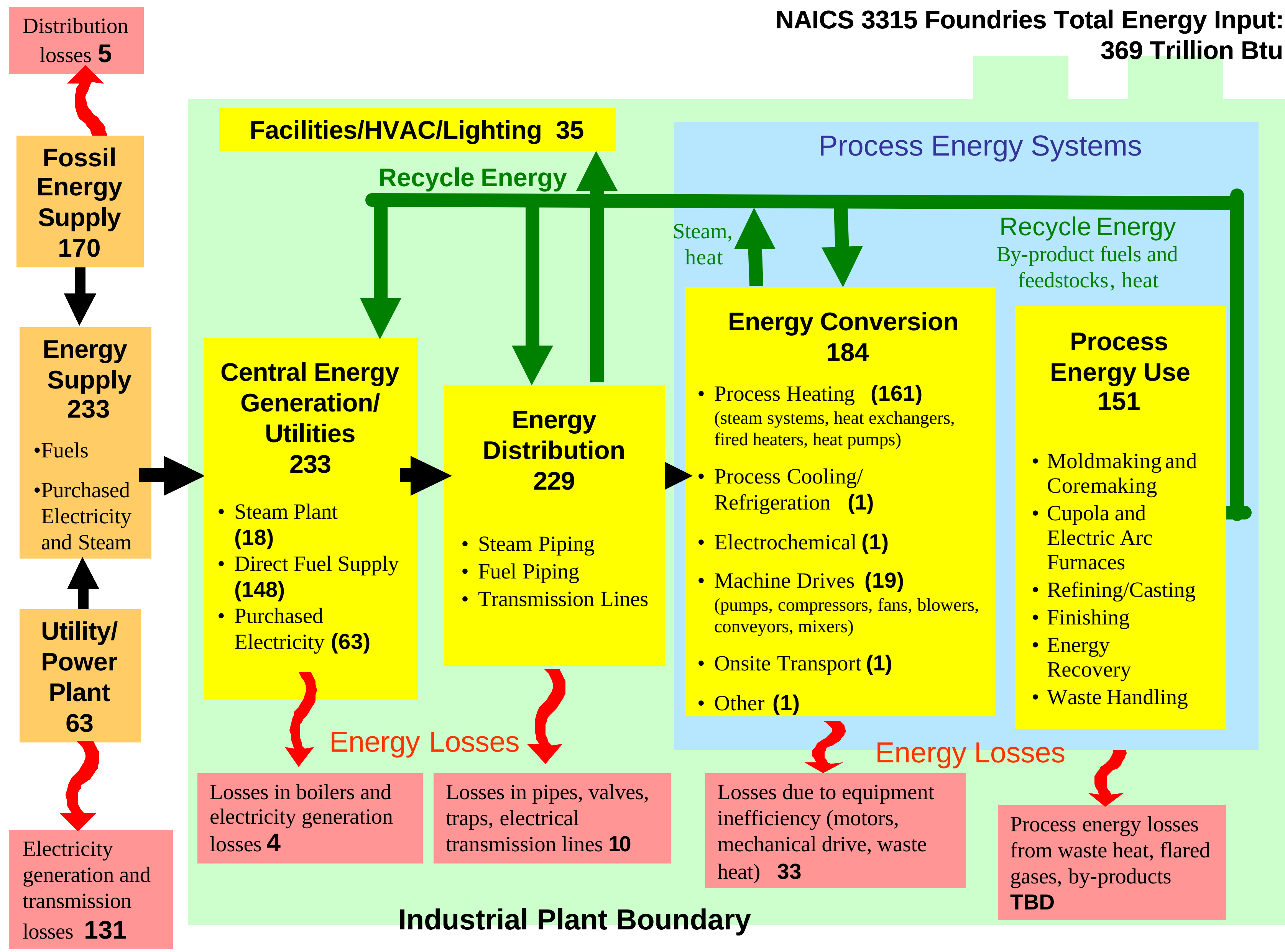


NAICS 321 and 322 Forest Products
Energy Footprint: 4039 Trillion Btu
Distribution losses 88
Fossil & Biomass Fuels 2936
Energy Supply 3263
• Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 327
Electricity generation and transmission losses 679
Energy Export 24
Facilities/HVAC/Lighting 76
Solar/Geo-thermal/Wind Energy 9
Recycle Energy
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
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, heat
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
Energy Losses
Losses in boilers and electricity generation losses 602
Losses in pipes, valves, traps, electrical transmission lines 402
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

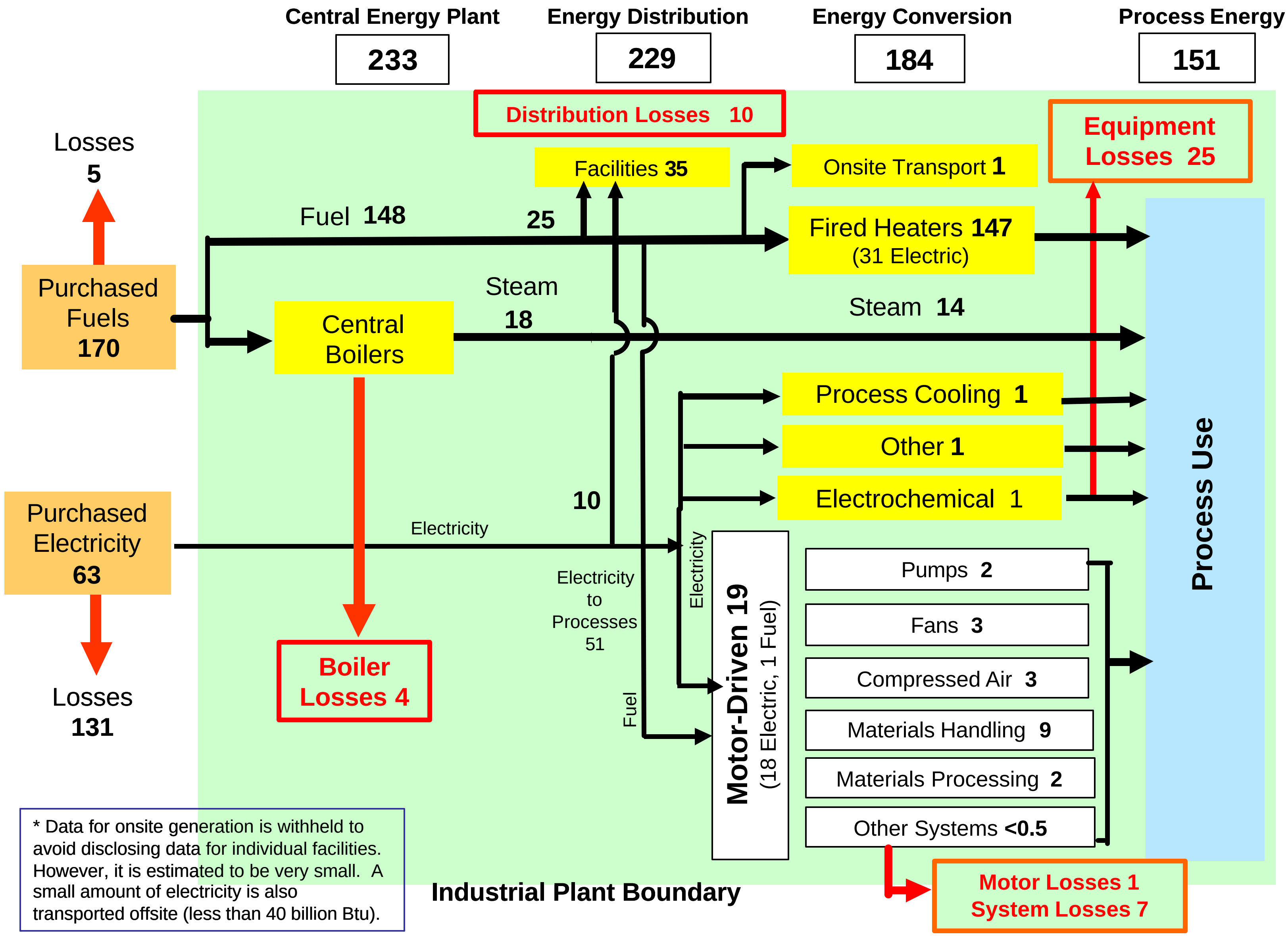
NAICS 321 and 322 Forest Products Total Energy Input: 4039 Trillion Btu



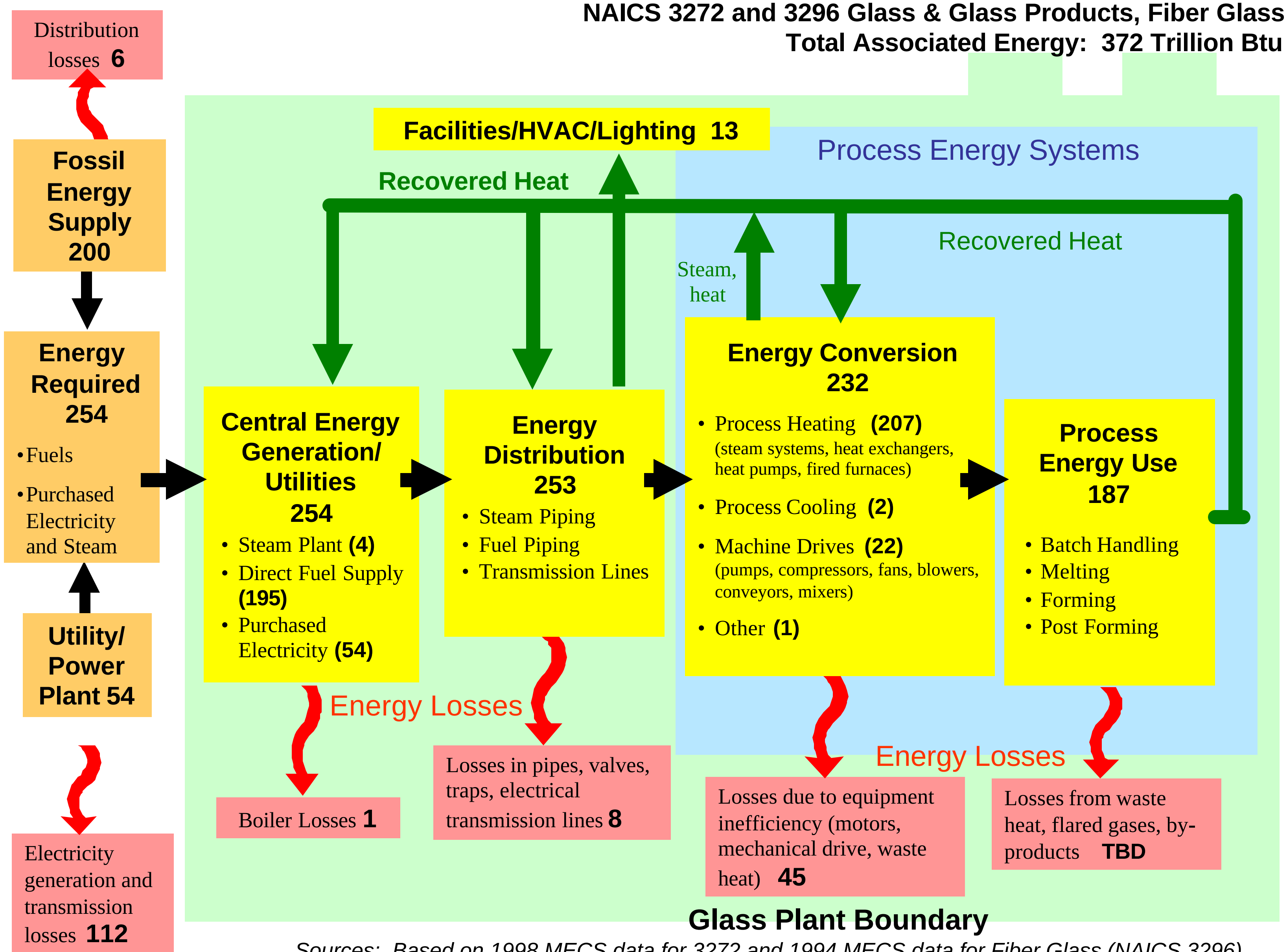
NAICS 3315 Foundries Total Energy Input: 369 Trillion Btu



NAICS 3315 Foundries Total Energy Input: 369 Trillion Btu

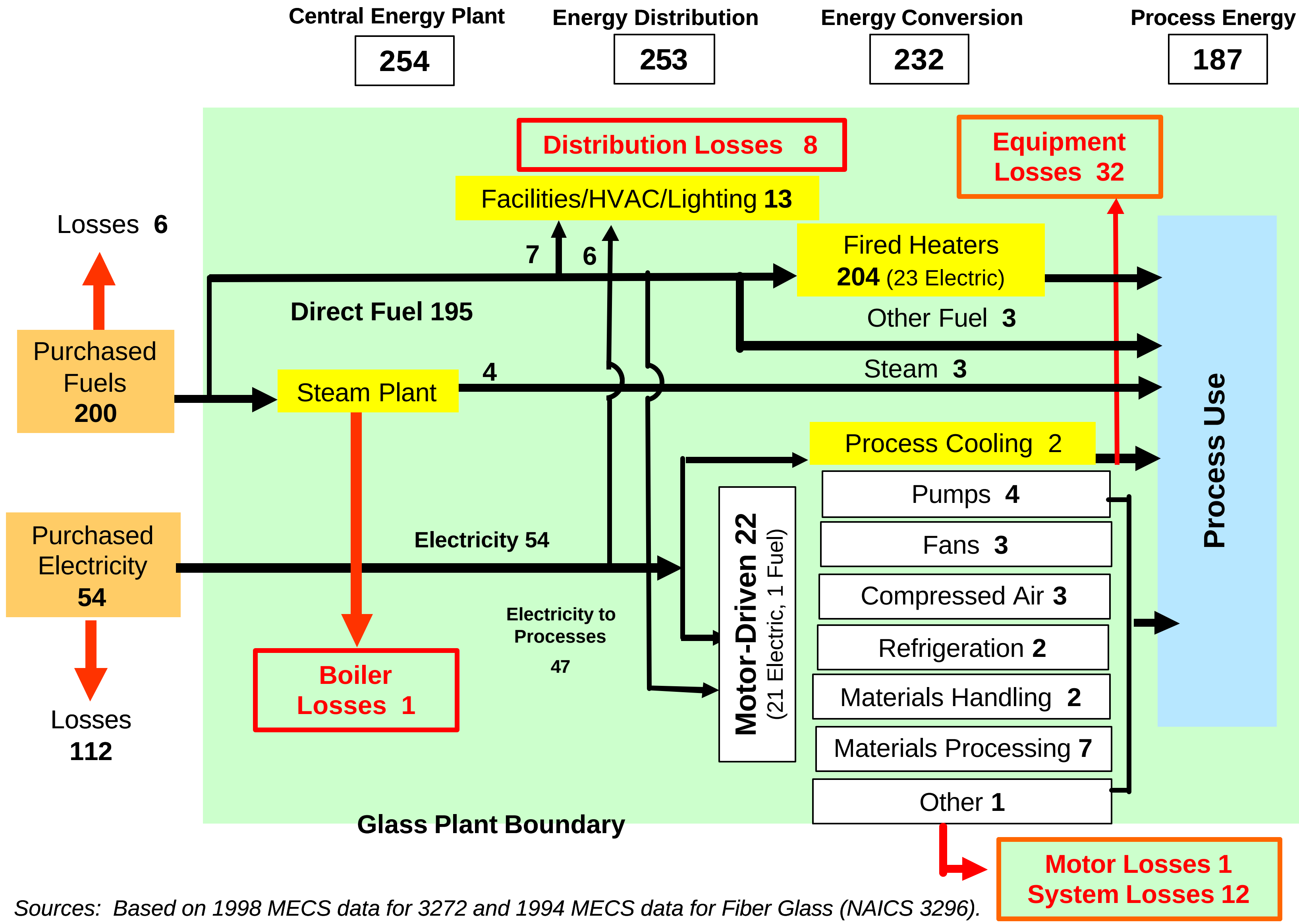


NAICS 3272 and 3296 Glass & Glass Products, Fiber Glass
Total Associated Energy: 372 Trillion Btu

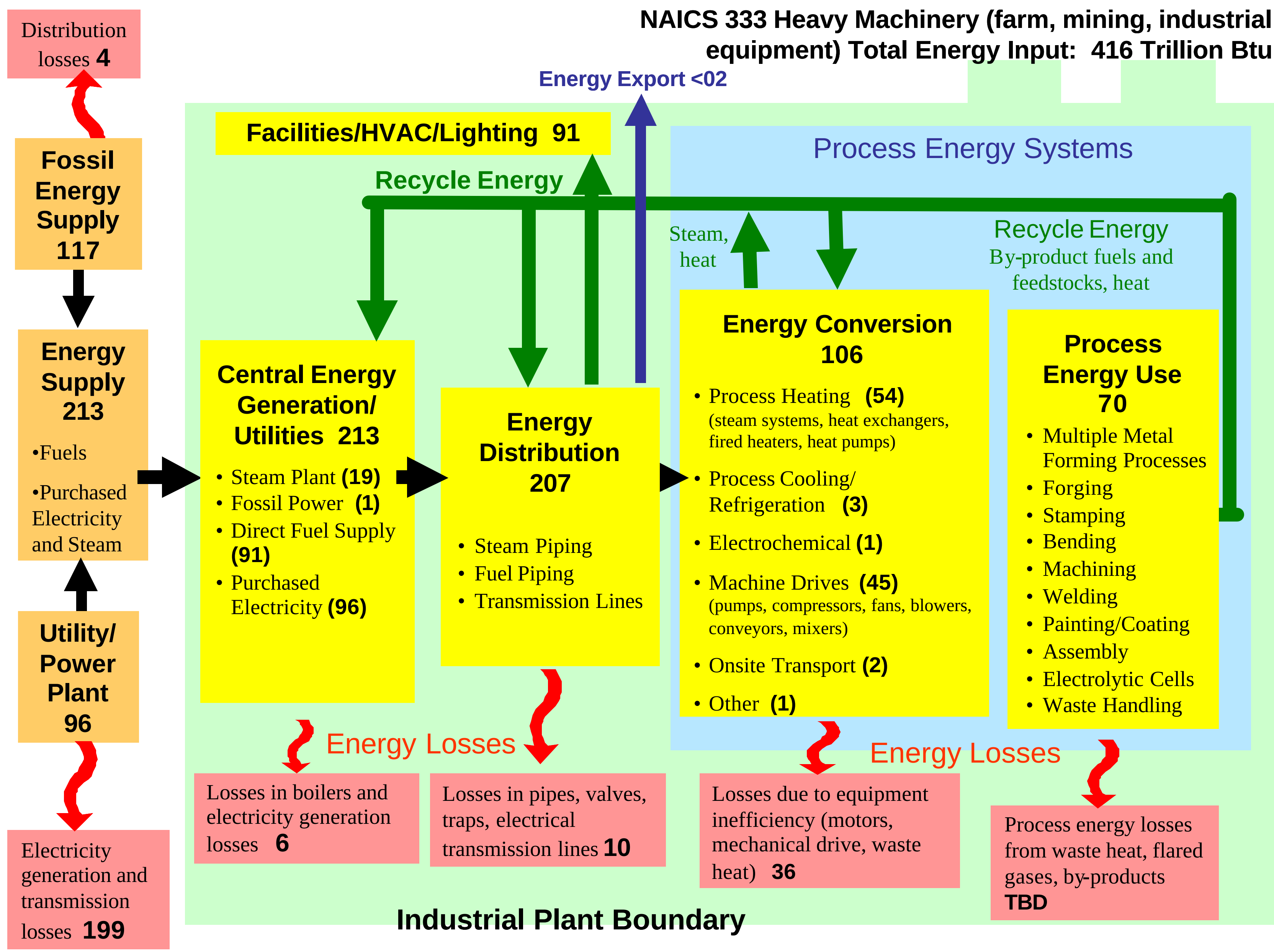


Sources: Based on 1998 MECS data for 3272 and 1994 MECS data for Fiber Glass (NAICS 3296).

