Energy Use, Loss and Opportunities Analysis for U.S Manufacturing and Mining

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ABSTRACT

The U.S. industrial sector uses about a third of the total energy consumed in the United States every year (~33 quads), most of it fossil fuels, at a cost of over $100 billion (DOE 2004, DOE 2001).[1] Increasing energy efficiency is one way to reduce the industrial energy burden. Less than optimum energy efficiency means that as equipment is used, not all of the energy is converted to useful work – some is released as lost energy that could be recovered. Energy losses in manufacturing and mining amount to quads of energy and billions of dollars in lost revenues every year.

To identify the most significant opportunities for increasing energy efficiency and reducing energy losses, a study was conducted to determine where and how industry is using energy – how much is used, which industries are using the most, how much is lost, how much goes directly to processes, and where energy losses could potentially be recovered or reduced. The study covers 16 industrial sectors, and utilizes data from the Manufacturing Energy Consumption Survey, literature sources, and industry experts.

This paper summarizes the results of the recently published study on ***Energy Use, Loss, and Opportunities Analysis for U.S. Manufacturing and Mining*** (Pellegrino et al. 2004). Industry energy use rankings are presented for primary energy use, fuel and power, onsite power generation, steam and fired systems, and other major functional energy use categories. Energy "footprints" are created for all industries, illustrating energy flows from offsite utilities to the plant boundary and throughout the plant to functional areas. The study provides a diagnostic tool for identifying windows of opportunity for reducing energy use.

Introduction

The industrial sector uses about a third of the total energy consumed in the United States every year (~33 quads), most of it fossil fuels, at a cost of about $100 billion (DOE 2004, DOE 2001).[1] Given that energy resources are limited, and demand for industrial products continues to rise, meeting industrial energy demand and its economic impact in the future could be a significant challenge.

The U.S. manufacturing sector depends heavily on fuels and power for the conversion of raw materials into usable products, and also uses energy as a source of raw materials (feedstock energy) for chemicals and materials. How efficiently energy is used, as well as the cost and

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[1] Energy expenditures for manufacturing taken from DOE 2001; for electricity losses and non-manufacturing, costs are based on $3/million Btu.

availability of energy, consequently has a substantial impact on the competitiveness and economic health of U.S. manufacturers. More efficient use of fuels and power lowers production costs, conserves limited energy resources, and increases productivity. Efficient use of energy also has positive impacts on the environment – reductions in fuel use translate directly into fewer emissions of pollutants such as sulfur oxides, nitrogen oxides, and particulates, as well as greenhouse gases (e.g., carbon dioxide).

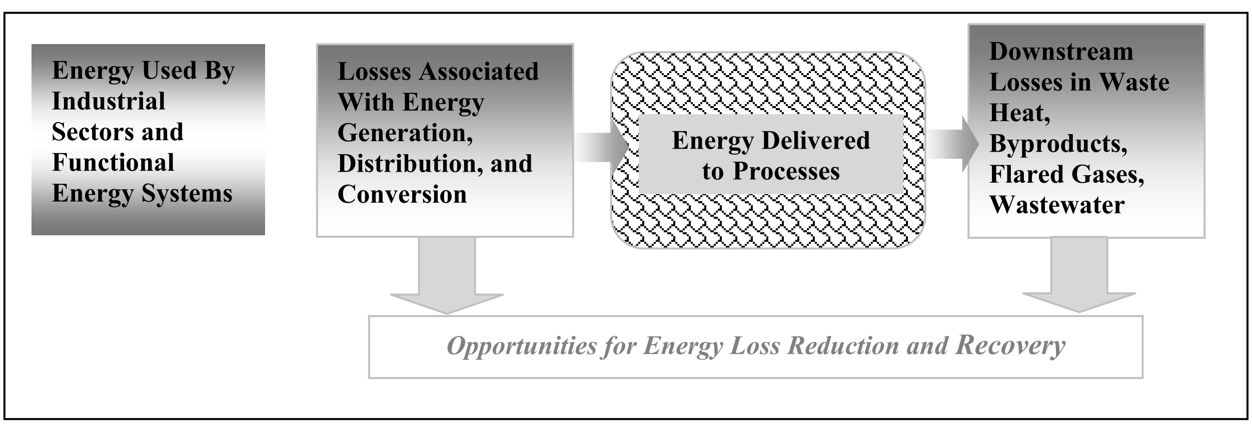
Less than optimum energy efficiency means that as equipment is used, not all of the energy is converted to useful work – some is released as lost energy. In the manufacturing sector, these energy losses amount to several quadrillion Btus (quadrillion British Thermal Units, or quads) and billions of dollars in lost revenues every year.