NAICS 3272 and 3296 Glass & Glass Products, Fiber Glass Total Associated Energy: 372 Trillion Btu

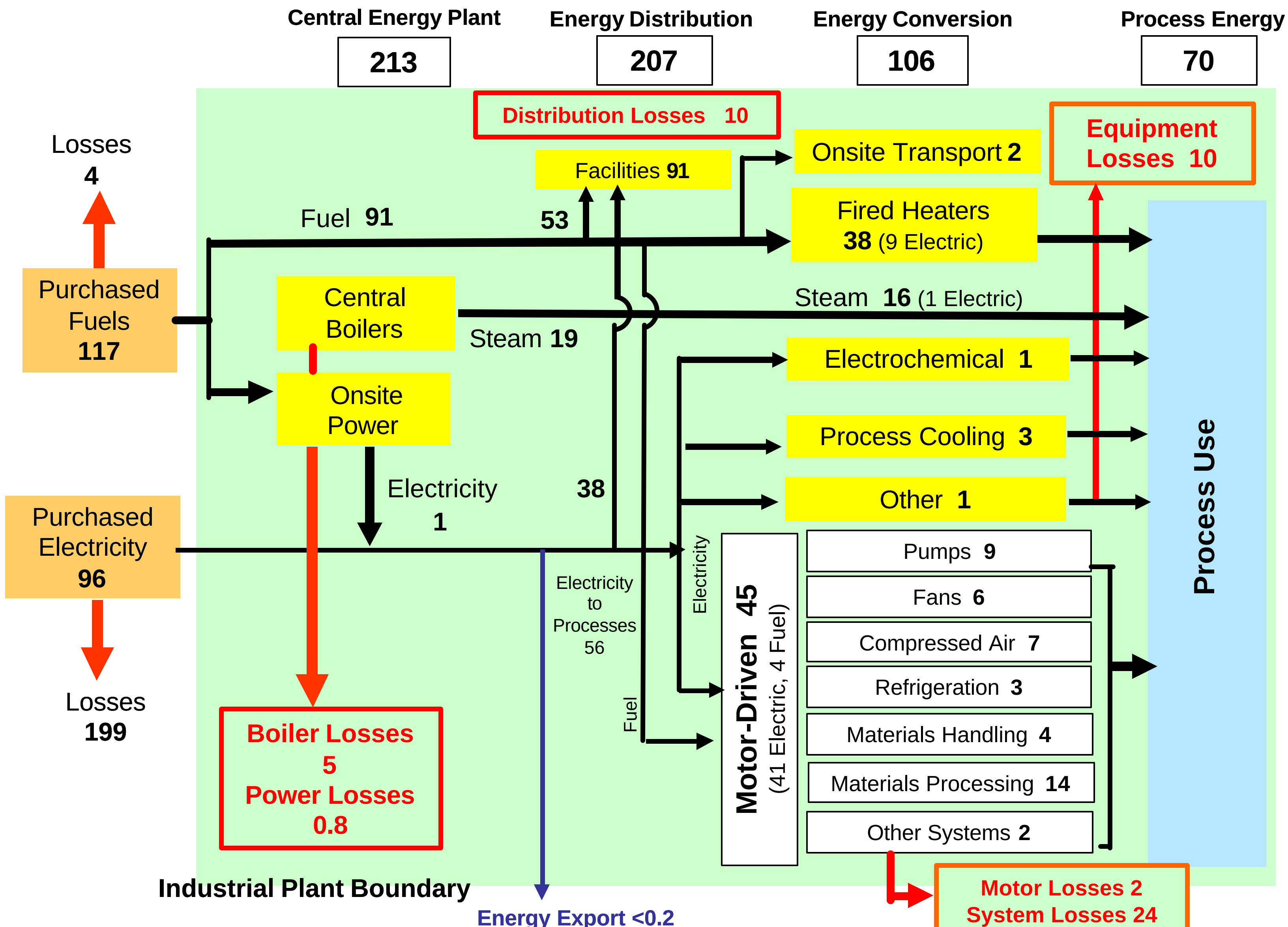


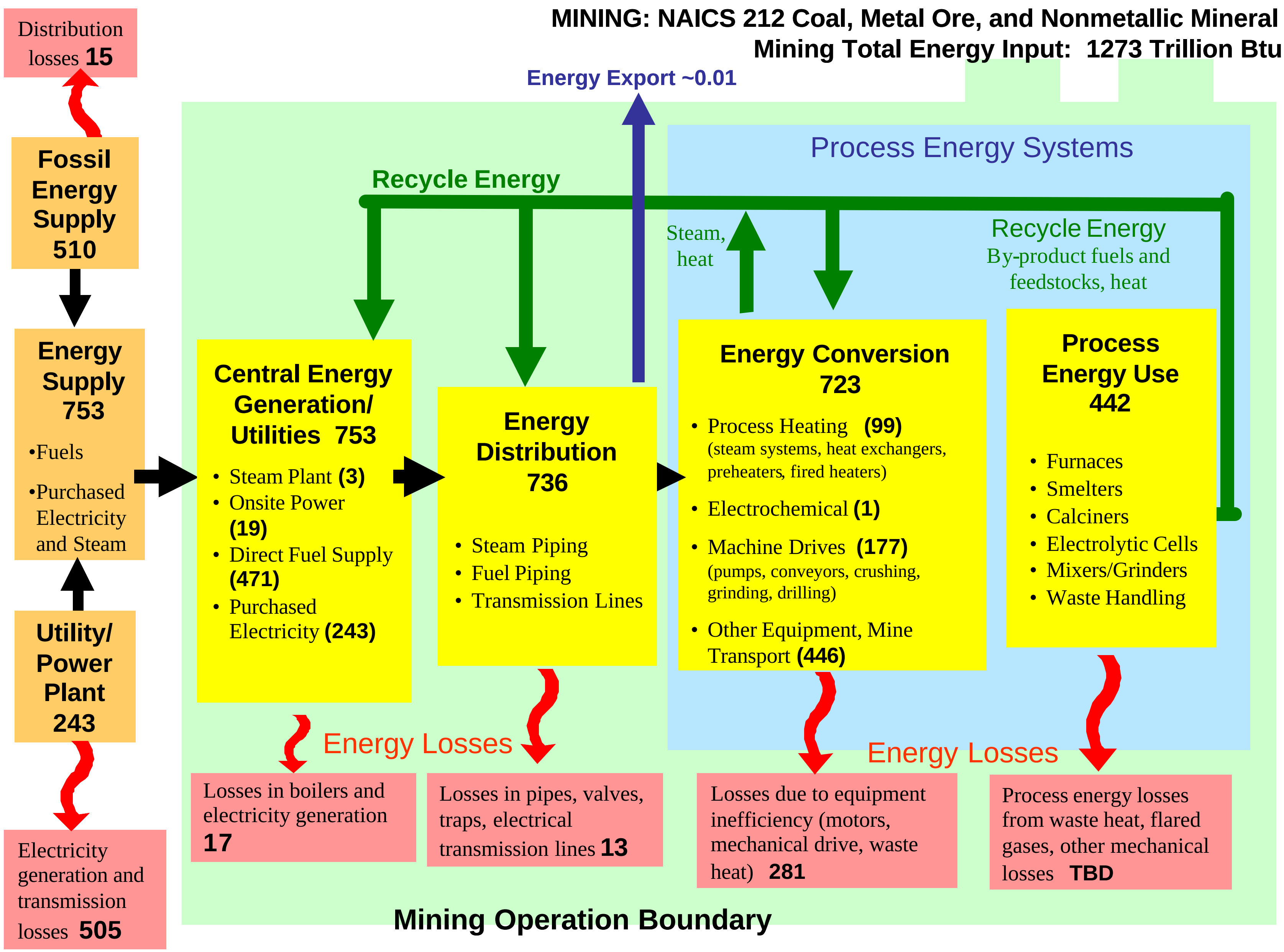
Sources: Based on 1998 MECS data for 3272 and 1994 MECS data for Fiber Glass (NAICS 3296).



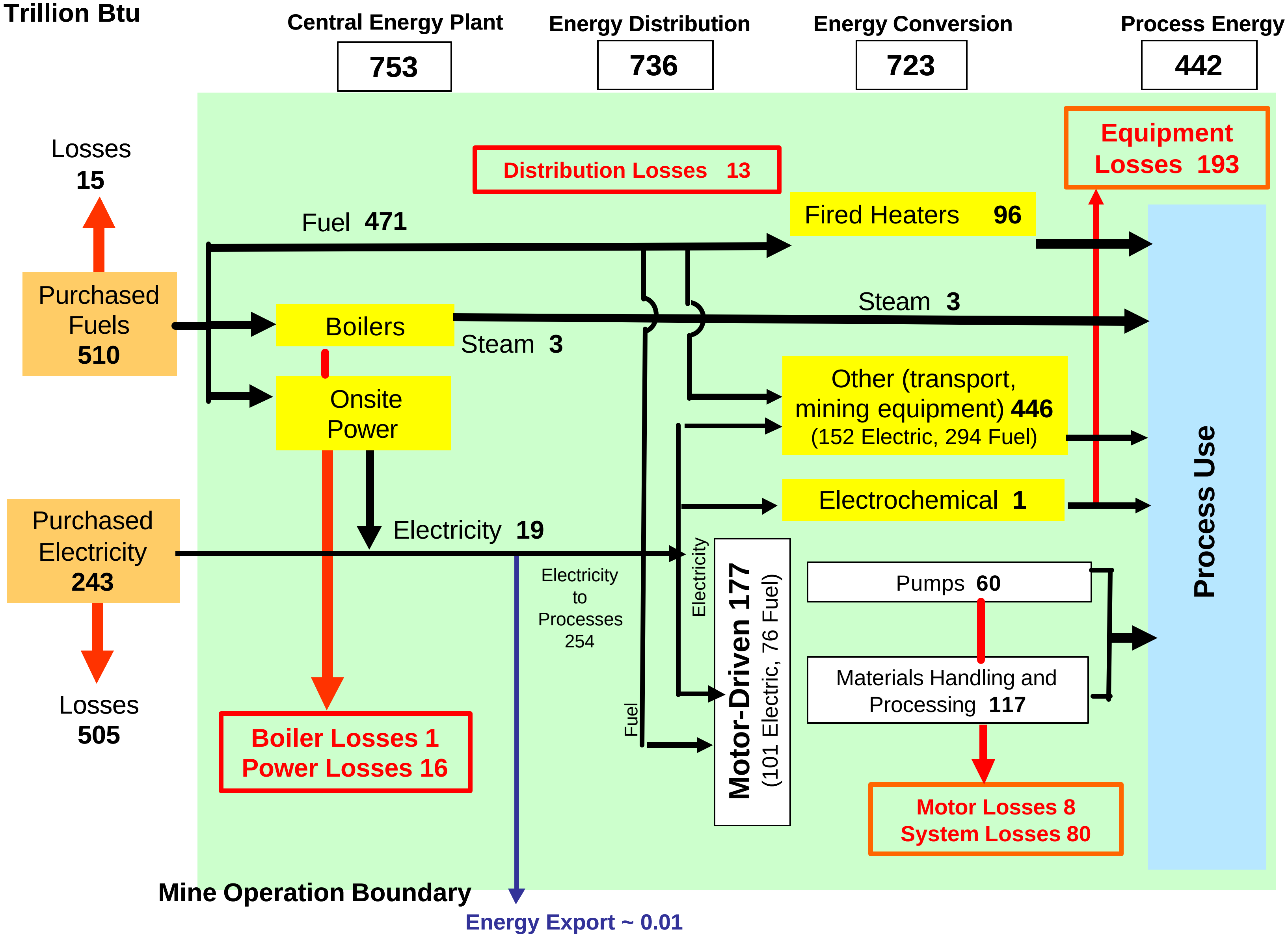
NAICS 333 Heavy Machinery (farm, mining, industrial equipment) Total Energy Input: 416 Trillion Btu
Distribution losses 4
Fossil Energy Supply 117
Energy Supply 213
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 96
Electricity generation and transmission losses 199
Energy Export <02
Facilities/HVAC/Lighting 91
Recycle Energy
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, heat
Central Energy Generation/ Utilities 213
• Steam Plant (19)
• Fossil Power (1)
• Direct Fuel Supply (91)
• Purchased Electricity (96)
Energy Distribution 207
• Steam Piping
• Fuel Piping
• Transmission Lines
Energy Conversion 106
• Process Heating (54)
(steam systems, heat exchangers, fired heaters, heat pumps)
• Process Cooling/ Refrigeration (3)
• Electrochemical (1)
• Machine Drives (45)
(pumps, compressors, fans, blowers, conveyors, mixers)
• Onsite Transport (2)
• Other (1)
Process Energy Use 70
• Multiple Metal Forming Processes
• Forging
• Stamping
• Bending
• Machining
• Welding
• Painting/Coating
• Assembly
• Electrolytic Cells
• Waste Handling
Energy Losses
Energy Losses
Losses in boilers and electricity generation losses 6
Losses in pipes, valves, traps, electrical transmission lines 10
Losses due to equipment inefficiency (motors, mechanical drive, waste heat) 36
Process energy losses from waste heat, flared gases, by-products TBD
Industrial Plant Boundary

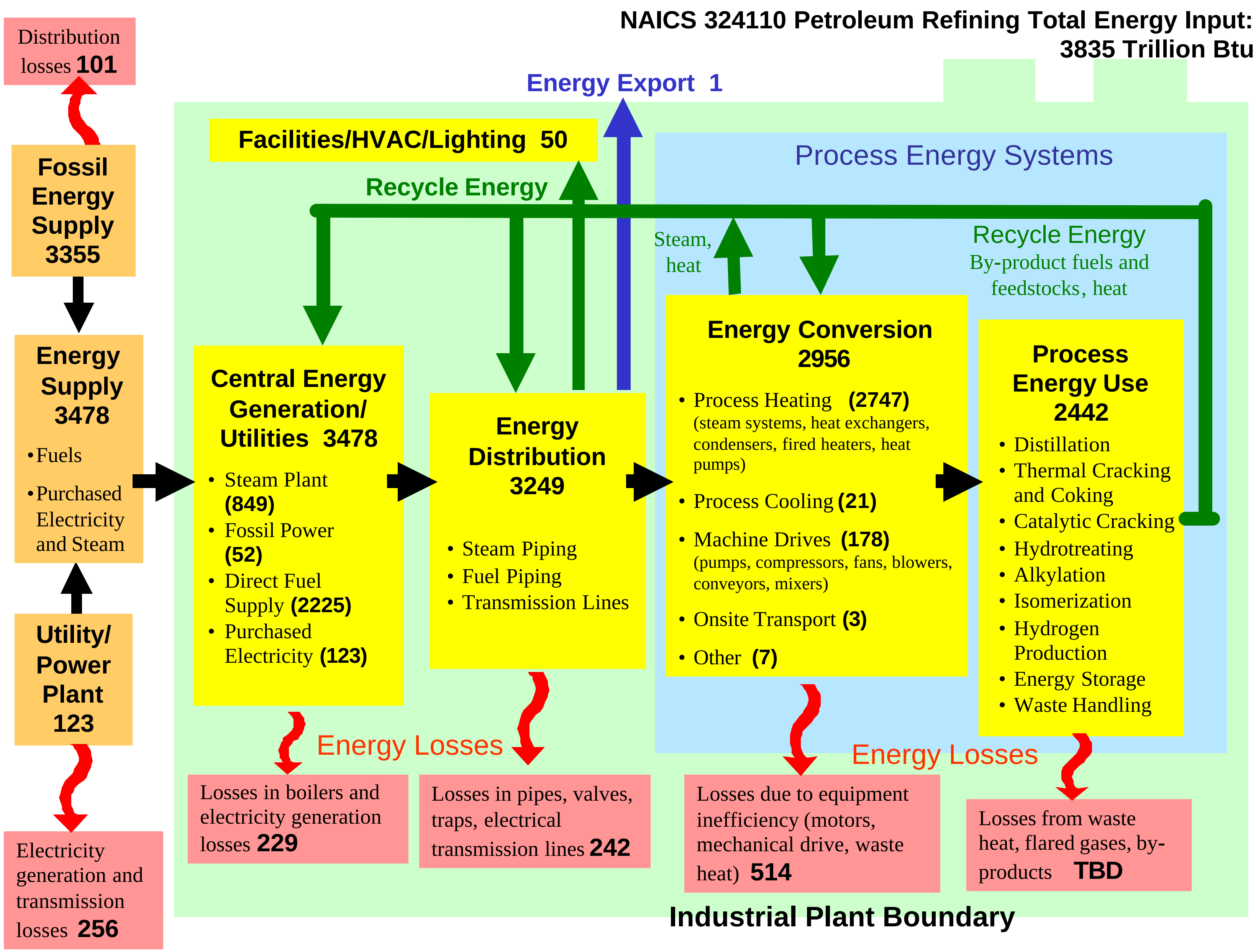
NAICS 333 Heavy Machinery (farm, mining, industrial equipment) Total Energy Input: 416 Trillion Btu

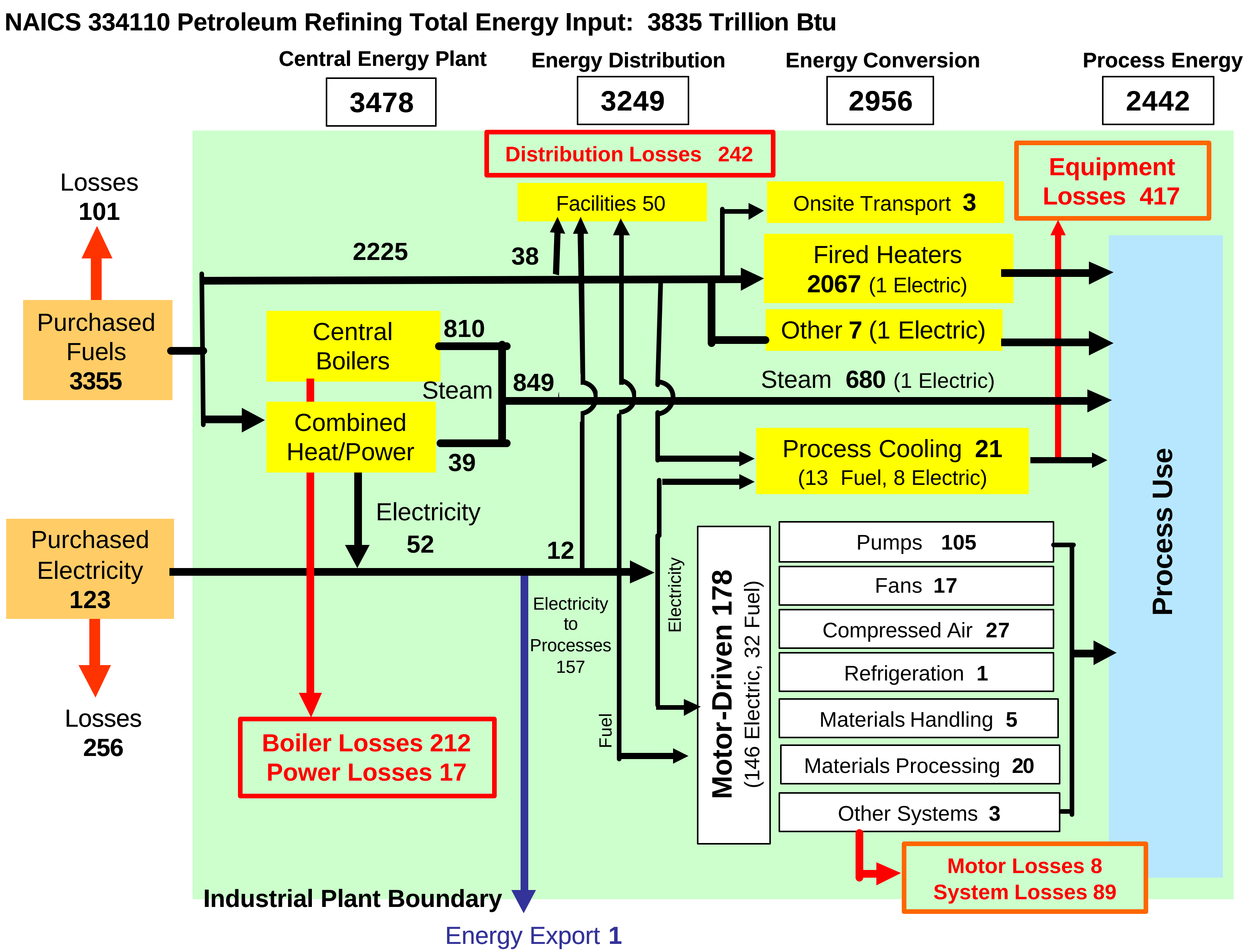



MINING: NAICS 212 Coal, Metal Ore, and Nonmetallic Mineral
Mining Total Energy Input: 1273 Trillion Btu
Distribution losses 15
Fossil Energy Supply 510
Energy Supply 753
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 243
Electricity generation and transmission losses 505
Energy Export ~0.01
Recycle Energy
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, 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
Energy Losses
Losses in boilers and electricity generation 17
Losses in pipes, valves, traps, electrical transmission lines 13
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

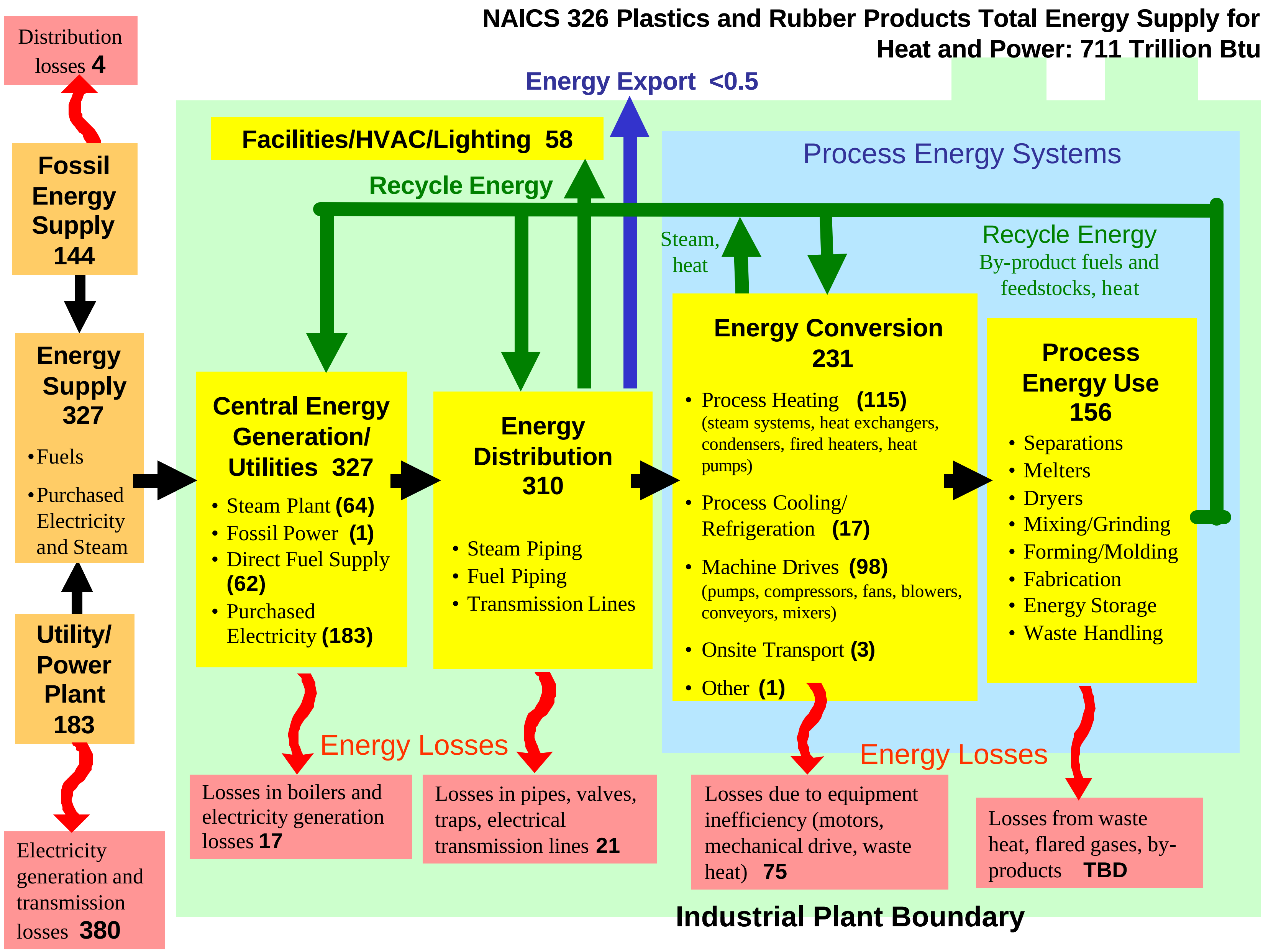
MINING: NAICS 212 Coal, Metal Ore, and Nonmetallic Mineral Mining Total Energy Input: 1273 Trillion Btu

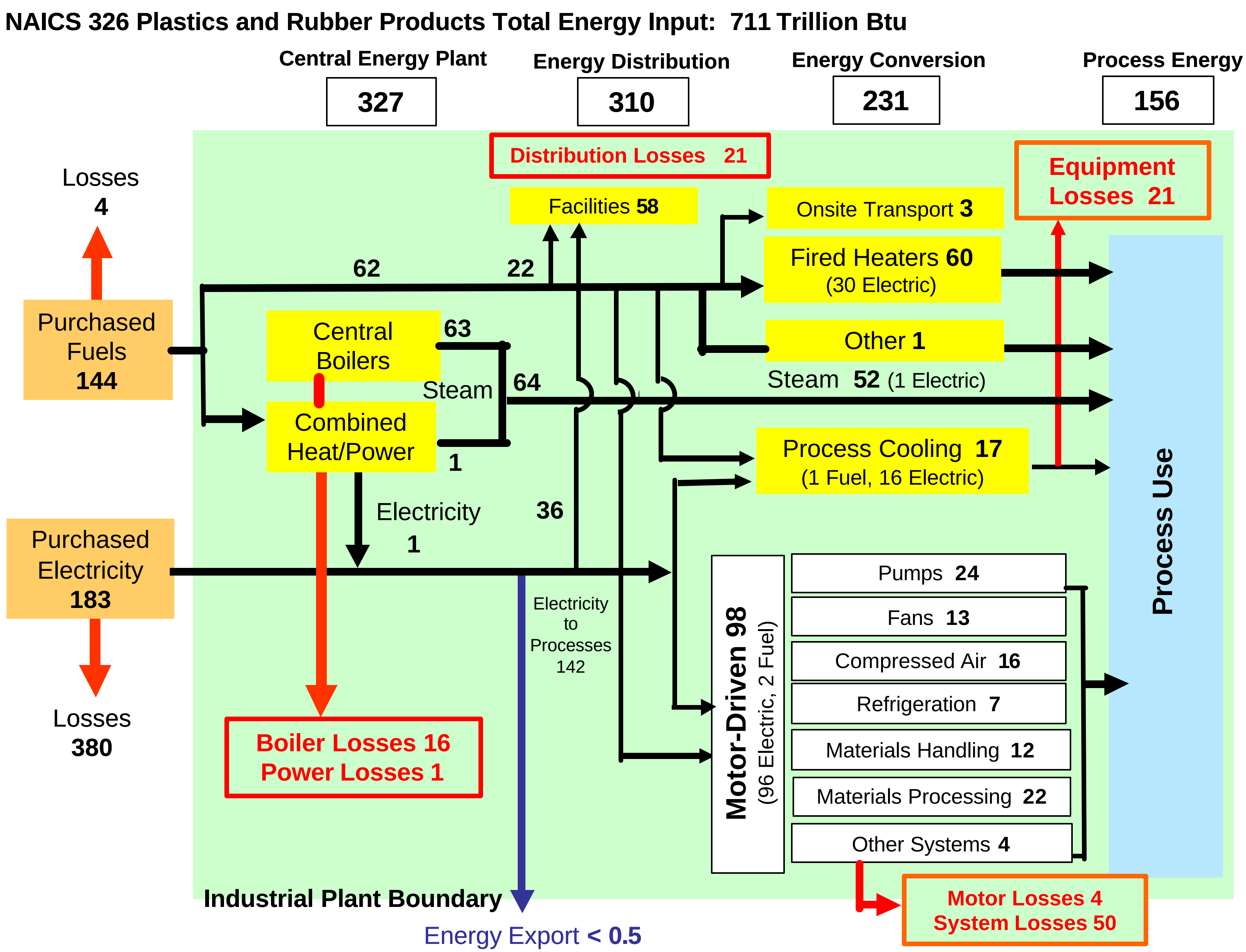


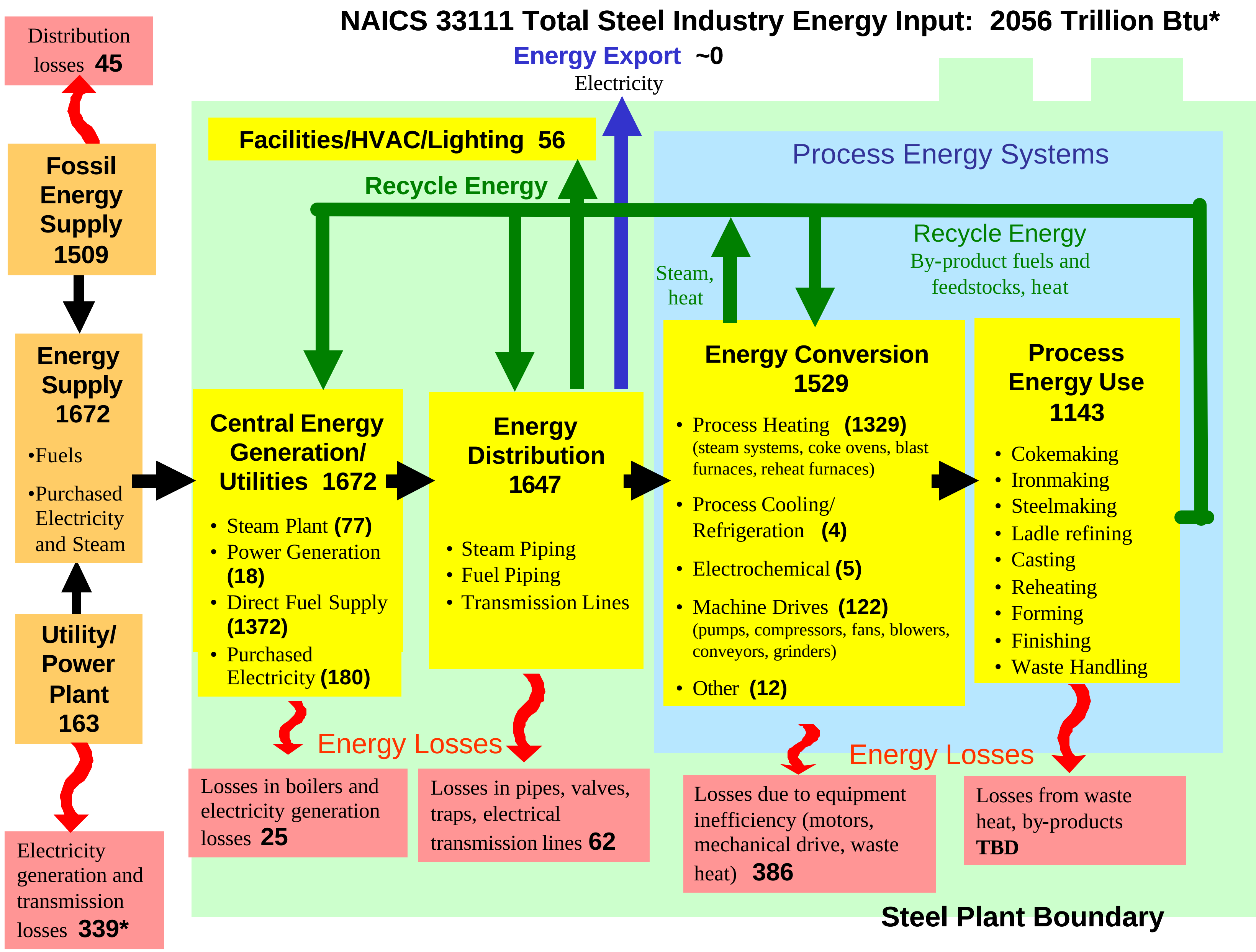

NAICS 324110 Petroleum Refining Total Energy Input:
3835 Trillion Btu
Distribution losses 101
Fossil Energy Supply 3355
Energy Supply 3478
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 123
Electricity generation and transmission losses 256
Energy Export 1
Facilities/HVAC/Lighting 50
Recycle Energy
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, heat
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
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
Energy Losses
Losses in boilers and electricity generation losses 229
Losses in pipes, valves, traps, electrical transmission lines 242
Losses due to equipment inefficiency (motors, mechanical drive, waste heat) 514
Losses from waste heat, flared gases, by-products TBD
Industrial Plant Boundary

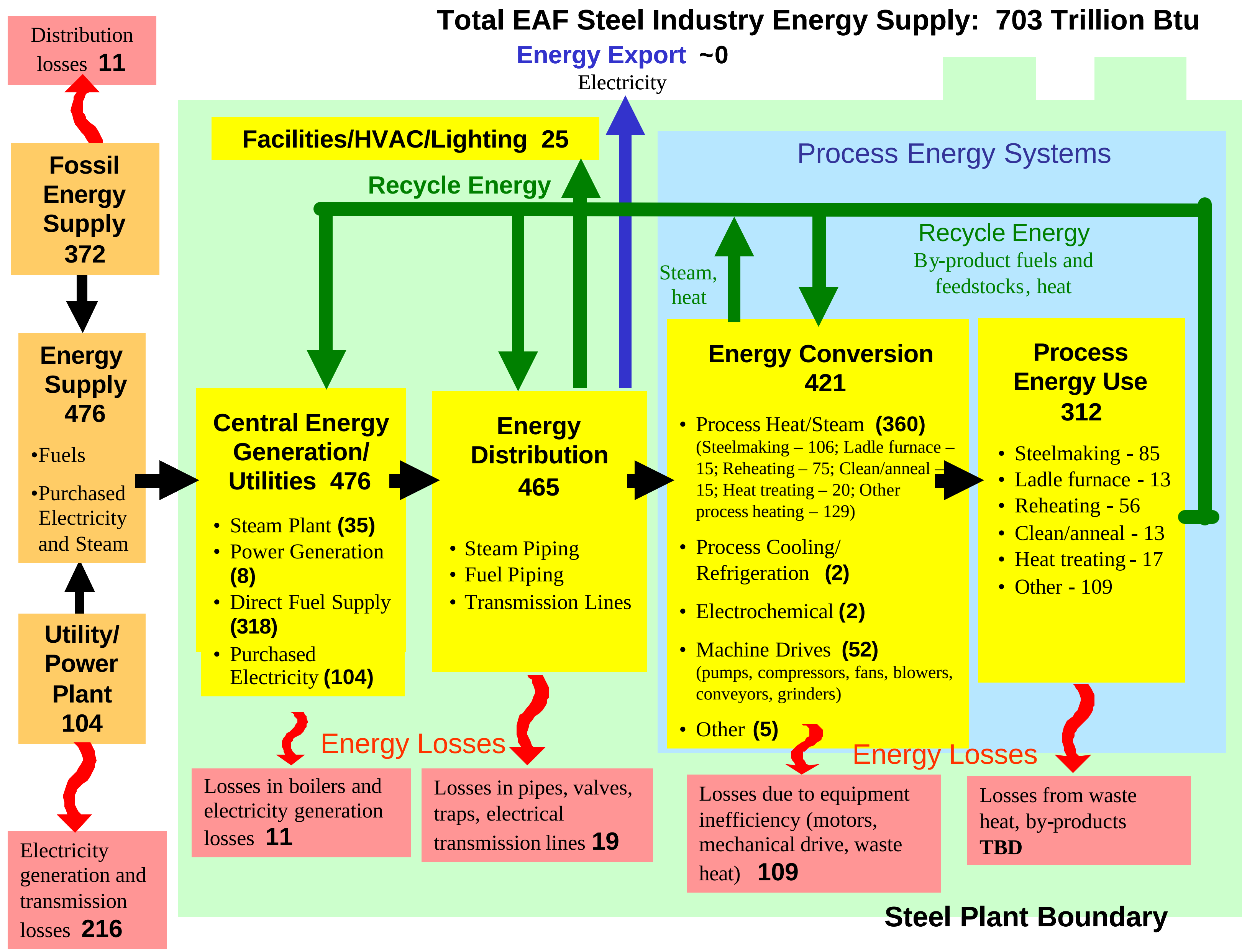


NAICS 334110 Petroleum Refining Total Energy Input: 3835 Trillion Btu
Central Energy Plant
3478
Energy Distribution
3249
Energy Conversion
2956
Process Energy
2442
Distribution Losses 242
Equipment Losses 417
Losses 101
Facilities 50
Onsite Transport 3
2225
38
Fired Heaters 2067 (1 Electric)
Purchased Fuels 3355
Central Boilers
810
Other 7 (1 Electric)
Steam
849
Steam 680 (1 Electric)
Combined Heat/Power
39
Process Cooling 21 (13 Fuel, 8 Electric)
Electricity 52
12
Purchased Electricity 123
Pumps 105
Fans 17
Compressed Air 27
Refrigeration 1
Materials Handling 5
Materials Processing 20
Other Systems 3
Electricity to Processes 157
Electricity
Fuel
Motor-Driven 178 (146 Electric, 32 Fuel)
Process Use
Losses 256
Boiler Losses 212
Power Losses 17
Motor Losses 8
System Losses 89
Industrial Plant Boundary
Energy Export 1

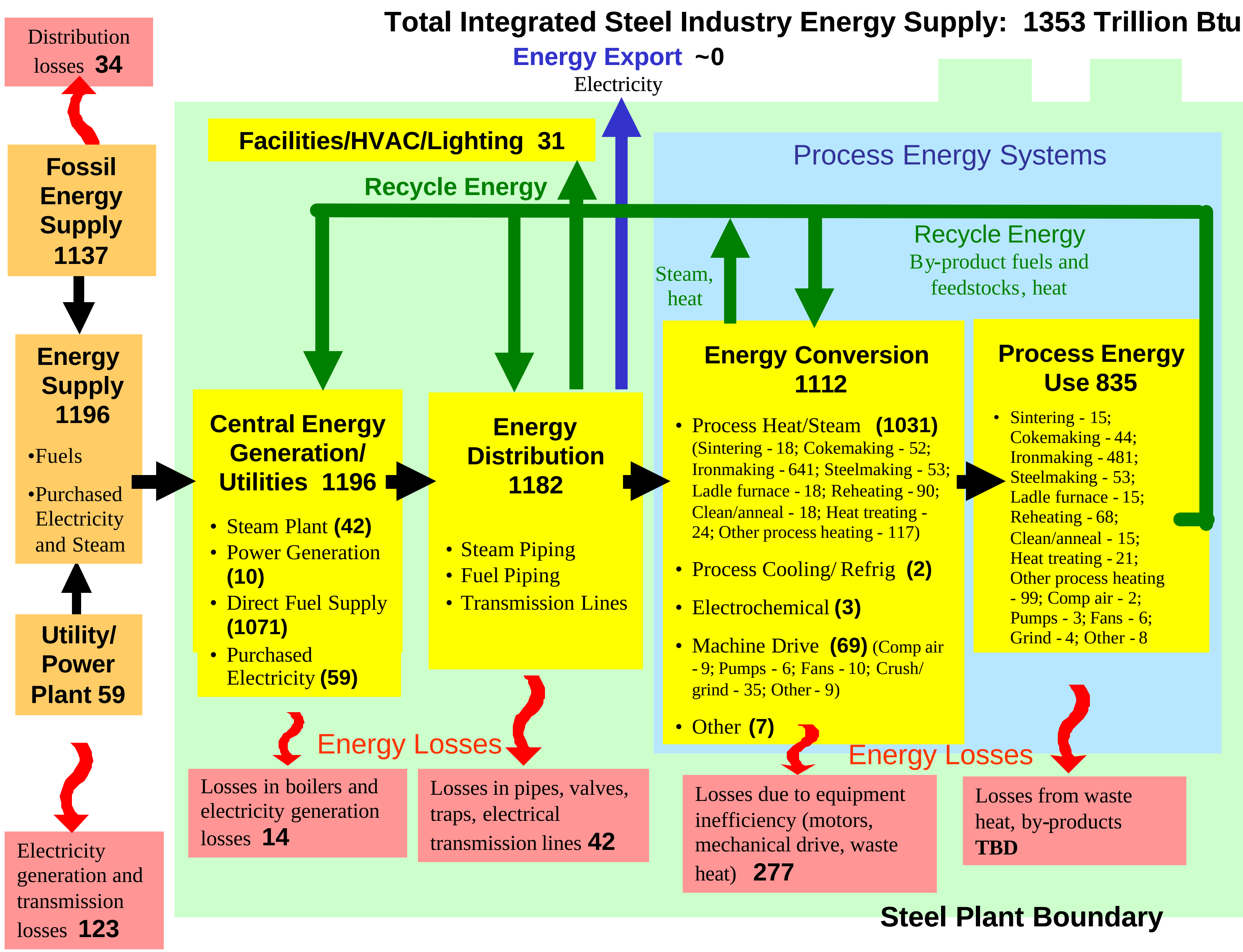

NAICS 326 Plastics and Rubber Products Total Energy Supply for Heat and Power: 711 Trillion Btu
Distribution losses 4
Fossil Energy Supply 144
Energy Supply 327
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 183
Electricity generation and transmission losses 380
Energy Export <0.5
Facilities/HVAC/Lighting 58
Recycle Energy
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, heat
Central Energy Generation/ Utilities 327
• Steam Plant (64)
• Fossil Power (1)
• Direct Fuel Supply (62)
• Purchased Electricity (183)
Energy Distribution 310
• Steam Piping
• Fuel Piping
• Transmission Lines
Energy Conversion 231
• Process Heating (115)
(steam systems, heat exchangers, condensers, fired heaters, heat pumps)
• Process Cooling/ Refrigeration (17)
• Machine Drives (98)
(pumps, compressors, fans, blowers, conveyors, mixers)
• Onsite Transport (3)
• Other (1)
Process Energy Use 156
• Separations
• Melters
• Dryers
• Mixing/Grinding
• Forming/Molding
• Fabrication
• Energy Storage
• Waste Handling
Energy Losses
Energy Losses
Losses in boilers and electricity generation losses 17
Losses in pipes, valves, traps, electrical transmission lines 21
Losses due to equipment inefficiency (motors, mechanical drive, waste heat) 75
Losses from waste heat, flared gases, by-products TBD
Industrial Plant Boundary


NAICS 326 Plastics and Rubber Products Total Energy Input: 711 Trillion Btu
Central Energy Plant
327
Energy Distribution
310
Energy Conversion
231
Process Energy
156
Distribution Losses 21
Equipment Losses 21
Losses 4
Facilities 58
Onsite Transport 3
Fired Heaters 60
(30 Electric)
62
22
Purchased Fuels 144
Central Boilers
63
Other 1
Steam
64
Steam 52 (1 Electric)
Combined Heat/Power
1
Process Cooling 17
(1 Fuel, 16 Electric)
Electricity 1
36
Purchased Electricity 183
Electricity to Processes 142
Motor-Driven 98
(96 Electric, 2 Fuel)
Pumps 24
Fans 13
Compressed Air 16
Refrigeration 7
Materials Handling 12
Materials Processing 22
Other Systems 4
Process Use
Losses 380
Boiler Losses 16
Power Losses 1
Industrial Plant Boundary
Energy Export < 0.5
Motor Losses 4
System Losses 50

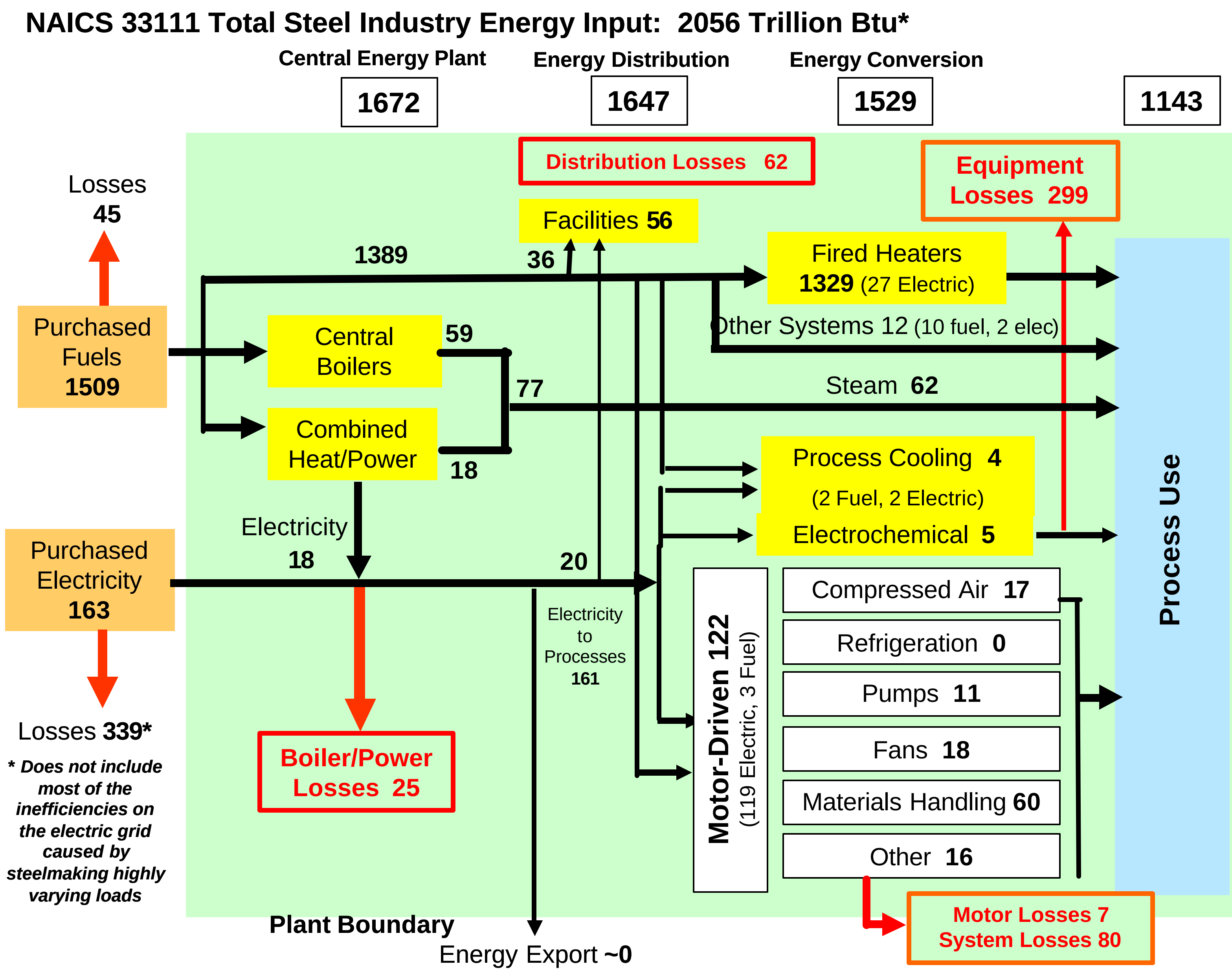

NAICS 33111 Total Steel Industry Energy Input: 2056 Trillion Btu*
Energy Export ~0
Electricity
Distribution losses 45
Fossil Energy Supply 1509
Energy Supply 1672
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 163
Electricity generation and transmission losses 339*
Facilities/HVAC/Lighting 56
Recycle Energy
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, heat
Central Energy Generation/ Utilities 1672
• Steam Plant (77)
• Power Generation (18)
• Direct Fuel Supply (1372)
• Purchased Electricity (180)
Energy Distribution 1647
• Steam Piping
• Fuel Piping
• Transmission Lines
Energy Conversion 1529
• Process Heating (1329)
(steam systems, coke ovens, blast furnaces, reheat furnaces)
• Process Cooling/ Refrigeration (4)
• Electrochemical (5)
• Machine Drives (122)
(pumps, compressors, fans, blowers, conveyors, grinders)
• Other (12)
Process Energy Use 1143
• Cokemaking
• Ironmaking
• Steelmaking
• Ladle refining
• Casting
• Reheating
• Forming
• Finishing
• Waste Handling
Energy Losses
Energy Losses
Losses in boilers and electricity generation losses 25
Losses in pipes, valves, traps, electrical transmission lines 62
Losses due to equipment inefficiency (motors, mechanical drive, waste heat) 386
Losses from waste heat, by-products TBD
Steel Plant Boundary