Increasing the efficiency of energy use could result in substantial benefits to both industry and the nation. 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, and how much goes directly to processes. The second step is to quantify the portion of lost energy that can potentially be recovered through improvements in energy efficiency, advances in technology, and other means.

The U.S. Department of Energy's Industrial Technologies Program (DOE/ITP) conducts research and development (R&D) to accelerate the development of energy efficient and environmentally sound industrial technology. To help focus its R&D portfolio, the DOE/ITP commissioned a multi-phase study to identify where and how industry is using energy, and to target the most significant opportunities for reducing energy use. The study focused on energy systems – steam and power systems, fired heaters, and motor systems – that are used across the industrial sector to convert energy resources into useful work or products. The various phases of the study are shown in Figure 1 (Pellegrino et al. 2004).

The first phase of the study examined energy use in broad categories and developed a "footprint" of energy use and loss across 16 industries. The second phase builds upon the first phase by taking an in-depth look at the largest industrial users of energy systems, and by linking energy use and losses to specific process operations and equipment. Potential technology options for recapturing some of the energy that is currently lost in industrial processes are also identified. The results of the first and second phases of the study were then used as the basis for developing opportunity areas for improving energy efficiency in energy systems.

Figure 1. Flow of the Multi-Phase Study on Energy Use, Loss and Opportunities



Source: Pellegrino et al. 2004

Methodology

The objective of the study was to evaluate the energy use and loss patterns of individual industries as well as the entire manufacturing sector. Industries were selected based on energy use, contribution to the economy, and relative importance to energy efficiency programs. The 16 industries selected for the study (see Table 1) represent over 80% of industrial energy use.

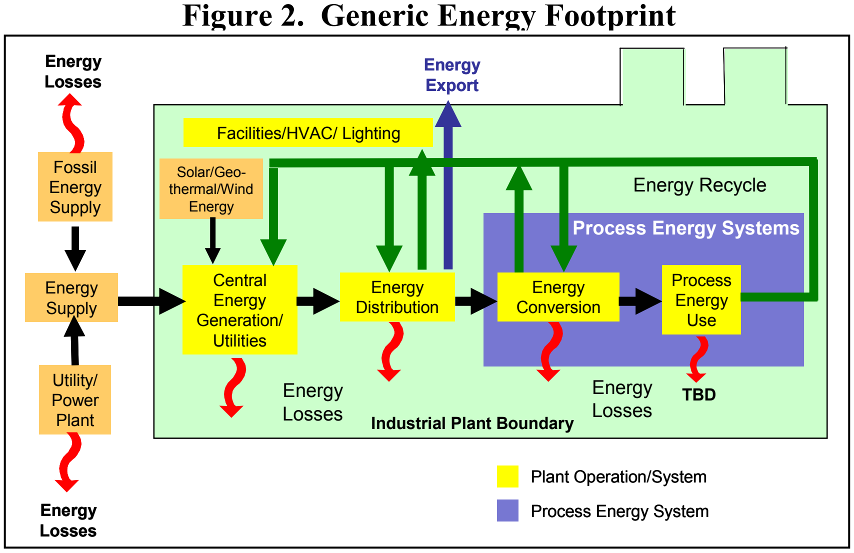
Table 1. Industries Selected for Analysis

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

Energy Footprints

Using energy data from the Manufacturing Energy Consumption Survey and other sources (DOE 1998, BCS 2002), a series of energy footprints was developed to map the flow of energy supply and demand in U.S. manufacturing and mining. A generic energy footprint is shown in Figure 2. On the supply side (far left of the diagram), the footprint provides 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 footprint illustrates where and how energy is used within a typical plant, from central boilers to process heaters and motors. Most important, the energy footprint identifies where energy is lost due to inefficiencies in equipment and distribution systems, both inside and outside the plant boundary.