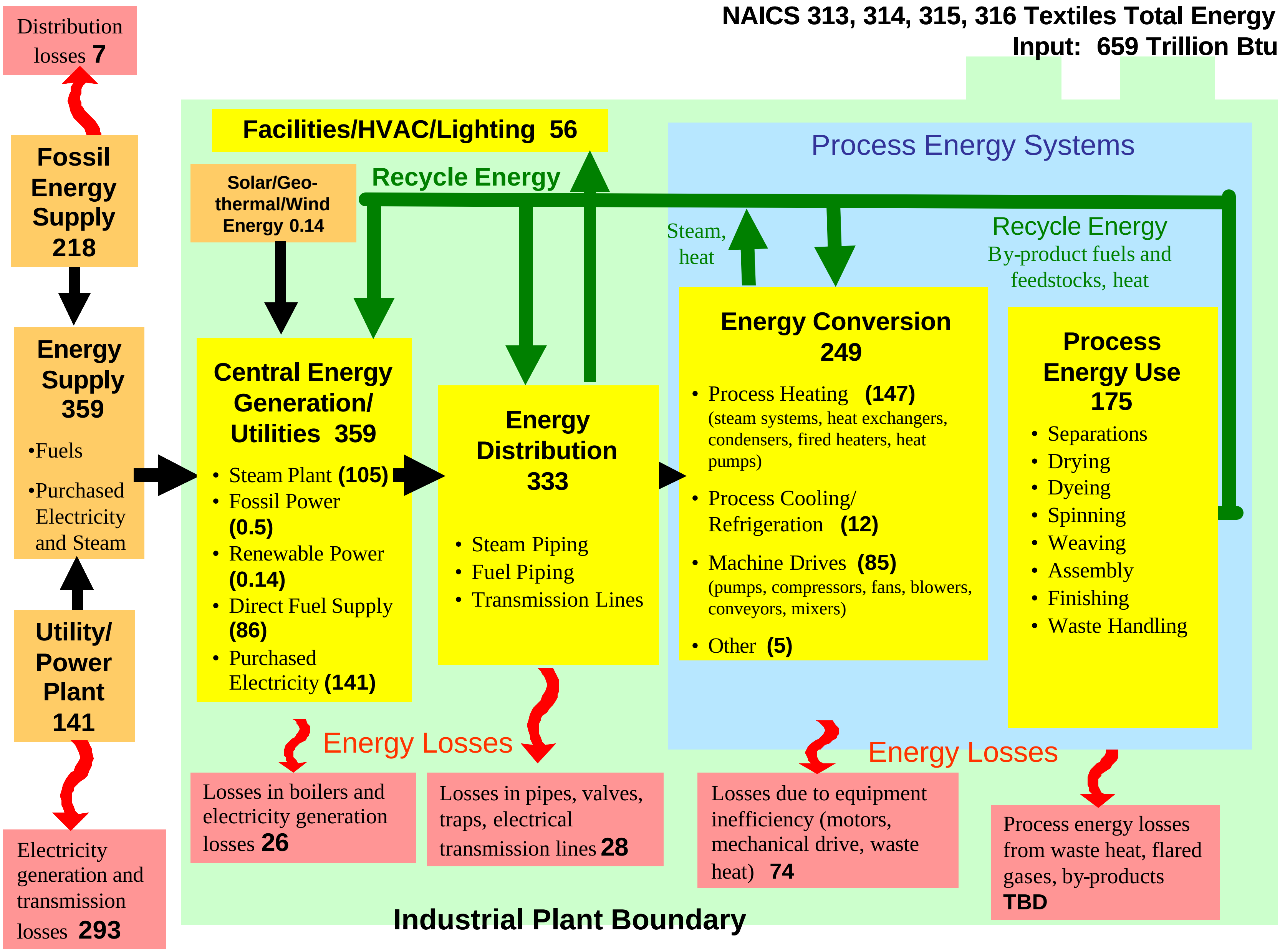


Total EAF Steel Industry Energy Supply: 703 Trillion Btu
Energy Export ~0
Electricity
Distribution losses 11
Fossil Energy Supply 372
Energy Supply 476
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 104
Electricity generation and transmission losses 216
Facilities/HVAC/Lighting 25
Recycle Energy
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, heat
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

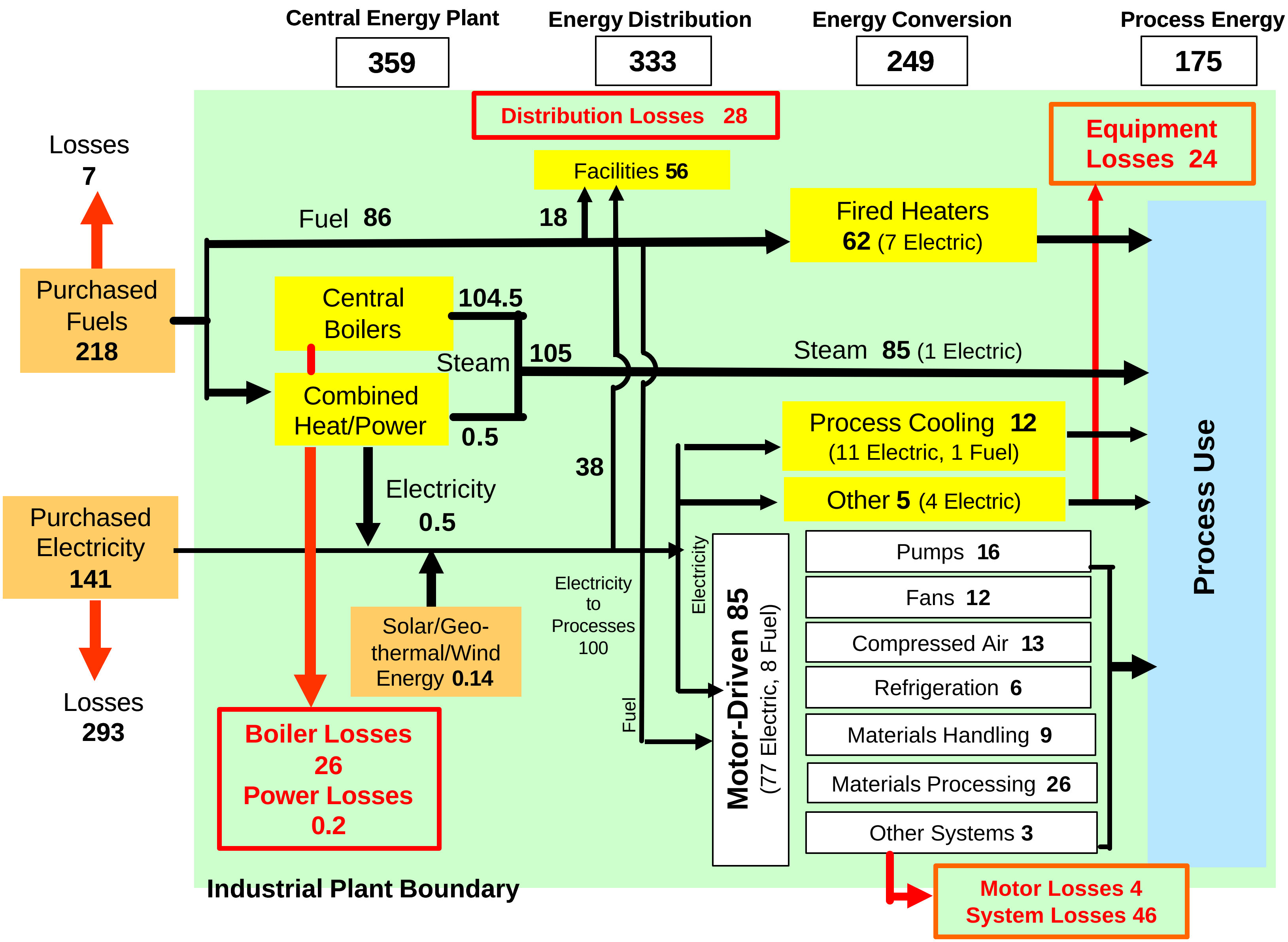


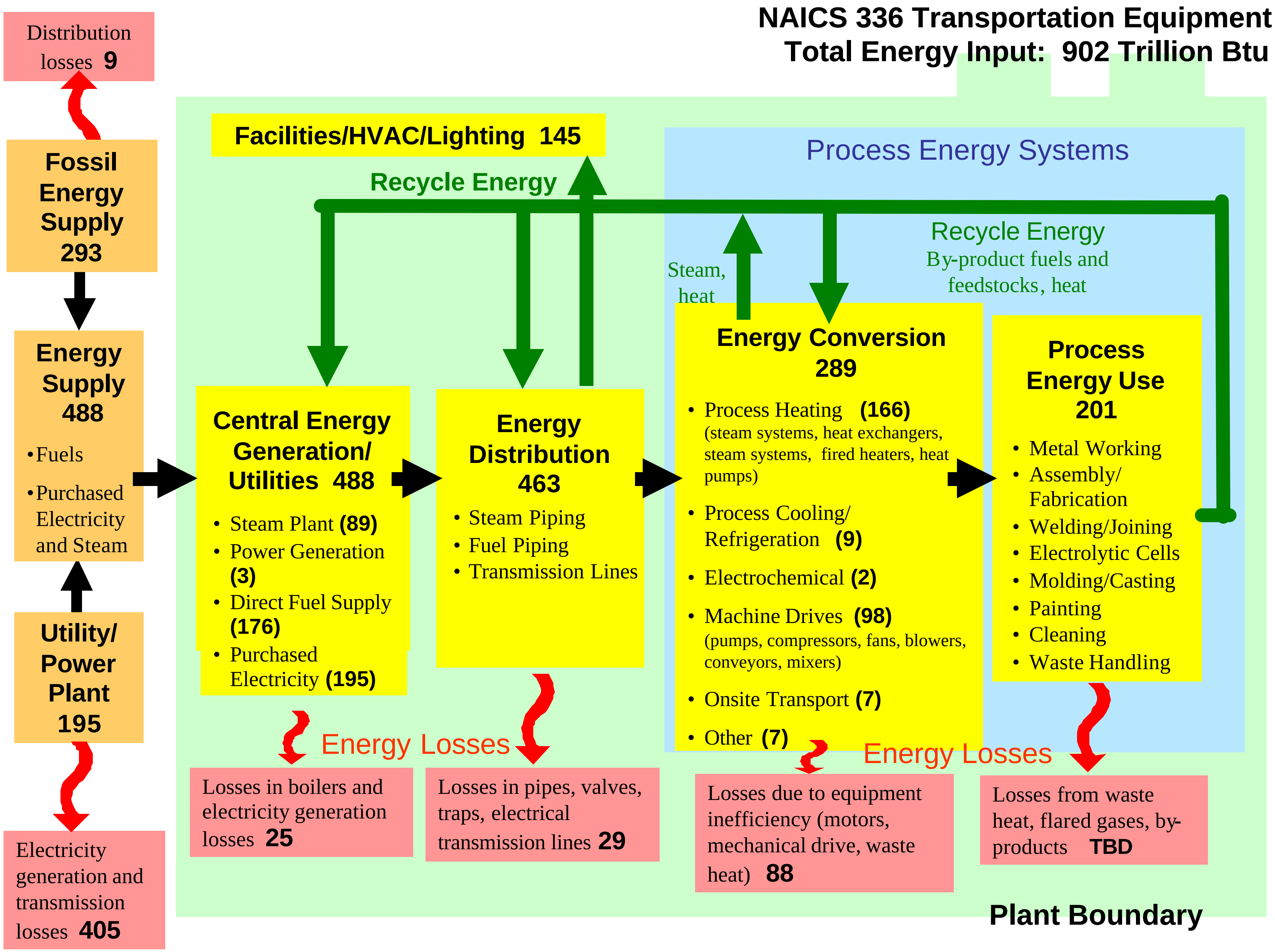
Total Integrated Steel Industry Energy Supply: 1353 Trillion Btu
Energy Export ~0
Electricity
Distribution losses 34
Fossil Energy Supply 1137
Energy Supply 1196
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 59
Electricity generation and transmission losses 123
Facilities/HVAC/Lighting 31
Recycle Energy
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, 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 1112
• 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 (69) (Comp air - 9; Pumps - 6; Fans - 10; Crush/ grind - 35; Other - 9)
• Other (7)
Process Energy Use 835
• 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 33111 Total Steel Industry Energy Input: 2056 Trillion Btu*
Central Energy Plant
1672
Energy Distribution
1647
Energy Conversion
1529
1143
Losses
45
Purchased Fuels
1509
Distribution Losses 62
Equipment Losses 299
Facilities 56
1389
36
Fired Heaters
1329 (27 Electric)
Central Boilers
59
Other Systems 12 (10 fuel, 2 elec)
77
Steam 62
Combined Heat/Power
18
Process Cooling 4
(2 Fuel, 2 Electric)
Electrochemical 5
Electricity
18
20
Purchased Electricity
163
Electricity to Processes
161
Motor-Driven 122
(119 Electric, 3 Fuel)
Compressed Air 17
Refrigeration 0
Pumps 11
Fans 18
Materials Handling 60
Other 16
Process Use
Losses 339*
* Does not include most of the inefficiencies on the electric grid caused by steelmaking highly varying loads
Boiler/Power Losses 25
Plant Boundary
Energy Export ~0
Motor Losses 7
System Losses 80

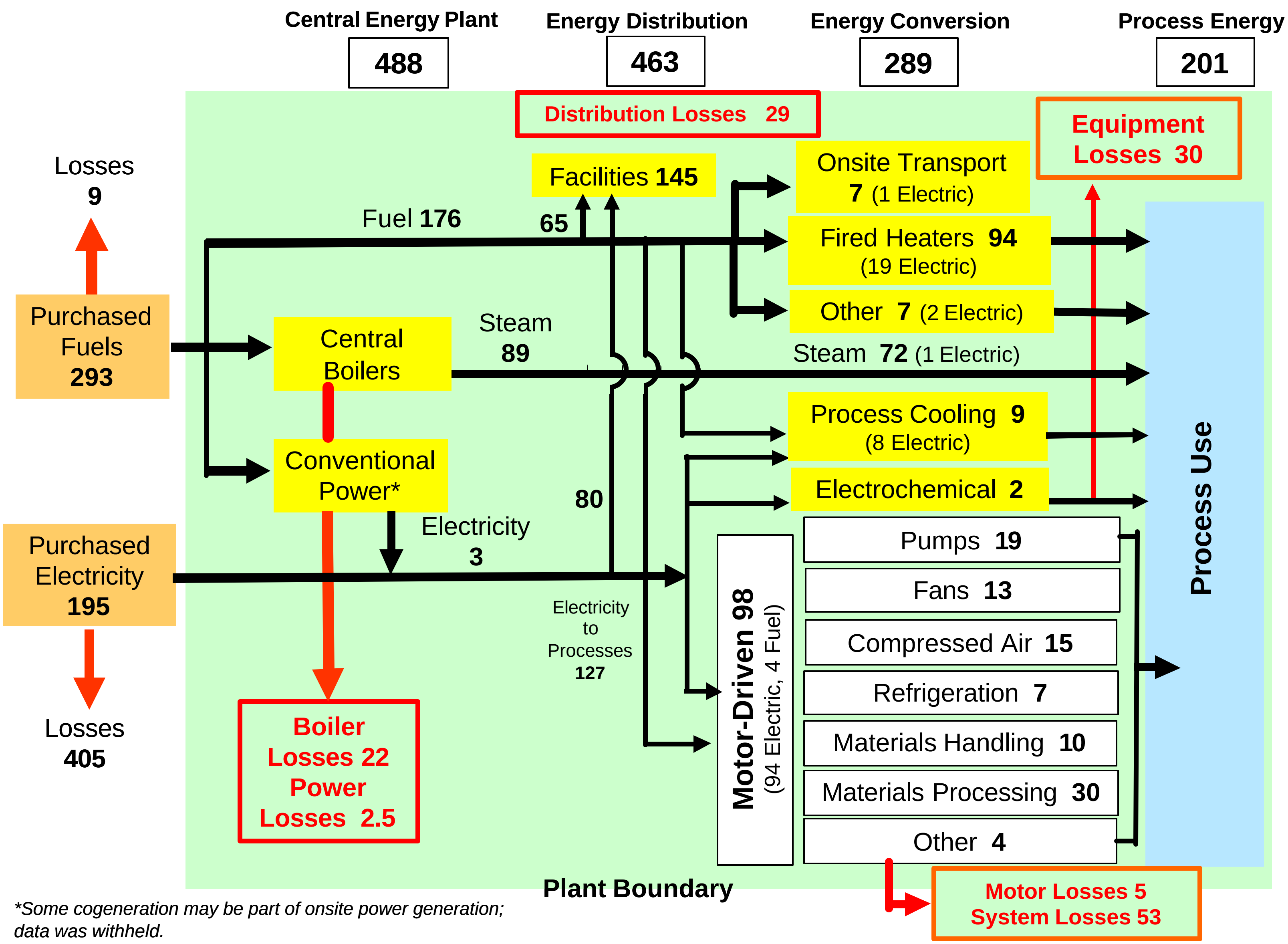

NAICS 313, 314, 315, 316 Textiles Total Energy Input: 659 Trillion Btu
Distribution losses 7
Fossil Energy Supply 218
Energy Supply 359
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 141
Electricity generation and transmission losses 293
Facilities/HVAC/Lighting 56
Solar/Geo-thermal/Wind Energy 0.14
Recycle Energy
Central Energy Generation/ Utilities 359
• Steam Plant (105)
• Fossil Power (0.5)
• Renewable Power (0.14)
• Direct Fuel Supply (86)
• Purchased Electricity (141)
Energy Distribution 333
• Steam Piping
• Fuel Piping
• Transmission Lines
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, heat
Energy Conversion 249
• Process Heating (147) (steam systems, heat exchangers, condensers, fired heaters, heat pumps)
• Process Cooling/ Refrigeration (12)
• Machine Drives (85) (pumps, compressors, fans, blowers, conveyors, mixers)
• Other (5)
Process Energy Use 175
• Separations
• Drying
• Dyeing
• Spinning
• Weaving
• Assembly
• Finishing
• Waste Handling
Energy Losses
Losses in boilers and electricity generation losses 26
Losses in pipes, valves, traps, electrical transmission lines 28
Energy Losses
Losses due to equipment inefficiency (motors, mechanical drive, waste heat) 74
Process energy losses from waste heat, flared gases, by-products TBD
Industrial Plant Boundary

NAICS 313, 314, 315, 316 Textiles Total Energy Input: 659 Trillion Btu




NAICS 336 Transportation Equipment
Total Energy Input: 902 Trillion Btu
Distribution losses 9
Fossil Energy Supply 293
Energy Supply 488
•Fuels
•Purchased Electricity and Steam
Utility/ Power Plant 195
Electricity generation and transmission losses 405
Facilities/HVAC/Lighting 145
Recycle Energy
Process Energy Systems
Steam, heat
Recycle Energy
By-product fuels and feedstocks, heat
Central Energy Generation/ Utilities 488
• Steam Plant (89)
• Power Generation (3)
• Direct Fuel Supply (176)
• Purchased Electricity (195)
Energy Distribution 463
• Steam Piping
• Fuel Piping
• Transmission Lines
Energy Conversion 289
• Process Heating (166) (steam systems, heat exchangers, steam systems, fired heaters, heat pumps)
• Process Cooling/ Refrigeration (9)
• Electrochemical (2)
• Machine Drives (98) (pumps, compressors, fans, blowers, conveyors, mixers)
• Onsite Transport (7)
• Other (7)
Process Energy Use 201
• Metal Working
• Assembly/ Fabrication
• Welding/Joining
• Electrolytic Cells
• Molding/Casting
• Painting
• Cleaning
• Waste Handling
Energy Losses
Energy Losses
Losses in boilers and electricity generation losses 25
Losses in pipes, valves, traps, electrical transmission lines 29
Losses due to equipment inefficiency (motors, mechanical drive, waste heat) 88
Losses from waste heat, flared gases, by-products TBD
Plant Boundary

NAICS 336 Transportation Equipment Total Energy Input: 902 Trillion Btu



*Some cogeneration may be part of onsite power generation; data was withheld.

Sample Calculations: NAICS 321 and 322 Forest Products Industry Footprint

All energy values are in trillion Btu (10^{12} Btu, or trillion Btu).

Total Energy Supply, 4039 trillion Btu
This is the sum of energy supply plus any energy losses incurred during energy generation, transmission and distribution.

3272 trillion Btu + 679 trillion Btu + 88 trillion Btu = 4039 trillion Btu

Energy Supply, 3272 trillion Btu
This number is the sum of Fuel Consumption, from MECS Table N3.2 for and Electricity Sales and Transfers Offsite, from MECS Table N13.1. The total includes purchased steam, biomass, black liquor, and byproduct fuels.

Fuel consumption: 504 + 2744 = 3248 trillion Btu
Transfers out: (805 + 6,130) million kWh * 3412 = 24 trillion Btu
Energy Supply = 3248 + 24 = 3272

Utility Power Plant, 327 trillion Btu
This number is the sum of Purchased Electricity and Transfers In, from MECS Table N13.1.

Purchased electricity: (21,826 + 73,464) = 95,290 million kWh * 3412 = 325 trillion Btu
Transfers in: (149 + 549) = 698 million kWh * 3412 = 2.4 trillion Btu
Electricity from Utility Power Plant = 325 + 2.4 = 327.4

Electricity Generation and Transmission Losses, 679 trillion Btu
This number represents losses incurred during the generation and transmission of electricity at off-site utilities. It is based on utility power plant purchases and a loss conversion factor of 10500 Btu/kWhr.

327 trillion Btu *(10500 Btu/kWhr/3412 Btu/kWhr) = 1006 trillion Btu (electricity use with losses)

1006 trillion Btu – 327 trillion Btu = 679 trillion Btu (losses)

Renewables, 9 trillion Btu
Table N13.2 Renewable Energy (excluding Wood and Other Biomass)

2,481 million kWh * 3412 = 8.5 trillion Btu ~ 9 trillion Btu

Biomass, 1534 trillion Btu Table N5.2

Black Liquor = 903 trillion Btu
Biomass = 271 + 360 = 631 trillion Btu
Total = 903 + 631 = 1534 trillion Btu

Fossil Energy Supply, 1402 trillion Btu
This number is obtained by subtracting utility power plant purchases (327 trillion Btu), renewables (9 trillion Btu), and biomass (1534 trillion Btu) from energy supply (3272 trillion Btu). This includes net purchased steam and byproduct fuels.

3272 – (327 + 9 + 1534) = 1402 trillion Btu

Fuel Distribution Losses, 88 trillion Btu
This number represents losses incurred in natural gas pipelines, and in the transport and/or transfer of fuels from off-site to on-site facilities. It is a rough estimate of 3%.

2936 trillion Btu * 0.03 = 88 trillion Btu

Central Energy Generation/ Utilities, 3272 trillion Btu
This number represents the energy that actually enters the plant boundary. It is the same as Energy Supply, above. Breakouts for central energy are calculated as shown below.

- **Steam Plant Energy, 1895 trillion Btu** – First the total energy going to boilers for all purposes is calculated by adding the total fuel to boilers, from MECS Table N6.2, End-uses of Fuel Consumption (832 trillion Btu) to the fuel for conventional electricity generation from the same table (Adjusted, 45 trillion Btu, see Non-process Energy table).

The end-use of 1824 trillion Btu of fuel and 7 trillion Btu of net electricity were not reported on the Table N6.2, therefore the end-uses were adjusted to account for this fuel and round-off errors:

FOREST PRODUCTS NAICS 321 & 322	Net Electricity	Total	Fuel Only	Added Biomass	Fuel Use %	Non-Reported (305)	Adjusted Fuel	Adjusted Net Electricity	Adjusted Total
TOTAL FUEL CONSUMPTION	312	3,248	2,936						
Indirect Uses-Boiler Fuel	**4**	**836**	**832**	**2,366**	**89.9%**	**274**	**2640.280**	**10.295**	**2651**
Direct Uses-Total Process	**267**	**455**	**188**	**188**	**7.1%**	**22**	**209.794**	**267.500**	**477**
Process Heating	8	174	166	166					
Process Cooling and Refrigeration	4	5	1	1					
Machine Drive	252	269	17	17					
Electro-Chemical Processes	1	1	0	0					
Other Process Use	0	4	4	4					
Direct Uses-Total Nonprocess	**34**	**111**	**77**	**77**	**2.9%**	**9**	**85.926**	**34.205**	**120**
Facility HVAC (g)	16	39	23	23					
Facility Lighting	15	15	0	0					
Other Facility Support	3	3	0	0					
Onsite Transportation	0	13	13	13					
Conventional Electricity Generation	0	40	40	40					
Other Nonprocess Use	0	0	0	0					
End-use Not Reported	**7**	**1,846**	**1,839**	**305**					

Net Electricity & Total = Data from Table N6.2. Total is the Total energy consumption broken down by end-use.

Fuel Only = (Total) – (Net Electricity)

Added Biomass = Biomass energy use (1534) added to indirect energy end-use – boiler fuel. This was done because biomass (black liquor and wood residues) is burned in boilers (recovery/hog fuel) to generate steam/electricity.

Fuel Use Distribution = Fuel use (w/biomass) percent distribution by end-use, 2366+188+77 = 2631
Indirect = 2366/2631 = 89.9%, etc.

Non-Reported Distribution = (Fuel Use Distribution) * 305
1831 (non-reported end-use energy) – 1534 (biomass energy) = 290, added 15 (round off errors with table so that total will add up to 3248 trillion Btu). Distributed net electricity (7 trillion Btu) using % fuel distribution because assumed that non-reported electricity was related to non-reported biomass (biomass accounted for 84% of non-reported), 7 trillion Btu included in Adjusted Net Electricity.

Adjusted Fuel = (Added Biomass) + (Non-Reported Distribution)

Adjusted Total = (Adjusted Fuel) + (Net Electricity)

Using the adjusted data, the fuel to the boilers is 2640 + 45 = 2685 trillion Btu

To calculate steam not used for electricity, the fuel used for cogeneration and conventional electricity generation must be subtracted. From MECS Table 13.2, Components of Onsite Generation, Cogeneration represents 50,814

(1,418 + 49,396) million kWh (173 trillion Btu), and conventional generation (Other) is 4327 million kWh (15 trillion Btu), based on a use factor of 3412 Btu/kWh. Steam is then calculated by difference using the following heat rates and applying boiler efficiency of 78 percent:

(Total fuel to boilers – energy for cogen– energy for conv electricity)*.80 = Steam Energy

(2685 trillion Btu – (173 trillion Btu *(4500/3412)) - (15 trillion*(6200/3412)))*.78 = 1895 trillion Btu

Heat rates and boiler efficiencies are taken from Overview of Energy Flow for Industries in Standard Industrial Classifications 20-39, Arthur D. Little, 2000. Boiler efficiencies were weighted based on 1998 MECS boiler fuel use (18% natural gas, 6% oil, 11% coal, and 65% biomass).

Steam Plant Energy to CHP = ((173 * (4500/3412)) / 2685) * 1895 = 161 trillion Btu
Steam Plant Energy to Central Boilers = 1895 – 161 = 1734 trillion Btu

- **Power generation, 188 trillion Btu** – This is the sum of electricity produced onsite by cogeneration and conventional electricity generation, from Table N13.2, as discussed in Steam Plant Energy (173 Tbtu + 15 Tbtu = 188 Tbtu).

- **Direct Fuel Supply, 251 trillion Btu** – This is calculated as follows:

  (Energy Supply) – (Steam Plant Energy) – (Power Generation) – (Utility Power Plant) – (Losses in Boilers and Electricity Generation) – 2(Exports) + (Renewables) – (Non-process Fuel)

  Net Electricity = 312 = (Utility Power Plant) – (Exports) + (Renewables)

  (Energy Supply) – (Steam Plant Energy) – (Power Generation) – (Losses in Boilers and Electricity Generation) – (Net Electricity) – (Non-process Fuel) – (Exports)

  Fuel to Boilers = (Steam Plant Energy) + (Power Generation) + (Losses in Boilers and Electricity Generation) = 1895 + 188 + 602 = 2685

  Direct Fuel Supply = (Energy Supply) – (Fuel to Boilers) – (Net Electricity) – (Exports) =
  3272 – 2685 – 312 – 24 = 251 trillion Btu
  To Process = 251 – 26 (Non-Process Fuel Use) = 225

Losses in Boilers and Electricity Generation, 602 trillion Btu
This number is calculated by first determining total energy to boilers and on-site electricity generation (see Steam Plant Energy, above), and subtracting steam and electricity generated.

(Fuel to Boilers) – (Steam Plant Energy) – (Power Generation)
2685 trillion Btu – 1895 trillion Btu – 188 trillion Btu = 602 trillion Btu losses

The losses attributed to turbines are:

(173 trillion Btu*(4500/3412) - 173) = 228 – 173 = 55 trillion Btu (cogeneration)
(15 Tbtu*(6200/3412) – 15) = 27 – 15 = 12 trillion Btu (conventional power generation onsite)
55 + 12 = 67 trillion Btu turbine losses

Boiler losses = 2685 – 228 – 27 = 2430*.22 = 535 trillion Btu

Exports, 24 trillion Btu
This number represents excess electricity that is sold and transferred to off-site facilities or to the local grid. It is obtained from Electricity Sales and Transfers Offsite, MECS Table N13.1 in million kWh, and converted to Btu as follows:

805 + 6,130 = 6,935 million kWh*3412 Btu/kWh = 24 trillion Btu

Non-Process Energy, 76 trillion Btu
This number is taken from End-uses of Fuel Consumption, MECS Tables N6.2 and N6.4. Table N6.4 includes use of electricity generated on-site (net demand). Values in Table N6.2 have been adjusted upward to include the end-uses that facilities did not report on and round off error. This non-reported energy was distributed among the categories using the same distributions as energy that was reported on. The values taken from Tables N6.2 and N6.4 include:

FOREST PRODUCTS NAICS 321 & 322	Net Demand for Electricity	Fuel	Fuel Use %	Adjusted Fuel Use	Adjusted Total
Direct Uses-Total Nonprocess	50	76		86	136
Facility HVAC (g)	23	23	30%	26	49
Facility Lighting	21	0	0%	0	21
Other Facility Support	5	0	0%	0	5
Onsite Transportation	0	13	17%	15	15
Conventional Electricity Generation	0	40	53%	45	45
Other Nonprocess Use	1	0	0%	0	1

Facility HVAC 49 trillion Btu
Facility Lighting 21 trillion Btu
Other Facility Support 5 trillion Btu

Other Nonprocess Use 1 trillion Btu
TOTAL 76 trillion Btu

*Conventional Electricity Generation included in Steam Plant Energy

Onsite Transportation 15 trillion Btu * Included in Direct Process

Energy Distribution, 2670 trillion Btu
This represents the energy that is distributed to process energy systems. It is obtained by subtracting boiler and on-site power generation losses from Central Energy Generation.

3272 trillion Btu – 602 trillion Btu = 2670 trillion Btu

Distribution Losses, 402 trillion Btu
Energy losses in pipes, valves, traps, and electrical transmission lines. This value is based on a rough estimate that from 5-40% of energy can be lost in pipes, valves, traps, and electrical transmission lines. This value is very site-specific and varies considerably across different types of plants and even in plants producing the same types of products. For this calculation 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% {Steam Trap Performance Assessment, PNNL, for the U.S. Dept of Energy, July 1999; "How Efficient is Your Steam Distribution System?" Frederic A. Hooper and Ronald D. Gillette, 2002, www.swopnet.com/engr/stm/steam_dist_eff.html. } For conservatism, a value of 20% was used for steam distribution losses.

Calculations are as follows:

Steam Pipes:	(Steam Plant Energy) * 20%
	1895 trillion Btu * 0.20 = 379 trillion Btu
Fuel Pipes:	(Direct Fuel Supply) * 3%
	225 trillion Btu * 0.03 = 6.75 ~ 7 trillion Btu
Electricity Lines:	{(Utility Power Plant) + (Power Generation) + (Renewable Power)} * 3%
	(327 trillion Btu + 188 trillion Btu + 9 trillion Btu) = 524 * 0.03 = 15.72 trillion Btu
Total Losses:	379 + 7 + 16 = 402 trillion Btu

Energy Conversion, 2168 trillion Btu
This value is calculated by subtracting distribution losses, facilities energy, and export energy from Energy Distribution. It represents the energy that is used by process energy systems, including motor driven equipment, process heating and cooling units, and other process equipment.

(Energy Distribution) – (Distribution Losses) – (Non-process Energy) – (Exports)
2670 trillion Btu – 402 trillion Btu – 76 trillion Btu – 24 trillion Btu = 2168 trillion Btu

- **Process Heating, 1724 trillion Btu** - This value is the sum of energy used for process heating and steam delivered to process systems. Using Adjusted table below:

FOREST PRODUCTS	Net Demand for Electricity	Fuel Distribution	Adjusted Net Demand for Electricity
NAICS 321 & 322			
TOTAL FUEL CONSUMPTION	500		
Indirect Uses-Boiler Fuel	12	89.9%	**19**
Direct Uses-Total Process	430	7.1%	431
Process Heating	11		
Process Cooling and Refrigeration	7		
Machine Drive	407		
Electro-Chemical Processes	2		
Other Process Use	1		
Direct Uses-Total Nonprocess	50	2.9%	50
Facility HVAC (g)	23		
Facility Lighting	21		
Other Facility Support	5		
Onsite Transportation	0		
Conventional Electricity Generation	0		
Other Nonprocess Use	1		
End-use Not Reported	8		

(Steam Plant Energy) – (Steam Pipe Losses) – (Fuel Pipe Losses) + (Net Demand for Electricity by Boilers) = 1895 trillion Btu – 379 trillion Btu – 7 trillion Btu + 19 trillion Btu = 1528 trillion Btu of steam used for Process Heating

Add this to the Adjusted Process Heating Energy table:

FOREST PRODUCTS NAICS 321 & 322	Net Demand for Electricity	Adjusted Net Demand for Electricity	Fuel Only	Fuel Use %	Adjusted Fuel	Adjusted Total
Direct Uses-Total Process	430	431	188		210	641
Process Heating	11	11	166	88.30%	185.24	**196**
Process Cooling and Refrigeration	7	7	1	0.53%	1.12	8
Machine Drive	407	410	17	9.04%	18.97	429
Electro-Chemical Processes	2	2	0	0.00%	0.00	2
Other Process Use	1	1	4	2.13%	4.46	6

1528 trillion Btu + 196 trillion Btu = 1724 trillion Btu of Energy used for Process Heating

- **Process Cooling, 8 trillion Btu –** This value is taken directly from the adjusted table above. This includes 7 trillion Btu of electricity and 1 trillion Btu of fuel.

- **Machine Drive, 413 trillion Btu -** This value is taken from the table above, minus the electricity distribution losses (16 trillion Btu).

  429 trillion Btu – 16 trillion Btu = 413 trillion Btu

- **Electrochemical Processes, 2 trillion Btu** - This value is taken fromthe table above.

- **Other, 6 trillion Btu** - This value is taken from the table above.

- **Onsite Transport, 15 trillion Btu** – This value is taken directly from the non-process adjusted table.

Losses Due to Equipment Inefficiencies, 470 trillion Btu
These represent losses occurring in machine driven systems and motors, preheaters, other heat exchange systems, inefficient burners, and other energy conversion systems prior to process-level losses. These include some of the waste heat lost during energy conversion. In practice, these losses overlap in many cases with the losses from process operations, as it is difficult to separate what is lost in energy conversion and what is lost from process equipment. Losses were thus calculated using rough estimates or potential efficiency improvements, as follows. Losses in actuality could be much higher. In compressed air systems, for example, a relatively efficient operating system will only produce about 11% of the input energy in the form of work at the point of use {"Compressed Air: A Facilities Perspective," R. Scot Foss, Applied Technology Publications, 1998, Maintenance Technology Magazine.} Sources also include rule-of-thumb judgments obtained from national laboratory experts in specific equipment systems. Values in some cases have been adjusted for round-off error.

Energy Conversion Equipment Losses, 268 trillion Btu
Steam delivery systems Losses: 1528 trillion Btu * 0.15 = 229 trillion Btu (15%, rough estimate)
Steam energy delivered: 1528 – 229 = 1299 trillion Btu

Process heating systems: 196 trillion Btu * 0.15 = 29 trillion Btu (15%, rough estimate)
Process heat energy delivered: 196 – 29 = 167 trillion Btu

Cooling systems: 8 trillion Btu * 0.10 = 0.80 ~ 1 trillion Btu (10%, rough estimate)
Cooling energy delivered: 8 – 1 = 7 trillion Btu

Electrochemical systems: 2 trillion Btu * 0.15 = 0.30 ~ 0 trillion Btu (15%, rough estimate)
Other: 6 trillion Btu * 0.10 = 0.60 ~ 1 trillion Btu (10%, rough estimate)
Other energy delivered: 6 – 1 = 5 trillion Btu

Onsite Transport: 15 trillion Btu * 0.50 = 7.5 ~ 8 trillion Btu (50%, assumes gasoline or diesel engines)
Onsite transport energy delivered = 15 – 8 = 7 trillion Btu

Total Energy Conversion Equipment Losses: 268 trillion Btu
Energy Delivered to these process systems: 1487 trillion Btu

Machine Driven System Losses, Total of 202 trillion Btu (windings plus systems)

	%	Energy Use	System Loss	Energy Loss	Usable Work
Machine Drive		**413**			
Pumps	31.40%	130	40.00%	52	78
Fans	19.80%	82	40.00%	33	49
Compressed Air	4.60%	19	80.00%	15	4
Refrigeration	5.00%	20	5.00%	1	19
Materials Handling	7.40%	30	5.00%	2	29
Materials Processing	21.30%	88	90.00%	79	9
Other	10.60%	44	5.00%	2	42
				184	229

Motor (Windings) Losses = 413 trillion Btu * 0.043 = 18 trillion Btu

Energy Use and Loss Percentages taken from ORNL/Xenergy U.S. Motor Systems Assessment)
Total Machine Drive Losses: 184 trillion Btu + 18 trillion Btu = 202 trillion Btu
Total Machine energy delivered: 413 – 202 = 211 trillion Btu

Total Equipment losses: 268 trillion Btu + 202 trillion Btu = 470 trillion Btu
Total Energy Delivered to all process systems: 1487 + 211 trillion Btu = 1698 trillion Btu (Process Energy Use)

Process Energy Use, 1698 trillion Btu
This is calculated by subtracting equipment losses from energy delivered to energy conversion systems.

2168 trillion Btu – 470 trillion Btu = 1698 trillion Btu

Appendix B

Opportunity Analysis Backup Data

Table B-1 Petroleum - Steam Systems Detailed Table

No.	Production Process	Steam Energy Use (10^12 Btu)[1]	Steam Use 10^3 Btu/barrel	Equipment Used [2,3]	Average Efficienc y %	Potential Heat Losses (10^12 Btu)	Major Sources for Losses	Possible Methods of Energy Recovery	Potential % Savings (to be verified)	Potential Savings (Tbtu/yr)
1	Atmospheric Distillation	246.1	44.0	Fractionating Tower, Stripping (Direct Contact - DC)	40	148	Contaminated waste steam	Low level steam recovery, recycle of steam, decon-tamination of steam	40	60
2	Vacuum Distillation	123.3	48.0	Reboiler, Steam Ejection (indirect contact), Stripping, Fractionating (DC)	55	55	Contaminated waste steam, heat losses from reboiler	Same as above	20	11
3	Visbreaking	-1.3	export	Stripping (DC)	40	-1	Contaminated waste steam	Same as above	20	0
4	Coking Operations	-9.4	export	Fractionating Tower (DC)	40		Contaminated waste steam	Same as above		0
5	Fluid Catalytic Cracking	0.5	0.3	Stripping (DC)	40	0	Contaminated waste steam	Same as above	20	0
6	Catalytic Hydro-cracking	33.6	71.0	Stripping, Quenching (DC)	40	20	Contaminated waste steam	Same as above	20	4
7	Catalytic Hydro-treating	212.0	54.0	Stripping (DC)	40	127	Contaminated waste steam	Same as above	20	25
8	Catalytic Reforming	117.2	89.0	Stripping (DC)	40	70	Contaminated waste steam	Same as above	20	14
9	Alkylation	139.5	348.0	Stripping (DC)	40	84	Contaminated waste steam	Same as above	20	17
10	Isomers	38.3	226.6	Stripping (DC)	40	23	Contaminated waste steam	Same as above	20	5
	Total	**900**				**527**				**136**

[1] *Steam Systems Opportunity Assessment for the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries* , Resource Dynamics Corp. 2000
[2] *Improving Steam Systems Performance, A Sourcebook for Industry,* U.S. DOE
[3] Direct contact indicates steam is directly contacting hydrocarbon stream, which creates a contaminated wastewater stream. Contaminated wastewater steam from stripping, for example, is often not reused, leading to lower thermal efficiency. In addition, it must often be heated later to reduce the amount of wastewater that must be treated and disposed of. Some waste steam is dilutely contaminated, making separation of contaminants costly.

Table B-2 Petroleum – Fired Systems Detailed Table

No.	Production Process		Thermal process	Average Energy Use 10^3 Btu/Barrel	Annual Energy Use 10^12 Btu/year	Equipment Used (Heat Addition)	Thermal Energy use 10^3 Btu/barrel
1	Topping	Atmospheric Distillation	Fluid heating, Boiling-distillation	113.8	641.6	Charge Heating With Fired Heater.	89.00
		Vacuum Distillation	Fluid heating, Boiling-distillation	91.5	238.8	Charge Heating With Fired Heater.	63.00
2	Thermal and Catalytic Cracking	Delayed Coking	Fluid heating, Agglomeration	166	114.6	Crude (charge) Heating With Fired Coker Heater.	230.00
		Fluid Coking	Fluid heating, Agglomeration	258	7.1	Combustion of Coke in "Burner".	
		Flexcoking	Fluid heating, Agglomeration	167	6.7	Oxidation of Coke in Gasifier. Steam addition to gasifier.	
		Visbreaking	Fluid heating, Agglomeration	99.5	2.07	Fired Heater/reactor, Steam Addition	145.00
						Fired Heater	700.00
		Fluid Catalytic Cracking	Fluid heating, Boiling-distillation	100	190.6	Cat feed Fired Heater, Catalyst Regenerator.	100.00
		Catalytic Hydrocracking	Fluid heating, Boiling-distillation	240	109.7	Fired Charge Heater and Exothermic Catalytic Reaction	195.00
3	Combination/ Rearrange-ment of Hydrocarbons	Alkylation	Fluid heating, Curing-forming	368	149	Reactor (Heat of Reaction)	377.00
		Catalytic Reforming	Fluid heating - Thermal oxidation reactions	284	376.3	Fired Heater	270.00
		Isomerization	Fluid heating, Curing-forming	359	40	Indirect Heating With Heat Exchangers.	359.00
4	Treating	Catalytic Hydrotreating/ Hydroprocessing	Fluid heating	120	468.3	Fired Heater	120.00
5	Specialty Product Manufacture	Lube Oil	Fluid heating, Curing-forming	1506	109.5		1506.00
TOTALS					2,487.50		

Table B-2 Petroleum – Fired Systems Detailed Table (continued)

No.	Production Process		Average (%) Efficiency of FIred Systems	Potential heat losses 10^12 Btu/year	Major source for losses	Three major possible methods of energy recovery			Potential for savings	
1	Topping	Atmospheric Distillation	**75.00**	125.44	Hot Flue Gases and Coolers	1	2	3	65.00	81.54
		Vacuum Distillation	**75.00**	41.10	Hot Flue Gases and Coolers	1	2	3	65.00	26.72
2	Thermal and Catalytic Cracking	Delayed Coking	**80.00**	31.76	Hot Flue Gases, Coke Drum Cooling, Oil Cooler	1	2	3	65.00	20.64
		Fluid Coking	**?**		Hot Flue Gases					
		Flexcoking	**?**		?					
		Visbreaking	**78.00**	0.66	Hot Flue Gases, Coolers and Condensers	1			65.00	0.43
			75.00		Hot Flue Gases and Cooler					
		Fluid Catalytic Cracking	**75.00**	47.65	Hot Flue Gases	1	2	3	65.00	30.97
		Catalytic Hydrocracking	**75.00**	22.28	Hot Flue Gases	1	2	3	65.00	14.48
3	Combination/ Rearrangement of Hydrocarbons	Alkylation	**75.00**	38.16	Cooling water			3	60	22.90
		Catalytic Reforming	**80.00**	71.55	Hot Flue Gases and Coolers	1	2	3	65.00	46.51
		Isomerization	**80.00**	8.00	Coolers			3	60	4.80
4	Treating	Catalytic Hydrotreating/ Hydroprocessing	**80.00**	93.66	Hot Flue Gases	1	2	3	65.00	60.88
5	Specialty Product Manufacture	Lube Oil	**75.00**	27.38	Hot Flue Gases, Coolers and Condensers	1	2	3	53.33	14.60
	TOTALS			**507.65**						**324.47**

Sources:
Energy and Environmental Profile of the Petroleum Refining Industry, Energetics, Inc. for the U.S. Department of Energy, 1998.
The John Zinc Combustion Handbook , John Zinc Corporation.
Personal communication with Dr. Richard Martin, Aztec Engineering, December 2003.

Table B-2 Notes and Assumptions				
No.	**Energy Recovery Technology**	**Status**	**Effectiveness ***	
1	Fluid heating - hot water, heat transfer fluids etc.	Mature - available	50	80
2	Steam generation	Mature - available	50	60
3	Absorption cooling (through steam generation or hot gases)	available	60	80
4	Power generation using low temperature fluid cycles	Emerging	60	80
5	Inert gas generation using combustion products	Emerging	60	70
6	Thermal reforming (H2/CO production)	R&D stage	40	50
7	Thermoelectric power production	R&D stage	25	40
8	Other technologies to be developed	Does not exist		
Notes	*** Effectiveness represents possible percentage heat recovery from the waste heat stream using one or more technologies. It is based on savings of primary energy (for electric power generation it is based on 10,500 Btu/Kwh).**			

Energy Savings Assumptions

- Energy Cost $4.00/million Btu
- 8736 operating hours per year
- Load factor 80%

Table B-3 Chemical Industry – Combined Steam and Fired Systems Detailed Table													
	Energy for Process Heat - Steam (10^12 btu/yr.)												
Process	Fuel Oil	N. Gas	Coal - Coke	Other	**Total from fuels**	Feed stock reaction	Total	Export	Net	Fired Heater /Boiler	Average % waste heat recovery	Possible waste heat recovery (10^12 Btu)/yr	Comments
The Ethylene Chain													
Ethylene	5.60	143.50	18.60	18.60	186.30	760.20	946.50	(146.90)	799.60	Yes	10.00	18.63	Waste gases
Polyethlene	0.30	6.30	0.80	0.80	8.20	583.90	592.10	-	592.10	Yes	5.00	0.41	Waste gases
Ethylene Dichloride	1.90	47.70	6.20	0.20	56.00	201.00	257.00	-	257.00			-	Waste gases
Poly Vinyl Chloride	0.40	10.80	1.40	1.40	14.00	143.10	157.10	-	157.10	Yes	5.00	0.70	Waste gases
Ethylene Oxide	0.30	6.70	0.90	0.90	8.80	138.20	147.00	-	147.00	Yes	5.00	0.44	Waste gases
Ethylene Glycol	0.30	6.50	0.90	0.90	8.60	138.20	146.80	-	146.80	Yes	5.00	0.43	Waste gases
Polystyrene	2.00	50.00	6.50	6.50	65.00	132.40	197.40			Yes	7.50	4.88	Waste gases
TOTAL	**10.80**	**271.50**	**35.30**	**29.30**	**346.90**	**2,097.**	**2,443.9**	**(146.90)**	**2,099.6**			**25.49**	
The Propylene Chain													
Propylene	1.00	24.50	3.20	3.20	31.90	582.50	614.40	-	614.40	Yes	10.00	3.19	
Polypropylene - 1997	0.10	3.30	0.40	0.40	4.20	281.10	285.30	-	285.30		3.00	0.13	Flared gases
Propylene Oxide - 1997	0.20	6.30	0.80	0.80	8.10	104.40	112.50	-	112.50	Yes	5.00	0.41	
Acrylonitrile	0.10	2.00	0.30	0.30	2.70	80.10	82.80	-	82.80	Yes	10.00	0.27	Flared waste gases - HCN
Acrylic Acid		4.00		4.4	8.4					Yes	10.00	0.84	
Acrylic Fiber	0.30	6.50	0.90	0.90	8.60	10.50	19.10	-	19.10		5.00	0.43	Polymeri-zation gases, solvent vapors
TOTAL	**1.70**	**42.60**	**5.60**	**5.60**	**55.50**	**1,058.6**	**1,114.1**	**-**	**1,114.1**			**5.27**	

Table B-3 Chemical Industry – Combined Steam and Fired Systems Detailed Table (continued)													
	Energy for Process Heat - Steam (10^12 btu/yr.)												
Process	Fuel Oil	N. Gas	Coal - Coke	Other	**Total from fuels**	Feed stock reaction	Total	Export	Net	Fired Heater/ Boiler	Average % waste heat recovery	Possible waste heat recovery (10^12 Btu)/yr.	Comments
The BTX Chain													
BTX	1.00	26.40	3.40	3.40	34.20	935.30	969.50	(6.70)	962.80	Yes	10.00	3.4	
Benzene	0.10	2.40	0.30	0.30	3.10	70.00	73.10	-	73.10	Yes	10.00	0.31	
Ethylbenzene	0.60	14.60	1.90	1.90	19.00	264.70	283.70	(3.20)	280.50		5.00	0.95	Vent gases, boiler waste heat
Styrene	3.30	84.50	11.00	11.00	109.80	130.40	240.20	-	240.20	Yes	7.50	8.24	Heater flue gases
Polystyrene	0.40	10.50	1.40	1.40	13.70	128.40	142.10	-	142.10	Yes	7.50	1.03	
Cumene	0.10	3.10	0.40	0.40	4.00	110.40	114.40	(2.30)	112.10		5.00	0.20	
Phenol/Acetone	1.60	41.90	5.40	5.40	54.30	1.60	55.90	-	55.90		-	-	
Terephthalic Acid	0.40	8.90	1.20	1.20	11.70	188.40	200.10	-	200.10	Yes	5.00	0.59	Oxidation process
Cyclohexene	0.10	2.70	0.40	0.40	3.60	3.70	7.30	(3.10)	4.20				
Adipic Acid	1.00	24.30	3.20	3.20	31.70	28.80	60.50	-	60.50				
Caprolactam	0.60	16.00	2.10	2.10	20.80	35.80	56.60	-	56.60				
Nylon 6.6	0.30	8.60	1.10	1.10	11.10	18.50	29.60	-	29.60	Yes	5.00	0.56	
Nylon 6	0.10	3.10	0.40	0.40	4.00	8.80	12.80	-	12.80	Yes	5.00	0.20	
TOTAL	**9.60**	**447.00**	**32.20**	**32.20**	**521.00**	**1,924.80**	**2,445.80**	**(15.30)**	**2,430.50**			**15.30**	

Table B-3 Chemical Industry – Combined Steam and Fired Systems Detailed Table (continued)

	Energy for Process Heat - Steam (10^12 btu/yr.)												
Process	Fuel Oil	N. Gas	Coal - Coke	Other	**Total from fuels**	Feedstock reaction	Total	Export	Net	Fired Heater /Boiler	Average % waste heat recovery	Possible waste heat recovery (10^12 Btu)/yr.	Comments
Agricultural Chemicals													
Ammonia	3.60	291.60	11.90	11.90	319.00	-	319.00	-	319.00	Yes	10.00	31.90	Reformer waste heat
Urea	0.30	6.70	0.90	0.90	8.80	-	8.80	(1.30)	7.50		2.50	0.22	
Nitric Acid	0.10	2.70	0.40	0.40	3.60	-	3.60	(7.80)	(4.20)	Yes	5.00	0.18	Process modification using CHP system
Ammonia Nitrate	0.10	2.10	0.30	0.30	2.80	-	2.80	-	2.80		-	-	
Ammonia Sulfate	0.40	10.40	1.30	1.30	13.40	-	13.40	-	13.40		2.50	0.34	Steam replacement
Sulfuric Acid	0.10	1.70	0.20	0.20	2.20	-	2.20	(74.80)	(72.60)		-	-	
Phosphoric Acid (Wet Process).	0.40	10.90	1.40	1.40	14.10	-	14.10	-	14.10		-	-	
Phosphoric Acid (furnace Process)	-	-	9.60	-	9.60	-	9.60	-	9.60	Yes	5.00	0.48	Waste heat recovery
Ammonia Phosphate	0.10	3.50	0.50	0.50	4.60	-	4.60	(2.20)	2.40	Yes	5.00	0.23	Drying system heat recovery
Superphosphates	0.10	0.90	0.10	0.10	1.20	-	1.20	-	1.20	Yes	5.00	0.06	Drying system heat recovery
TOTAL	**5.20**	**330.50**	**26.60**	**17.00**	**379.30**	**-**	**379.30**	**(86.10)**	**293.20**			**33.41**	
The Chlor-Alkali Industry													
Caustic Soda (Chlorine/Sodium Hydroxide) Mfg.	2.30	58.30	7.60	7.60	75.80	-	75.80	-	75.80	Yes	10.00	7.58	Use of CHP, heater flue gases
Soda Ash (Sodium Carbonate) Mfg.	2.30	59.60	7.70	7.70	77.30	-	77.30	-	77.30	Yes	10.00	7.73	Use of CHP, heater flue gases
TOTAL	**4.60**	**117.90**	**15.30**	**15.30**	**153.10**	**-**	**153.10**	**-**	**153.10**			15.31	
Industry Total	**31.90**	**1,209.5**	**115.0**	**99.40**	**1,455.8**	**5,080.4**	**6,536.2**	**(248.3)**	**6,090.5**			**94.10**	

Sources: *Energy and Environmental Profile of the U.S. Chemical Industry*, Energetics, Inc. 2000; *John Zinc Combustion Handbook*
Private communication with Dr. Richard Martin, Aztec Engineering, 2004.

Table B-4 Major Fired Heater Applications in the Chemical Industry

Chemical	Process	Heater Type	Firebox Temperature	Fired Heater Energy Intensity	Fired Heater Energy Requirement ('85)
			Deg. F.	Btu/unit	10^12 Btu/year
Benzene	Reformer extraction	Reboiler	700		64.8
Styrene	Ethylbenzene dehydrogenation	Steam superheater	1500 -1600		32.1
Vinyl chloride monomer	Ethylene dichloride cracking	Cracking furnace			12.6
p-Xylene	Xylene isomerization	Reactor-fired preheater			13
Dimethylterephalate	Reaction of p-Xylene and methanol	Preheater, hot-oil furnace	480-540		11.1
Butadiene	Butylene dehydrogenation	Preheater, reboiler	1100		2.6
Ethanol (synthetic)	Ethylene hydration	Preheater	750		1.3
Acetone	Various	Hot oil frunace			0.8
Ethylene - propylene	Thermal cracking	Pyrolysis furnace	1900-2300		337.9
Ammonia	Natural gas reforming	Steam hydrocarbon reformer	1500-1600		150.5
Methanol	Hydrocarbon reforming	Steam hydrocarbon	1000-2000		25.7

Sources: *Energy and Environmental Profile of the U.S. Chemical Industry*, Energetics, Inc. 2000; *John Zinc Combustion Handbook;* Private communication with Dr. Richard Martin, Aztec Engineering, 2004.

Table B-5 Forest Products: Steam Systems Detailed Table											
No.	Production Process	Steam Use Mbtu/ton of Pulp[1]	2000 Production M tons of Pulp[2]	Annual Steam Use Trillion Btu	Equipment Used[1,3]	Average % Efficiency[1,3]	Potential Heat Losses (10^12 Btu/yr)	Major Sources for Losses[1,3]	Possible Energy Recovery Methods[1,3]	Potential Savings %	Potential Savings 10^12 Btu/yr
1	Kraft Pulping	3.78	51.96	196.41	Steam heated batch/continuous digesters, pre-steamers	55	88	Waste steam	Recycling of waste heat, improved steam recovery, indirect heating	25	22
2	Sulfite Pulping	3.61	1.17	4.22	Steam heated batch digesters	55	2	Waste steam	Improved steam recovery, indirect heating	20	0
3	Thermo-mechanical Pulping	0.77	3.75	2.89	Pre-steamers	55	1	Waste steam	Low pressure steam recovery, mechanical vapor recompression, heat pumps	10	0
4	Semi-chemical Pulping	4.56	3.96	18.03	Digesters or pre-steamers	55	8	Waste steam	Waste heat recovery	20	2
5	Bleaching	3.7	37.60	139.13	Steam-heated bleaching towers/stages	60	56	Waste steam	Waste heat recycling, reduced bleaching stages	25	14
6	Chemical Recovery	3.78	57.09	215.78	Recovery boilers, superheaters, stripper, evaporators	60	86	Exit gases, radiation losses, waste steam	Falling film evaporation, steam recycling, concentrators	20	17
7	Pulp Drying	3.87	8.41	32.54	Dryer, condenser, thermocompressor	50	16	Exit gases		20	3
9	Paper drying (million tons of paper)	9.2	96.31	886.04	Drum dryers and Yankee dryers	48	461	Hot water, exit gases, waste steam	Direct fired dryers, alternative dryers (Condebelt), air heat recovery, waste heat recovery (mechanical vapor recompression, heat pumps)	30	138
	TOTAL			**1495.05**			**719**				**197**

[1] Lawrence Berkeley National Laboratory, *Opportunities to Improve Energy Efficiency and Reduce Greenhouse Gas Emissions in the U.S. Pulp and Paper Industry*. July 2000

[2] American Forest & Paper Association. 2002a. *Paper, Paperboard & Wood Pulp: 1998 Statistics, Data through 2001*

3 Other Sources: G.A. Smook, *Handbook for Pulp and Paper Technologists*, 1997; Christopher Biermann, *Handbook of Pulping and Papermaking*, 1996
A. Elaahi, H. Lowitt, *U.S. Pulp and Paper Industry: An Energy Perspective,* Energetics, Inc. 1988.

Table B-6. Forest Products: Fired Systems Detailed Table											
No.	Production Process	Average Energy Use 10^6 Btu/ton of pulp[1]	2001 U.S. Production 10^6 Short Tons	2001 Annual Energy Use 10^12 Btu/year	Equipment Used (Heat Addition)	Average (%) Efficiency of Fired System	Potential heat losses 10^12 Btu/year	Major Source of Losses	Possible Methods of Energy Recovery	Potential % Savings	Potential Savings (10^12 Btu/yr)
1	Kraft Chemical Recovery/Lime Mud Calcining [1]	2	52	103	Lime Kiln	37.00	65	Exit gases (evaporated water, combustion gases, carbon dioxide from calcination), radiation losses	Enhanced heat transfer become lime mud and combustion gases, lime product coolers for heating combustion air, flash dryers to predry mud	35	23
	TOTALS			**103**							**23**

[1] N. Martin, N. Anglani, D. Einstein, M. Khrushch, E. Worrell, an L.K. Price. Opportunities to Improve Energy Efficiency and Greenhouse Gas Emissions in the Pulp and Paper Industry, July 2000.
[2] American Forest & Paper Association (AF&PA), 2002 Statistics, Data Through 2001, Page 11
[3] U.S. Pulp and Paper Industry: An Energy Perspective, A. Elaahi and H.E. Lowitt, April 1988. Energetics, Inc. for Pacific Northwest National Laboratory.

Table B-7 Steam Systems - Food and Beverage

Wet Corn Milling (SIC 2046) Based on 1998 MECS Energy Data for Boiler Fuel

No.	Production Process	Total Energy Use Btu/lb	Steam Use Btu/lb[1]	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Equipment Used[1]	Average Efficiency[1,2]	Potential Heat Losses	Major Sources for Losses[1]	Possible Energy Recovery Methods[1]	Potential Savings[1] %	Potential Savings[1] 10^12 Btu/yr
1	Steeping, Steepwater evaporation, Germ Drying		2625		115	Rotary steam tube dryers, flash dryers	45	63.25	Waste steam, exit gases, radiative heat losses	Heat recovery from flue gas, blowdown steam recovery	25.0	15.8

Cane Sugar and Beet Sugar Processing and Refining (SIC 2061, 2062 and 2063) Based on MECS 1994 Energy Data for Boiler Fuel

No.	Production Process	Total Energy Use Btu/lb	Steam Use Btu/lb	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Equipment Used[2]	Average Efficiency[2]	Potential Heat Losses	Major Sources for Losses[2]	Possible Energy Recovery Methods	Potential Savings[3] %	Potential Savings[3] 10^12 Btu/yr
1	Solution and Refining				169.00	Evaporators, dryers, vacuum pans	45	92.95	Waste steam, exit gases	Heat recovery from flue gas, blowdown steam recovery	25.0	23.2

Meat Products (SIC 201)

No.	Production Process	Total Energy Use Btu/lb[3]	Steam Use Btu/lb[3]	2001 Production (Million lbs)[4]	Total Steam Energy (Trillion Btu)	Equipment Used[3,4]	Average Efficiency	Potential Heat Losses	Major Sources for Losses	Possible Energy Recovery Methods	Potential Savings[3] %	Potential Savings[3] 10^12 Btu/yr
1	Evisceration	383	333	19000	6.33	Steam Vacuum, Steam Pasteurization	50	3.1655	Waste steam, exit gases	Heat recovery	25.0	0.8

Table B-7 Steam Systems - Food and Beverage (continued)

Cheese Natural And Processed (SIC 2022)

No.	Production Process	Total Energy Use Btu/lb	Steam Use Btu/lb[5]	1995 Production (Million lbs)[5]	Total Steam Energy (Trillion Btu)	Equipment Used[5]	Average Efficiency	Potential Heat Losses	Major Sources for Losses	Possible Energy Recovery Methods	Potential Savings[3] %	Potential Savings[3] 10^12 Btu/yr
1	Whey Drying	2000	1020	6900	7.04	Feed System, Drying Chamber, Fluid Bed	50	3.519	Exit gases	Heat recovery from exit gases	25.0	0.9

Fats and Oils (SIC 2075)

No.	Production Process	Total Energy Use Btu/lb[3]	Steam Use Btu/lb[3]	1999 Production (Million lbs)[6]	Total Steam Energy (Trillion Btu)	Equipment Used[6]	Average Efficiency	Potential Heat Losses	Major Sources for Losses	Possible Energy Recovery Methods	Potential Savings[3] %	Potential Savings[3] 10^12 Btu/yr
1	Meal Drying	182	93	72515	7	Dryer	50	3.36544	Exit gases	Heat recovery from exit gases	25.0	0.8

Other Food Processes (baking, dairy processing,others) 1998 MECS Boiler Fuels

No.	Production Process	Total Energy Use Btu/lb	Steam Use Btu/lb	Production (Million lbs)	Total Steam Energy (Trillion Btu)	Equipment Used[2,3]	Average Efficiency	Potential Heat Losses	Major Sources for Losses	Possible Energy Recovery Methods	Potential Savings %	Potential Savings 10^12 Btu/yr
1	Miscellaneous				272	Steam Pasteurization, Ovens, Dryers	50	136	Waste steam, exit gases, radiative heat losses	Heat recovery, heat reduction	25.0	34.0
	TOTALS				**576.1**			**302.2**				**75.6**

Sources:
1 LBNL, Energy Efficiency Improvement and Cost Saving Opportunities for the Corn Wet Milling Industry, July 2003
2 Industrial Energy Data Book, Oak Ridge Associated Universities, 1988.
3 DOE, Office of Industrial Technologies, Industry Profiles Final Report: Energy Profiles for U.S. Industry, Prepared by Energetics Inc. 1990
4 Accountingweb, Industry Profiles Meat Products Manufacture 2011, http://www.accountingweb.com/cgi-bin/kasbrowse.cgi?action=detail&id=2553
5 1995 data. EPA Emission Factor Documentation for AP-42 Section 9.6.1 Natural and Processed Cheese, July 1997
6 EPA, Economic Impact Analysis for the Final Vegetable Oil Processing NESHAP, EPA-452/R-01-005, January 2001

Table B-8 Cement Manufacturing: Fired Systems Detailed Table

No.	Production Process	Thermal process [1]	Average energy use 10^6 Btu/ton of clinker [1,2]	2002 U.S. Production Short Tons [4]	Annual Energy Use 10^12 Btu/yr	Equipment Used [1,2,3]	Thermal Energy use 10^12 Btu/yr
1	Wet Process Long Kiln	Dry, preheat, calcine, and sinter slurry feed	6.0	24647428	148	Rotary kiln	148
2	Dry Process Long Kiln	Dry, preheat, calcine, and sinter feed	4.5	46450922	209	Rotary kiln (equipped with crosses, lifters, and trefoils for heat recovery)	209
3	Dry Process Preheater Kiln	Dry, preheat, calcine, and sinter feed	3.8	11849725	45	Rotary Kiln with Preheat Towers	45
4	Dry Process Precalciner Kiln	Dry, preheat, calcine, and sinter feed	3.3	11849725	39	Rotary Kiln with Precalciner Units	39
	TOTALS				**441**		**441**

Note: Production values are for 2002. Dry process kilns estimated to account for 74% of the total cement production.
Of dry processes, preheaters and precalciners account for 25% of all U.S. cement production.
Sources:
[1] EPA, Alternative Control Techniques Document_NOx Emissions From Cement Manufacturing, 1994
[2] Energy Efficiency and Carbon Dioxide Emissions Reductions Opportunities in the U.S. Cement Industry, N. Martin, E. Worrelland L. Price, LBL 1999
[3] The U.S. Cement Industry: An Energy Perspective, S.R. Venkateswaran, H.E. Lowitt, Energetics, Inc. 1988.
[4] DOE/EIA, Documentation for Emissions of Greenhouse Gases in the United States, 2002 January 2004 [USGS data]
[5] Colorado Energy Efficiency Guide: Recommendations By Sector - Cement Manufacturing, Www.coloradoefficiencyguide.com

Table B-8 Cement Manufacturing: Fired Systems Detailed Table (continued)

No.	Production Process	Average (%) Efficiency of Fired System[3] (to be verified)	Potential heat losses 10^12 Btu/yr	Major Source for Losses	Possible Methods of Energy Recovery	Potential % Savings [2,3,5]	Potential Savings (10^12 Btu/yr)
1	Wet Process Long Kiln	30.00%	104	Water evaporation, combustion, exhaust gases, radiative/convective losses	Combustion improvements, controls, preheat, semi-wet conversion, heat recovery in the clinker cooler, improved grate cooler	50	52
2	Dry Process Long Kiln	52.00%	100	Combustion, exhaust gases, radiative/convective losses	Combustion improvements, controls, preheat, heat recovery in the clinker cooler, improved grate cooler, heat recovery with cogeneration	25	25
3	Dry Process Preheater Kiln	68.00%	14	Combustion, exhaust gases, radiative/convective losses	Combustion improvements, controls, heat recovery in the clinker cooler, improved grate cooler	11	2
4	Dry Process Precalciner Kiln	71.00%	11	Combustion, exhaust gases, radiative/convective losses	Combustion improvements, controls, heat recovery in the clinker cooler, improved grate cooler	11	1
	TOTALS		**230**				**80**

Appendix C

Additional Data for Top Twenty Opportunities

Opportunity 1 Waste Heat Recovery From Gases and Liquids in Chemicals, Petroleum, and Forest Products

This opportunity area encompasses energy savings possible from waste heat recovery from gases and liquids (both high and low quality energy) in chemicals, petroleum refineries, and the forest products industry. Waste heat sources include waste steam (possibly contaminated), exhaust and flue gases, flares, hot water and radiation heat losses. The energy potential in these sources is considerable; energy content in waste streams above 75°F has been conservatively estimated to be nearly 7 quads.

Priority technology R&D areas include innovative energy recovery cycles, alternatives to shaft power, waste heat pumping and thermally activated technologies for low temperatures, waste heat boilers recovering corrosive heat streams, heat recovery from contaminated fluids, new heat recovery techniques, and improved energy transport and storage. Enabling R&D areas include separations such as hot gas cleanup and the dehydration of liquid waste streams, development of corrosion-resistant materials, innovative heat exchanger geometries, and development of innovative working fluids.

Energy Savings (TBtu)	Cost Savings (million $)
Pre-Process 0 **Post-Process 807** **TOTAL 807**	**TOTAL $2,154**

Methodology

Potential heat recovery from gases and liquids in **chemicals manufacture** was calculated for five chemical chains based on average waste heat recovery potentials found in common practice, which range from 2.5-10%, with most values around 5-10% (see Table 1.1). Waste heat recovery potentials were applied to energy use in these chains to yield energy savings of 94 Tbtu. This accounts for about 6.5% of energy used by these chains for steam and fired systems (94/1456 Tbtu). However, these chains only represent 42% of total energy use (3451 Tbtu) in chemicals manufacture for steam and fired systems. To capture the savings represented by the other 58% of energy use, the energy savings rate of 10% was applied to the remaining energy (1995 Tbtu) to estimate additional potential savings from waste heat recovery of ~200 Tbtu. Combined energy savings are 294 Tbtu.

Potential heat recovery in **petroleum refineries** was calculated separately for steam and fired systems. For fired systems, average efficiencies of 75-80% were applied to energy used in major unit operations to estimate potential energy losses (see Table 1.2 below). It was then assumed that between 20-45% of those losses could be captured, depending upon the process. This yielded energy savings of 357 Tbtu. For steam systems, an average efficiency of 40-55% was assumed for steam-using operations, with 20% recovery of the potential losses, except for atmospheric distillation, where a recovery value of 40% was applied (see Table 1.2). Energy savings using this approach came to 136 Tbtu. Combined savings for petroleum refining in this category amount to 493 Tbtu.

Potential heat recovery in the **forest products** industry was calculated for four major processes utilizing steam and fired systems (see Table 1.3). Average efficiencies of 40-45% were applied to energy use in these processes, followed by a potential10-25% recovery of energy losses in the form of waste energy from gases or liquids. Total energy savings from the four processes amount to 64 Tbtu. Combined energy savings for all three industries of 827.5 Tbtu are shown in Table 1.4.

For simplicity, cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% coal ($1.50/MMBtu) and 5% electricity ($0.0477/kWh). The remainder is assumed to be mostly waste fuels – no cost assigned). Boiler fuel mix is taken from the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Chemicals: *Energy and Environmental Profile of the U.S. Chemical Industry*, Energetics, Inc. 2000. *John Zinc Combustion Handbook*; Personal communication with Dr. Richard Martin, Aztec Engineering, 2004 and Arvind Thedki, E3M, Inc., 2004.

Petroleum: *Steam Systems Opportunity Assessment for the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries*, Resource Dynamics Corp. 2000; *Improving Steam Systems Performance, A Sourcebook for Industry,* U.S. DOE; *Energy and Environmental Profile of the U.S. Petroleum Refining Industry*, Energetics, Inc. 1998; Personal communication with Dr. Richard Martin, Aztec Engineering, 2004 and Arvind Thedki, E3M, Inc., 2004.

Forest Products:
Lawrence Berkeley National Laboratory, *Opportunities to Improve Energy Efficiency and Reduce Greenhouse Gas Emissions in the U.S. Pulp and Paper Industry*. July 2000; American Forest & Paper Association. 2002a. *Paper, Paperboard & Wood Pulp: 1998 Statistics, Data through 2001;* G.A. Smook, *Handbook for Pulp and Paper Technologists*, 1997; Christopher Biermann, *Handbook of Pulping and Papermaking*, 1996; A. Elaahi, H. Lowitt, *U.S. Pulp and Paper Industry: An Energy Perspective,* Energetics, Inc. 1988.

General: *Characterization of Industrial Process Waste Heat and Input Streams*, PNNL, May 1984, for U.S. DOE.

Opportunity 1 Waste Heat Recovery From Gases and Liquids in Chemicals, Petroleum, and Forest Products: Supporting Data Tables

Table 1.1 Chemicals Manufacture	Energy Savings 10^12 Btu
The Ethylene Chain	**25.6**
Ethylene	18.63
Polyethlene - 1997	0.41
Poly Vinyl Chloride	0.70
Ethylene Oxide	0.44
Ethylene Glycol	0.43
Polystyrene	4.88
	5.27
The Propylene Chain	**5.27**
Propylene	3.19
Polypropylene - 1997	0.13
Propylene Oxide - 1997	0.41
Acrylonitrile	0.27
Acrylic Acid	0.84
Acrylic Fiber	0.43
The BTX Chain (Benzene, Toluene, Xylene)	**15.3**
BTX	3.40
Benzene	0.31
Ethylbenzene	0.95
Styrene	8.24
Polystyrene	1.03
Cumene	0.20
Terephthalic Acid	0.59
Nylon 6.6	0.56
Nylon 6	0.20
Agricultural Chemicals - Fertilizers	**32.80**
Urea	0.22
Phosphoric Acid (furnace Process)	0.48
Ammonia	31.90
	15.31
Caustic Soda (Chlorine/Sodium Hydroxide)	7.58
Soda Ash (Sodium Carbonate)	7.73
Total Five Chains	**94.28**
Estimated Additional Savings	**200**
TOTAL Industry	**294.28**

Table 1.2 Petroleum Fired Systems	Energy Savings 10^12 Btu
Atmospheric Distillation	96.24
Vacuum Distillation	29.85
Solvent Deasphalting	2.6
Delayed Coking	7
Fluid Coking	1.42
Flexcoking	1.34
Visbreaking	0.26
Fluid Catalytic Cracking	20
Catalytic Reforming	47.04
Alkylation	29.8
Ethers Manufacture	3.34
Isomerization	4
Catalytic Hydrotreating	70.25
Catalytic Hydrocracking	24.7
Lube Oil Mfg	19.16
	357.0
Petroleum Steam Systems	
Atmospheric Distillation	60
Vacuum Distillation	11
Fluid Catalytic Cracking	0
Catalytic Hydrocracking	4
Catalytic Hydrotreating	25
Catalytic Reforming	14
Alkylation	17
Isomers	5
	136.0
	493.0

Table 1.3 Forest Products Steam Systems	Energy Savings 10^12 Btu
Kraft Pulping	22
Semi Chem Pulping	2
Chemical Recovery	17
Lime Reburning	**23**
Total Forest Products	**64**

Table 1.4 Combined Energy Savings	Energy Savings 10^12 Btu
Chemicals	294
Petroleum	493
Forest Products	64
TOTAL All Industries	**851**

Opportunity 2 Combined Heat and Power

This opportunity area encompasses potential energy savings accruing from the increased use of combined heat and power (CHP, or cogeneration) systems in the industrial sector. Cogeneration systems produce both electricity and steam, which increases the thermal efficiency of the system when compared with utility power generating systems (from thermal efficiency of about 30-40% to as much as 75% or more for cogeneration). Energy savings accrue from a reduction in the energy losses associated with power generation inefficiencies. Net electricity generated by the manufacturing sector in 1998 amounted to nearly 500 Tbtu, with 428 Tbtu generated through cogenerating systems. Total purchased electricity for manufacturing amounted to 3.1 quads in 1998; the generation and transmission losses associated with manufacturing purchases were over 6.4 quads for that year. Onsite power generation currently accounts for only about 14% of manufacturing electricity demand.

While any power-consuming industry can potentially install onsite cogeneration units, the industry must be able to use or export the steam that is produced. In addition, if the industry produces excess electricity, it can be exported to the local grid (if permitted by local regulation), providing an additional revenue stream to offset energy costs. While this opportunity specifically targets the forest products, chemicals, food, metals, and machinery industries, other steam-using industries such as textiles manufacture are potential but smaller targets for increased use of CHP. Advanced cogeneration technologies include systems made more efficient through advances in turbine designs (microturbines, reciprocating gas turbines) or other innovations (e.g., advanced materials). Such technologies can also provide "trigeneration" capability, i.e., generation of power, heating and cooling.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**634**	
Post-Process	**0**	**TOTAL $2,000**
TOTAL	**634**	

Methodology

Energy savings are based on the potential adoption of 56 GW of new CHP capacity by 2020 (total predicted potential capacity is 88 GW). These additions were assumed to be installed in four industries: pulp and paper (26 GW), chemicals (9 GW), food (8 GW), machinery (6 GW), and metals (7 GW). Energy consumption was estimated by first calculating the energy required to produce electricity at the heat rate of 10,500 Btu/kWh (typical of purchased electricity generated at utilities) and at the more efficient heat rate of 4500 Btu/kWh (typical for cogeneration facilities). Energy savings were then determined by calculating the reduction in energy losses achieved by producing electricity at the more efficient heat rate. Energy loss reductions are taken offsite, at the utility that would have been producing the purchased power. New capacity was assumed to be operating at 67% of capacity, or about 5900 hours per year, which yields an estimated 106 billion kWh. Fuel required by the utility to produce 106 billion kWh was estimated to be about 1110 Tbtu (750 Tbtu losses); for the industrial cogenerator, the same amount of kWh would require 476 Tbtu (115 Tbtu losses). The reduction in losses (and the potential opportunity for energy savings) was calculated to be 635 Tbtu.

For simplicity, cost savings are based on a fuel mix of 40% natural gas ($5.65/MMBtu) and 60% coal ($1.50/MMBtu). Average fuel prices were taken from the EIA Monthly Energy Review June 2004, and EIA Petroleum Marketing Monthly June 2004.

References

"Combined Heat And Power: Capturing Wasted Energy, " R. Neal Elliott and Mark Spurr. American Council for an Energy Efficiency Economy (ACEEE). May 1999. Additional communication with the authors in June 2004.

National CHP Roadmap, U.S. Combined Heat and Power Association, with the U.S. Department of Energy and U.S. Environmental Protection Agency, March 2001 and updates.

CHP Market Assessment, Onsite Sycom Energy Corporation, for the U.S. Department of Energy, 2000.

Hendrick G. van Oss, *Cement 2001*, U.S. Geological Survey.

N Martin, E. Worrell, and L. Price, *Energy Efficiency and Carbon Dioxide Emissions Reduction Opportunities in the U.S. Cement Industry*, Lawrence Berkeley National Laboratory, 1999.

Manufacturing Energy Consumption Survey, 1998, Energy Information Administration, U.S. Department of Energy, 2001.

Opportunity 2 Combined Heat and Power Systems: Supporting Data Tables

Table 2.1 Industrial Onsite Power Generation				
	Onsite Electricity			
Industry	Million kWh	Trillion Btu	% of Electricity Demand	Future Potential for CHP (MegaWatts)
Pulp & Paper	55,000	188	37	26,198
Cement	560	2	4	204
Steel	5,275	18	10	6,941 (primary metals)
Chemicals	45,721	156	21	9,440
Petroleum Refining	15,240	52	30	6,789 (refining plus coal products)
Food	6,155	21	8	8,086

Sources:

CHP Market Assessment, Onsite Sycom Energy Corporation, for the U.S. Department of Energy, 2000.

Hendrick G. van Oss, *Cement 2001*, U.S. Geological Survey.

Opportunity 3 Advanced Industrial Boilers

This opportunity area encompasses the development and adoption of more efficient boilers, such as the "Super Boiler" now under development, and other revolutionary boiler and combustion system innovations. While many industry steam users could benefit from advanced boilers, most of the impact will be achieved in the heavy steam-using industries such as chemicals, forest products, petroleum refining, food processing, and textiles.

About 6 quads of energy are currently consumed in industrial boilers every year (manufacturing and mining). Based on 80% conversion efficiency (an average value – some boilers have efficiencies as low as 60%, depending on age and fuel type), the energy losses associated with conversion of water to steam in boilers is about 1.2 quads annually.

The conversion efficiency of industrial boilers can be improved by boiler innovations such as high intensity heat transfer, high efficiency, low emission burners, smart control systems, efficient preheating, flame radiation and other enhancements. The Super Boiler technology, for example, combines a number of innovations in one system to achieve optimum efficiency.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**400**	
Post-Process	**0**	**TOTAL $1,090**
TOTAL	**400**	

Methodology

Energy savings are based on an energy and environmental analysis performed for the Super Boiler technology using the ITP Impacts Projection Model, and extrapolated to larger market segments. This analytical model projects energy benefits for a span of 30 years, based on escalation of current markets, selected market penetration curves, and user inputs of energy impacts relative to conventional technology. A conservative scenario for the Super Boiler was assumed to be a potential accessible market of 35%, with 70% of that market penetrated by 2025. This scenario yields a projected energy savings of about 200TBtu in 2025 (see Table 3.1).

Since Super Boiler technology is assumed to impact a limited market segment (about ½ of industrial boilers of 10 MMBtu/h capacity or larger, and about 40% of total firing capacity of these boilers), it was assumed that similar results could be achieved with other technology advances in at least 80% of the total boiler market. Extrapolating results to this larger market yielded roughly an additional 200 TBtu of potential energy savings by 2025. Total energy savings were thus assumed to be about 400 TBtu, based on long-term market penetration of advanced boiler systems over 20 years (see Table 3.2).

For simplicity, cost savings are based on a fuel mix of 41% natural gas ($5.65/MMBtu), 12% coal ($1.50/MMBtu), 5% fuel oils ($4.7/MMBtu) and 42% other (mostly waste fuels – no cost assigned). Boiler fuel mix is taken from the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004, and EIA Petroleum Marketing Monthly June 2004.

References

Engineering and Economic Analysis Tool: "Super Boilers", Energetics, Inc. for the U.S. Department of Energy, Government Performance Reporting Act (GPRA) FY 2006 submissions, June 2004.

Energy Use, Loss and Opportunities Analysis, Energetics, Inc. and E3M, Inc. for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, U.S. Department of Energy, 2001.

Opportunity 3 Advanced Industrial Boilers: Supporting Data Tables

Table 3.1 Potential Energy Impacts Based Solely on Super Boiler Technology				
Impact By Year	2010	2015	2020	2025
ANNUAL SAVINGS				
Energy Metrics				
Total primary energy displaced (trillion Btu)	3.57	30.12	130.03	186.86
Direct electricity displaced (billion kWh)	0.00	0.00	0.00	0.00
Direct natural gas displaced (bcf)	3.48	29.33	126.61	181.94
Direct petroleum displaced (million barrels)	0.00	0.00	0.00	0.00
Direct coal displaced (million short tons)	0.00	0.00	0.00	0.00

Table 3.2 Potential Energy Impacts Based on 80% of Boiler Population				
Impact By Year	2010	2015	2020	2025
ANNUAL SAVINGS				
Energy Metrics				
Total primary energy displaced (trillion Btu)	8.17	68.85	297.22	427.10
Direct electricity displaced (billion kWh)	0.00	0.00	0.00	0.00
Direct natural gas displaced (bcf)	7.95	67.04	289.40	415.87
Direct petroleum displaced (million barrels)	0.00	0.00	0.00	0.00
Direct coal displaced (million short tons)	0.00	0.00	0.00	0.00

Opportunity 4 Heat Recovery From Drying Processes

This opportunity represents energy savings from the recovery of waste heat from relatively inefficient drying processes in a number of industries, including chemicals, forest products, and food processing. Improvements are possible in processes such as paper drying, concentration, evaporation, and other processes where water is removed. This opportunity would also encompass process operations such as paint drying and curing, which are used in assembly and fabrication industries such as heavy machinery, fabricated metals, and transportation equipment.

Energy used for drying processes in just two industries (pulp and paper and food processing) is over 1 quad annually, and most drying processes are inherently inefficient. Technologies for energy recovery could potentially include direct-fired dryers, alternative-fuel dryers, air heat recovery, mechanical vapor recompression, and advanced heat pumps. Heat could potentially be recovered from exhaust or flue gases and saturated vapors that are vented to the atmosphere.

Energy Savings (TBtu)		Cost Savings (million $)	
Pre-Process	**160**		
Post-Process	**217**	**TOTAL**	**$1,240**
TOTAL	**377**		

Methodology

Energy savings are derived from pre-process and post-process drying operations in the chemicals, forest products and food processing industries. Pre-process drying losses are based on 10% recovery of steam losses in steam-driven drying systems in these three industries, which encompass losses from generation, distribution and conversion of steam to useful work. Post-process drying heat recovery is based on 5-15% recovery of heat downstream of the drying process, with the bulk of energy loss recovery coming from paper drying and food processing (see Table 4.1).

For simplicity, cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% electricity ($0.0477/kWh) and 49% other (mostly waste fuels – no cost assigned). This is based on the fuels used for process heating according to the 1998 MECS. Drying is not specifically separated out in the MECS and better estimates of fuel distribution for drying are only available for some industries. Drying systems can be direct-fuel fired, steam-driven, or powered by electricity. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunity Analysis, Energetics, Inc. and E3M, Incorporated, for the U.S. Department of Energy, November 2004.

Table 4.1 Potential Downstream Energy Recovery in Drying Processes

Sector	**Pre-Process Steam Losses 10^12 Btu**	**Pre-Process Energy Savings 10^12 Btu**	**Post-Process Energy Savings 10^12 Btu**
Chemicals	748	**74.8**	**0.29**
Ammonia Phosphate			0.23
Superphosphates			0.06
Forest Products	1143	**114.3**	**141**
Pulp Drying			3
Paper Drying			138
Food Processing	277	**27.7**	**76**
TOTAL		**216.8**	**217.29**

Opportunity 5 Steam Best Practices

This opportunity area covers the application of best operating and maintenance practices to steam generation, distribution and recovery systems (excluding development of advanced boilers) prior to steam delivery to the process. Significant energy is lost throughout steam systems during generation, distribution, and conversion of steam to useful work. Overall, these losses have been estimated to be as much as 55% of the energy that is input to the steam system.

Current fuel inputs to steam systems amount to over 6 quads annually. Losses associated with steam systems, from generation to distribution and conversion, amount to over 2.8 quads, representing a significant opportunity for efficiency improvement.

Best practices includes a combination of improved maintenance and upkeep (e.g., leaks in pipes, traps, vents); increased use of energy management tools to optimize steam system operation (vent steam, condensate recovery, combustion efficiency, steam distribution, feed water heat exchange); and incremental equipment improvements (e.g., insulation).

Energy Savings (TBtu)		Cost Savings (million $)	
Pre-Process	**310**		
Post-Process	**0**	**TOTAL**	**$850**
TOTAL	**310**		

Methodology

Energy savings are based on a 5% reduction in energy inputs to steam systems across the entire manufacturing and mining sector.

For simplicity, cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% electricity ($0.0477/kWh), 10% coal ($1.50/MMBtu) and 39% other (mostly waste fuels – no cost assigned). This is based on boiler fuel inputs according to the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc. and E3M, Inc for the U.S. Department of Energy, November 2004.

Opportunity 6   Pump System Optimization

This opportunity area involves the optimization of motor-driven pump systems that are used throughout the industrial sector. Pumps are inherently inefficient (about 40% of energy inputs are lost in conversion), and are often improperly sized or utilized. Pump system optimization can be achieved, for example, by identifying systems that are inefficiently configured for the application (e.g., continuous pumping for batch operations, over-sized), upgrading old or high-maintenance systems, and identifying damaged pumps.

Optimization of pumping systems can have significant energy impacts. These systems currently account for about 25% of motor drive energy use in the manufacturing sector, or about 600 Tbtu (not including offsite losses incurred during generation of purchased electricity at the utility).

Most pump systems are driven by electricity, which is primarily purchased from outside utilities. Consequently, pump systems represent a unique opportunity to reduce energy losses both within and outside the plant boundary. Reducing electricity demand for pumping in the plant translates into less purchased electricity, which is typically generated at utilities with relatively inefficient power generation systems (efficiency of electricity generation at utilities ranges from 25-45%).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**302* (98)**	
Post-Process	**0**	**TOTAL $2,000**
TOTAL	**302* (98)**	

Methodology

Energy savings are based on energy reduction potentials derived in a recent survey conducted by Xenergy in 1998 for the U.S. manufacturing sector. The conservative, lower range of energy savings was assumed for this opportunity (see Table 6.1), and amounts to 98 TBtu. Additional energy savings were estimated by calculating the amount of offsite energy losses associated with reduced purchased electricity for pumping, assuming all pumping systems were power-driven. A conversion factor of 10,500 Btu/kWh was assumed for offsite utility losses, which amounted to 204 Tbtu.

Cost savings are based on avoided electricity costs ($0.0477/kWh) for the plant. Average electricity price was taken from the EIA Monthly Energy Review June 2004.

References

U.S. Industrial Motor Systems Market Opportunities Assessment, Xenergy for Oak Ridge National Laboratory and the U.S. Department of Energy, 1998.

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Notes

*Includes losses associated with offsite generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh. Number in parenthesis does not include offsite losses.

Table 6.1 Estimated Energy Savings for Pumping Systems

	Billion KiloWatt-Hours	Trillion Btu (Net)
Mid-Range Energy Savings	28.7	97.9
High-Range Energy Savings	38.4	131.0

Source: *U.S. Industrial Motor Systems Market Opportunities Assessment*, Xenergy for Oak Ridge National Laboratory and the U.S. Department of Energy, 1998.

Opportunity 7 Energy System Integration

This opportunity area encompasses energy savings from energy system integration, which involves a diversity of methods for integrating energy sources and sinks, integration of energy requirements to minimize the cost of operations, and part-load cycling and load management. The objective is to optimize plant-wide energy utilization by identifying and developing synergies among energy flows in process design and operation. Heat integration and CHP are key facets of energy systems integration. Technologies to promote and implement energy system integration would include tools to perform energy balances across the plant to integrate energy use and cost; pinch opportunity identification tools; tariff calculators to assist in minimizing purchases from utilities; and tools to more effectively deal with part-load cycling and load management. Tools should be user-friendly, and motivate end-users to pursue outside expertise for in-depth cost and benefits analysis and systems engineering. A challenge will be to develop tools that are suitable for a diverse industrial sector.

This opportunity potentially impacts all energy inputs used for heat and power in the manufacturing sector, which amount to nearly 18 quads each year. The total pre-process energy losses (generation, distribution, and conversion) associated with manufacturing equal about 5.9 quads annually.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**110**	
Post-Process	**150**	**TOTAL $860**
TOTAL	**260**	

Methodology

Energy savings are first based on a reduction in pre-process energy losses in steam systems, power generation, and process heating (fired systems) for six industrial sectors: petroleum refining, chemicals, forest products, iron and steel, food processing, and aluminum manufacture. This includes generation, distribution, and conversion (pre-process) losses. A conservative across-the-board reduction of 3% was assumed to be achievable due to the implementation of enhanced energy system integration, which yielded energy savings of 110 TBtu.

Post-process loss reductions were estimated to be 2% of steam and other fuels delivered to processes (2% of about 7.5 quads) in five industries (all the above, excluding aluminum). These reductions amounted to 150 Tbtu.

For simplicity, cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% electricity ($0.0477/kWh) and 49% other (mostly waste fuels – no cost assigned). This is based on a composite of the fuels used for steam and process heating according to the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Table 7.1 Pre-Process Losses Considered for Energy Systems Integration

	Steam System Losses*	Fired System Distribution Losses	Fired System Conversion Losses	Total Pre-Process Losses
Petroleum Refining	484	68	312	864
Chemicals	748	38	172	958
Forest Products	1143	30	7	1180
Iron and Steel	44	42	199	285
Food Processing	277	10	40	327
Aluminum	19	5	30	54

Opportunity 8 Improved Process Heating/Heat Transfer Systems in Non-Metals Industries

This opportunity area encompasses potential improvements to process heaters (i.e., fired systems) and supporting heat transfer systems (boilers excluded) in the non-metal industries, specifically chemicals and petroleum. Typical fired systems in these industries include pyrolysis furnaces, preheat furnaces, evaporators, kettle boilers (reboilers) and others. Energy expended in fired systems in these two industries currently amounts to 3.4 quads annually.

Technologies might include improved materials, innovative heat exchanger designs and geometries, better heat transport configurations, predictive heat exchanger design, and other process heating enhancements. While the opportunity is evaluated specifically for two industries, advances in process heating and heat transfer systems could be extended to numerous other non-metal sectors, such as food processing, forest products, textiles, and plastics and rubber.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**121**	
Post-Process	**139**	**TOTAL $860**
TOTAL	**260**	

Methodology

Pre-process energy savings are based on a 25% reduction in pre-process energy conversion losses only in fired systems in the two industries analyzed (see Table 8.1). Post-process losses are based on a 5% reduction in the final energy delivered to fired systems in these two industries (taking into account generation, distribution and conversion losses.

For simplicity, cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% electricity ($0.0477/kWh) and 49% other (mostly waste fuels – no cost assigned). This is based on a composite of the fuels used for process heating according to the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Table 8.1 Pre-Process Losses and Energy Delivered to Fired Systems (Tbtu)

	Generation Losses	Distribution Losses	Conversion Losses	Total Pre-Process Losses	Delivered to Process
Petroleum Refining	0	68	312	380	1776
Chemicals	0	38	172	210	997

Opportunity 9 Energy Efficient Motors and Rewind Practices

This opportunity area involves the adoption of high efficiency motor systems and improving motor rewind practices. Every industrial sector makes use of motor-driven equipment, and in many cases the efficiency of motor use can be enhanced by upgrading the motor (e.g., variable speed drives, high efficiency motor) or through rewinding. Motor-driven equipment currently accounts for over 2.3 quads of energy use throughout manufacturing and mining.

Motors represent a unique opportunity to reduce energy losses both within and outside the plant boundary. Reducing motor electricity demand translates into less purchased electricity, which is typically generated at utilities with relatively inefficient power generation systems (efficiency of electricity generation at utilities ranges from 25-45%).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**258* (84)**	**TOTAL $1,175**
Post-Process	**0**	
TOTAL	**258* (84)**	

Methodology

Energy savings are based on energy reduction potentials derived in a recent survey conducted by Xenergy in 1998 for the U.S. manufacturing sector. The conservative, lower range of energy savings was assumed for this opportunity and amounts to 84 TBtu. Additional energy savings were estimated by calculating the amount of offsite energy losses associated with the reduced purchased electricity for more energy efficient motors, assuming all are power-driven. A conversion factor of 10,500 Btu/kWh was assumed for offsite utility losses, which amounted to 174 Tbtu.

Cost savings are based on avoided electricity costs ($0.0477/kWh) for the plant. Average electricity price was taken from the EIA Monthly Energy Review June 2004.

References

U.S. Industrial Motor Systems Market Opportunities Assessment, Xenergy for Oak Ridge National Laboratory and the U.S. Department of Energy, 1998.

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Notes

*Includes losses associated with offsite generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh. Number in parenthesis does not include offsite losses.

Opportunity 10 Waste Heat Recovery From Gases In Metals and Non-Metallic Minerals Manufacture

This opportunity involves the recovery of waste heat from gases generated in metals and non-metallic minerals manufacturing (excluding calcining, which is covered in Opportunity 18). Exit gases from processes used to manufacture metals and other materials often have substantial embodied energy, but cannot be cost-effectively captured as an energy source. New technologies are needed to recover waste heat from exit gases, especially those that are corrosive or laden with contaminants.

Technologies could include enhanced heating system to improve quality and utility of exit gases (secondary heating, destruction of selected chemical species), integration of heating and heat recovery (including transport), and feedback systems to optimize performance. Supporting technologies such as hot gas cleanup and corrosion-resistant materials are also included. While the energy savings for this opportunity have been determined only for iron and steel and cement, these technologies could potentially be extended to a number of industries, such as lime and soda ash manufacture, coal gasification, and others where hot contaminated, or corrosive gases are an issue.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**0**	
Post-Process	**235**	**TOTAL $1,230**
TOTAL	**235**	

Methodology

Savings are based on a recent analysis of iron and steel and cement (see Table 10.1). This analysis assumes an average percent of waste heat recovery that could be possible (10-20%), based on consultation with various industry experts. A percentage of the flue gases from cement calcining are included here. Because of potential overlaps, the remaining potential energy savings for cement calcining are covered under opportunities specific to calcining (Opportunity 18).

For simplicity, cost savings are based on a fuel mix of 80% natural gas ($5.65/MMBtu) and 20% coal ($1.50/MMBtu). Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Table 10.1 Recovery of Waste Heat from Exit Gases from Metals/Non-Metallics

	Energy Savings 10^12 Btu
Iron and Steel	
Coke Making	4
BF Iron Making	97
EAF Steelmaking	59
Tunnel Furnace	4
Slab Reheat Furnace	31
Steel Subtotal	**195**
Cement	
Calcining Flue Gases	**40**
TOTAL	**235**

Opportunity 11 Energy Source Flexibility

This opportunity area encompasses covers energy source flexibility, which is defined as finding new or alternative sources to meet energy requirements for manufacturing processes. Alternatives should be more energy efficient and cost-effective when compared with conventional technology, and should be environmentally sound or exhibit improved environmental performance. In some cases emerging or existing technology can be reconfigured to provide alternatives; in other cases, research, development and demonstration of entirely new concepts will be required.

Energy source flexibility can impact a significant portion of energy use. Total manufacturing energy consumption for steam generation and fired systems currently amounts to nearly 14 quads annually.

Technology options include innovations such as microwaves or heat-activated power; the substitution of steam for direct heat or vice versa; CHP as a direct power source; small, cost-effective modular energy systems (e.g., chillers); steam applied directly to mechanical drives; and alternative-fuel-fired systems (e.g., advanced burners for combustion of animal products, ethers, other waste fuels).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**119**	
Post-Process	**75**	**TOTAL $655**
TOTAL	**194**	

Methodology

Pre-process energy savings are based on a reduction of 5% of steam system pre-process losses in major steam using industries (petroleum refining, chemicals and forest products), and amount to 119 Tbtu. The baseline steam losses for these industries are 484 Tbtu, 748 Tbtu, and 1143 Tbtu, respectively. Post-process energy savings (downstream of the process) are based on a prior analysis (see Table 11.1) that encompasses four industries – chemicals, petroleum refining, forest products, and iron and steel. In ammonia sulfate, manufacture, for example, savings were estimated to be 0.34 Tbtu, based on typical conversion efficiencies and replacement of steam with an alternative energy source. Details of this analysis can be found in the *Energy Use, Loss and Opportunities Analysis*, cited below.

Cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% electricity ($0.0477/kWh), 5% coal ($1.50/MMBtu) and 49% other (mostly waste fuels – no cost assigned). This is based on a composite of the fuels used for process heating according to the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Table 11.1 Potential Energy Recovery Achieved Through Energy Source Flexibility: Post-Process

	Energy Savings 10^12 Btu
Chemicals	
Nitric Acid Mfg	0.18
Ammonia Sulfate	0.34
Subtotal	0.52
Petroleum	
Delayed Coking	7
Forest Products	
Bleaching	14
Iron and Steel	
10% Loss Reduction	53
by energy redirection	
TOTAL	**74.52**

Opportunity 12 Improved Sensors, Controls, and Automation

This opportunity area is a broad category for optimizing energy through the use of improved sensors, controls, and automation. Research is needed to develop improved sensors and controls for process optimization. The goal is to meet product specifications while minimizing energy use and cost, and ultimately achieve reductions in energy requirements. Automation and robotics could also play a role in energy optimization in some industrial processes.

Technologies include remote measurement of temperature and pressure in harsh environments, direct measurement of product specification parameters, and predictive models for on-line controls. Effective optimization of process heater operations and innovations that enable automation of process heaters are also represented in this category, including those that better control or reduce environmental emissions (e.g., NOX).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**39**	
Post-Process	**152**	**TOTAL $630**
TOTAL	**191**	

Methodology

Pre-process energy savings are based on a reduction of 1% of pre-process losses in chemicals, petroleum, forest products, iron and steel, food, foundries, aluminum and cement (see Table 12.1.)

End-of-process energy savings are based on a recent study which identified losses and target opportunities for six selected industries (chemicals, petroleum, iron and steel, forest products, food processing, and cement (see reference below, Energetics 2004). The savings are based on a 5% reduction in the identified losses, assumed to be achieved through improved sensor and control systems and ultimate optimization of steam and fired systems.

For simplicity, cost savings are based on a fuel mix of 46% natural gas ($5.65/MMBtu), 5% electricity ($0.0477/kWh) and 49% other (mostly waste fuels – no cost assigned). This is based on a composite of the fuels used for process heating according to the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Table 12.1 Pre-Process Losses Considered for Improved Sensors and Controls

	Steam System Losses*	Fired System Distribution Losses	Fired System Conversion Losses	Total Pre-Process Losses
Petroleum Refining	484	68	312	864
Chemicals	748	38	172	958
Forest Products	1143	30	7	1180
Iron and Steel	44	42	199	285
Food Processing	277	10	40	327
Cement	0.4	9	44	53
Aluminum	19	5	30	54
Foundries	10	4	22	36

*Includes steam generation, transport through distribution systems, and pre-process conversion to useful work.

Opportunity 13 Improved Process Heating/Heat Transfer for Metals Melting, Heating and Annealing

This opportunity area covers potential improvements to process heaters (fired systems) and heat transfer systems in the metal and non-metallic mineral industries (analogous to Opportunity 8 for chemicals and petroleum). Process heating systems represent a large share of energy use and production costs in the metals and non-metallic minerals industries (nearly 2 quads in iron and steel, aluminum, foundries, and fabricated metals). The competitiveness of these industries could be enhanced by optimizing productivity (inputs, reliability, maintenance, product output) and minimizing the energy intensity (Btu/lb of material processed) of process heating systems. The overall goal is to improve thermal efficiency and maximize heat transfer (not necessarily reduce waste heat).

Technology options include innovative heat exchanger designs and geometries, better heat transfer (faster heating, faster throughput), improved productivity via reduction in product waste, cascade heating techniques, switching from batch to continuous furnace operation, rapid heat treating, metal heating, and melting technologies, hybrid heating systems, and other process heating enhancements.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**63**	
Post-Process	**127**	**TOTAL $915**
TOTAL	**190**	

Methodology

Pre-process energy savings are based on 25% reduction in pre-process energy conversion losses in fired systems in three industries – iron and steel, aluminum, and metalcasting (based on a previous energy footprint analysis – see references). Post-process energy savings are based on a 5-10% reduction in post-process losses in fired systems in the industries analyzed (see Table 13.1).

For simplicity, cost savings are based on a fuel mix of 80% natural gas ($5.65/MMBtu) and 20% coal ($1.50/MMBtu). This is based on a composite of the fuels used for process heating according to the 1998 MECS. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Footprints, Energetics, Inc for the U.S. Department of Energy, November 2003.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Table 13.1 Potential Energy Savings for Fired Systems

	Conversion Losses	Pre-Process Potential Savings (25%)	Energy Delivered to Process	Post-Process Potential Savings (5-10%)
Iron and Steel	199	50	1131	113
Aluminum	29	7	272	14
Foundries	22	6	125	-
TOTAL	250	63	1403	127

Opportunity 14 Compressed Air System Optimization

This opportunity area involves the optimization of motor-driven compressed air systems. Compressors are inherently inefficient (about 80-90% of energy inputs are lost in conversion to useful work). Compressor system optimization can be achieved, for example, by identifying systems that are leaking, poorly configured for the end-use, and by reducing system air pressure or reducing run times.

Optimization of compressed air systems can have significant energy impacts. These systems currently account for about 15-16% of motor drive energy use in the manufacturing sector, or over 300 Tbtu (not including offsite losses incurred during generation of purchased electricity at the utility).

Compressors are driven by electricity, which is primarily purchased from outside utilities. Consequently, compressor systems represent a unique opportunity to reduce energy losses both within and outside the plant boundary. Reducing electricity demand for compressors in the plant translates into less purchased electricity, which is typically generated at utilities with relatively inefficient power generation systems (efficiency of electricity generation at utilities ranges from 25-45%).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**163* (53)**	
Post-Process	**0**	**TOTAL $740**
TOTAL	**163* (53)**	

Methodology

Energy savings are based on energy reduction potentials derived in a survey conducted by Xenergy in 1998 for the U.S. manufacturing sector. The conservative, lower range of energy savings was assumed for this opportunity (see Table 14.1), and amounts to 53 TBtu. Additional energy savings were estimated by calculating the amount of offsite energy losses associated with reduced purchased electricity for compressors. A conversion factor of 10,500 Btu/kWh was assumed for offsite utility losses, which amounted to 110 Tbtu.

Cost savings are based on avoided electricity costs ($0.0477/kWh) for the plant. Average electricity price was taken from the EIA Monthly Energy Review June 2004.

References

U.S. Industrial Motor Systems Market Opportunities Assessment, Xenergy for Oak Ridge National Laboratory and the U.S. Department of Energy, 1998.

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Notes

*Includes losses associated with offsite generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh. Number in parenthesis does not include offsite losses.

Table 14.1 Estimated Energy Savings for Pumping Systems

	Billion KiloWatt-Hours	Trillion Btu (Net)
Mid-Range Energy Savings	15.5	52.9
High-Range Energy Savings	20.0	68.2

Source: *U.S. Industrial Motor Systems Market Opportunities Assessment*, Xenergy for Oak Ridge National Laboratory and the U.S. Department of Energy, 1998.

Opportunity 15 Optimized Materials Processing

This opportunity area involves the optimization of motor-driven material processing systems (e.g., mixers, grinders, crushers) that are used throughout the industrial sector. These systems are very inefficient in the conversion of energy to usable work (as much as 80-90% of energy inputs are lost in conversion). Optimization of these systems could be achieved through innovations in equipment, better integration of equipment and end-use, implementation of continuous versus batch operations, upgrading old or high-maintenance systems, and identifying damaged systems.

Optimization of materials processing systems can have significant energy impacts. These systems currently account for about 25% of motor drive energy use in the manufacturing sector, or about 600 Tbtu (not including offsite losses incurred during generation of purchased electricity at the utility).

Most materials processing systems are driven by electricity, which is primarily purchased from outside utilities. Consequently, these systems represent a unique opportunity to reduce energy losses both within and outside the plant boundary. Reducing electricity demand for such systems in the plant translates into less purchased electricity, which is typically generated at utilities with relatively inefficient power generation systems (efficiency of electricity generation at utilities ranges from 25-45%).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**145* (47)**	
Post-Process	**0**	**TOTAL $660**
TOTAL	**145* (47)**	

Methodology

Energy savings are based on a reduction of 15% of current equipment conversion losses (473 TBtu) attributed to materials processing systems in the U.S. manufacturing sector. These losses were estimated in a recent study (see reference below).

Additional energy savings were estimated by calculating the amount of offsite energy losses associated with reduced purchased electricity for these systems, assuming all pumping systems were power-driven. A conversion factor of 10,500 Btu/kWh was assumed for offsite utility losses, which were calculated to be 102 Tbtu.

Cost savings are based on avoided electricity costs ($0.0477/kWh) for the plant. Average electricity price was taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Notes

*Includes losses associated with offsite generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh. Number in parenthesis does not include offsite losses.

Opportunity 16 Energy Recovery From Byproduct Gases

This opportunity area involves the recovery of energy from combustible byproduct gases in various industries, notably petroleum refining and iron and steel. Byproduct gases contain various components (e.g., methane, propane, light hydrocarbons, carbon monoxide) that often have significant fuel value but are not economically recoverable with today's technology. In some cases the components are very dilute, making recovery technically and economically difficult.

Data is lacking on the true energy potential for this area, although sources indicate that millions of pounds of combustible chemicals are lost in byproduct streams annually. Some of the technology options for capturing the energy potential of these byproducts include novel techniques for separating or concentrating combustible components, hot gas cleanup technology, materials for corrosive environments, and innovative burners. Examples of sources include CO-rich gases from the electric arc furnace in steelmaking, and gases from fluid catalytic cracker catalyst reburning.

Energy Savings (TBtu)		Cost Savings (million $)	
Pre-Process	**0**		
Post-Process	**132**	**TOTAL**	**$750**
TOTAL	**132**		

Methodology

Savings are based on a prior analysis (see references below and Table 16.1) for petroleum refining and iron and steel. Sources in petroleum refining are the feed fired heater and catalyst regenerator on the fluid catalytic cracker (average efficiency about 75%). As the prior study significantly underreports losses of combustible gases, it was also assumed that another 5% of the energy delivered to fired systems after pre-process losses (1776 TBtu) could be recouped as a combustible gas, or about 89 TBtu. Combined energy savings for petroleum refining are 112 TBtu.

The electric arc furnace is the primary source of combustible gases in iron and steel. Average efficiency of the furnace was assumed to be about 56%.

Cost savings are based entirely on natural gas at $5.65/MMBtu, assuming this would be the primary fuel replaced. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Table 16.1 Energy Savings Potentials for Recovery of Combustible Gases

Sector	Energy Savings 10^12 Btu
Petroleum	
Fluid Catalytic Cracking	23
Other Offgases	89
	112
Iron and Steel	
EAF Steelmaking	**20**
TOTAL	**132**

Opportunity 17 Energy Export and Co-Location

This opportunity area looks at the potential for exporting energy from pulp mills and other plants, such as fuels produced by Fischer-Tropsch synthesis of synthetic gases from black liquor gasification. This topic also covers co-location of plants to optimize energy resources (e.g., location of large excess steam producer near heavy steam user).

Fuels such as renewable ethanol could supplement current petroleum-based fuels and reduce our dependence on foreign oil. Pulp mill wastes and forestry residues, as well as primary forestry resources could serve as the feedstock for renewable fuels and chemicals. Such resources are considerable (see Figure 17.1). Co-location of plants provides energy optimization by linking waste energy with potential users. It also provides opportunities to increase the use of on-site combined heat and power (CHP).

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**0**	
Post-Process	**105**	**TOTAL $580**
TOTAL	**105**	

Methodology

While some estimates project potential wood-based fuels at 1 quad annually, this estimate uses a more conservative estimate based on current mill waste and forestry residues (see Figure 17.1). The estimated conversion factor for wood resources to ethanol is 72.8 gallons ethanol/dry ton of material. Based on this conversion factor, an energy content of 3.539 MMBtu/bbl for ethanol, and 86 dry tons of wood-based materials available for conversion, energy potential was calculated to be about 105 trillion Btu. These savings represent the petroleum feedstock that would be supplemented with ethanol. Opportunities for co-location were not estimated, but could be substantial.

Other studies [Agenda 2020 Presentation 2004, below] have indicated that if 100% of pulp mills were converted to forestry biorefineries, as much as 1.9 billion gallons of ethanol could be produced annually (about 160 TBtu). For this analysis the more conservative number of 105 TBtu was chosen.

Cost savings are based entirely on cost of petroleum products at $5.80/MMBtu, assuming this would be the primary fuel replaced. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Industrial Bioproducts: Today and Tomorrow, Energetics, Inc for the U.S. Department of Energy, Biomass Program, March 2004.

Aden et al, *Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover*, National Renewable Energy Laboratory, Golden, Colorado (NREL/TP-510-32438), June 2002.

B.A. Thorp, "The Forest Biorefinery: A Partial View," Presentation on behalf of Agenda 2020, June 2004; data also to appear in September and October issues of Paper Age.

Opportunity 17 Energy Export and Co-Location: Supporting Data Tables

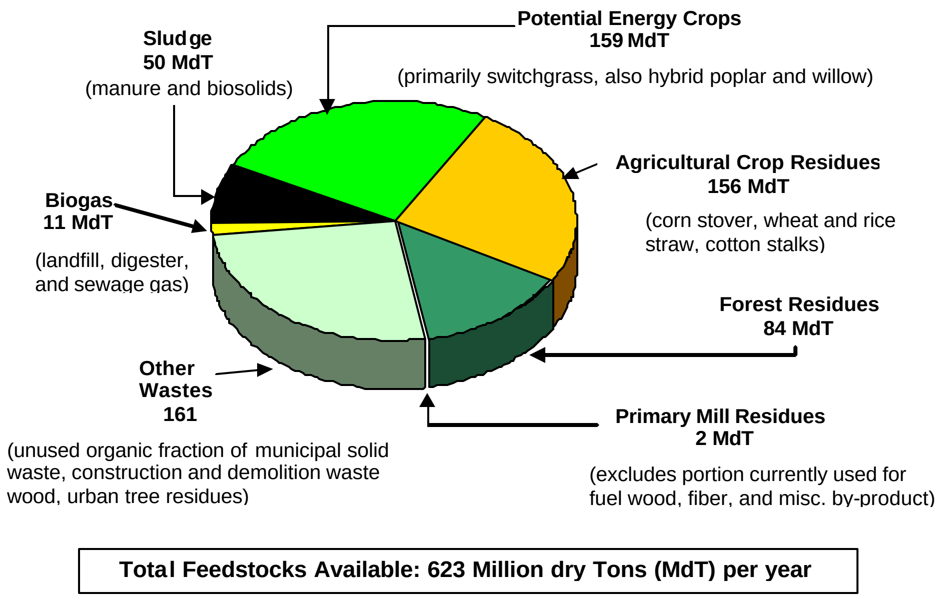


Figure 17.1 Biomass Resources Available for Fuels and Chemical Feedstocks

Opportunity 18 Waste Heat Recovery From Calcining

This opportunity area involves the recovery of waste heat from calcining, specifically lime mud reburning in the pulp and paper industry, and cement calcining. Flue gases from cement calcining are not considered, as these are covered under Opportunity 10, Waste Heat Recovery From Metals and Non-Metallic Minerals. Calcining in these two industries amounts to about 0.5 quads of energy use annually.

In cement manufacture, technology options include recovery of heat in evaporated water, dust, clinker cooling, and from radiative and convective heat losses. In pulp and paper making, the efficiency of the lime kiln used for reburning is very low (30-40%) and could be improved by increasing heat transfer between lime mud and combustion gases, and using heat recovery for better preheating of combustion air and lime mud.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	**11**	
Post-Process	**63**	**TOTAL $159**
TOTAL	**74**	

Methodology

Pre-process energy savings are based on a 25% reduction in pre-process equipment conversion losses (25% of 44 TBtu). Post-process energy savings are based on an analysis that examines opportunities for reducing energy losses in a number of industries, including cement and forest products. The assumptions and results are shown in Appendix B. About 50% of recoverable losses (40 TBtu) in cement calcining are assumed to be flue gases and are included under Opportunity 10. All potentially recoverable losses from lime mud reburning are considered here.

Cost savings are based on a mix of 30% natural gas ($5.65/MMBtu), 30% coal ($1.50/MMBtu), and 40% waste fuels (no cost assigned), according to approximate fuel distribution for process heating in the 1998 MECs (see references below) for process heating in iron and steel. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Opportunity 19 Heat Recovery From Metal Quenching/Cooling

This opportunity area represents energy savings from recouping heat lost in the quenching and cooling of metals. These processes lose significant energy in the form of evaporated water that is vented to the atmosphere, energy embodied in medium - to low-temperature steam and cooling water. Capturing this waste heat is often not technically or economically feasible with today's technologies.

Technology options would efficiently recover heat from quenching and cooling of metals, glass and other high temperature materials (both molten and solid metals). This includes technology to utilize combustion products of flue gases from reheat furnaces, coke oven batteries, and continuous annealing. Innovations such as thermo-electric systems for medium temperature, clean flue products or cooling air are desirable.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	0	
Post-Process	57	TOTAL $275
TOTAL	57	

Methodology

Savings are based on a prior analysis (see references below) for iron and steel, although they could be much higher if other metal producing, casting and fabricating industries were considered. Results of the analysis are shown in Table 19.1, indicating the specific processes covered.

Cost savings are based a mix of 80% natural gas ($5.65/MMBtu) and 20% coal ($1.50/MMBtu), based on the approximate fuel distribution in the 1998 MECs (see references below) for process heating in iron and steel. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Table 19.1 Potential Energy Savings From Quenching/Cooling of Metals

Sector	Energy Savings 10^12 Btu
Iron and Steel	
Ingot	11
Continuous casting	8
Slab Reheat	20
Cleaning/Annealing	18
TOTAL	**57**

Opportunity 20 Advanced Process Cooling and Refrigeration

This opportunity area covers advances in cooling and refrigeration processes, specifically in the chemicals and food processing industries. Cooling and refrigeration accounts for over 200 trillion Btu of energy use in the manufacturing sector every year. A large portion of current technology is motor-driven. Although not one of the largest users of energy, refrigeration systems can be very energy-intensive (e.g., cryogenic chemical separations).

Technology options include innovative or alternative approaches to cooling, process redesign to eliminate the need for energy-intensive cooling units, and system optimization.

Energy Savings (TBtu)		Cost Savings (million $)
Pre-Process	***47(15)**	
Post-Process	**0**	**TOTAL $212**
TOTAL	***47(15)**	

Methodology

Pre-process savings are based on a 20% reduction in electricity requirements for motor-driven refrigeration in these industries as sited in a recent study (Xenergy 1998). Energy use for refrigeration in these industries was based on the Xenergy study and a prior study utilizing MECs data (see references below, and Table 20.1). Additional savings would be possible through improvements in other cooling systems (non-motor-driven), although these were not estimated for this study.

Cost savings are based entirely on the avoided use of electricity ($0.0477/kWh). Savings are counted only for the electricity saved by the industry user – not the losses avoided at the utility generator. Average fuel prices were taken from the EIA Monthly Energy Review June 2004.

References

U.S. Industrial Motor Systems Market Opportunities Assessment, Xenergy for Oak Ridge National Laboratory and the U.S. Department of Energy, 1998.

Energy Use, Loss and Opportunities Analysis, Energetics, Inc and E3M, Inc for the U.S. Department of Energy, November 2004.

Manufacturing Energy Consumption Survey 1998, Energy Information Administration, 2001.

Notes

*Includes losses associated with offsite generation and transmission of electricity, based on a conversion factor of 10,500 Btu/kWh. Number in parenthesis does not include offsite losses.

Table 20.1 Potential Energy Savings for Advanced Refrigeration Systems

Sector	Energy Use for Motor-Driven Refrigeration, Tbtu (with losses)	Potential Savings (Tbtu)
Chemicals	111	22
Food Processing	123	25
TOTAL	**234**	**47**

Appendix D

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.