Figure 2. Generic Energy Footprint



Source: Pellegrino et al. 2003

Energy supply begins with the electricity, energy losses from generation and transport, steam, natural gas, coal, and other fuels supplied to a plant from off-site power plants, gas companies, and fuel distributors. Onsite-generated byproducts and fuels are also part of energy supply. Renewables such as solar and wind are shown separately, and are assumed to be primarily for electricity production.

Once energy crosses the plant boundary, it flows either to a ***central energy generation utility system*** (e.g., steam plant, power generation) or goes directly to process units. Central energy generation represents the production of electricity and steam in a centralized location, with the energy subsequently transported through ***distribution systems*** to various process units. This is a generalization of what may actually be occurring, as energy systems are often more closely integrated into the process. Excess energy is exported off-site to the local grid or another plant, and for this analysis is assumed to be all electricity.

Fuels and power are routed to ***energy conversion*** equipment that is generally integrated with specific processes. For this analysis, energy conversion represents 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. 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 to the plant and within the plant boundaries. Losses also occur in energy conversion systems (e.g., heat exchangers, process heaters, pumps, motors) where efficiencies are thermally or mechanically limited by materials of construction and equipment design. Energy is sometimes lost simply because it cannot be stored. Energy is also lost from processes whenever waste heat is not recovered and when waste by-products with fuel value are not utilized.

Distinguishing between energy conversion occurring "prior to the process" and "during the process" is difficult as equipment is often closely integrated with the process unit. For this analysis it was assumed that some portion of losses would occur prior to the process and another portion would occur downstream. As a result, pre-process losses may overlap somewhat with post-process losses. Downstream losses (energy in flue or exhaust gases or liquids, radiative/convective heat) can be substantial, and were only calculated for a few major processes (shown as TBD on footprint). Pre-process losses were determined by applying equipment loss factors to the energy used in selected functional categories. The loss factors used in this study are listed in Table 2. These were derived from published literature, communication with industry experts in steam, and motor systems, and typical engineering practice. A more complete description is found in the main report (Pellegrino et al. 2003).

Industry Rankings

Using the results of the energy footprint analysis, the 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. 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.

Table 2. Energy Loss and Equipment Efficiency Assumptions

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% Windings – 5% Compressed air – 80% Refrigeration – 5% Materials handling – 5% Materials processing – 90%

Source: Pellegrino et al. 2003

Loss Reduction and Recovery Opportunities

Six industries were selected for further analysis of loss reduction and recovery opportunities based on the following criteria: 1) large energy use and losses, 2) energy losses that included large quantities of waste heat, and 3) high potential for cross-industry impacts. These industries included petroleum refining, chemicals, forest products, iron and steel, food and beverage, and cement. For these six industries, estimates of the energy intensity (Btu/product unit) and production values associated with specific energy systems were made for major processes in each industry. Average processing efficiencies were estimated based on open literature (topical industrial reports, industry handbooks, journal articles, government publications from the Department of Energy and the Environmental Protection Agency), widely known best practices, and communication with industry experts, equipment suppliers and energy system consultants. Complete references and assumptions are provided in the main report (Pellegrino et al. 2004). Energy losses were then calculated for each process to quantify energy loss reduction and recovery opportunities.

Unlike the first phase of the study, the opportunities analysis examines losses occurring at the end of the process (e.g., exit gases, flue gases, hot water) and in some cases combines those with pre-process losses to estimate the total opportunity (where possible). After assessing potential opportunities, estimates were made concerning the amount of energy that could likely be reduced or recovered, and potential technology options for doing so. Estimates were based on communications with equipment and industry experts, open literature citations documenting potential efficiency improvements (primarily U.S. trade journals and industrial reports from public and private sources), and best engineering practices. Energy systems were grouped according to specific thermal processes (e.g., fluid heating, metal heating) and are aggregated into two major categories – steam systems and fired systems.

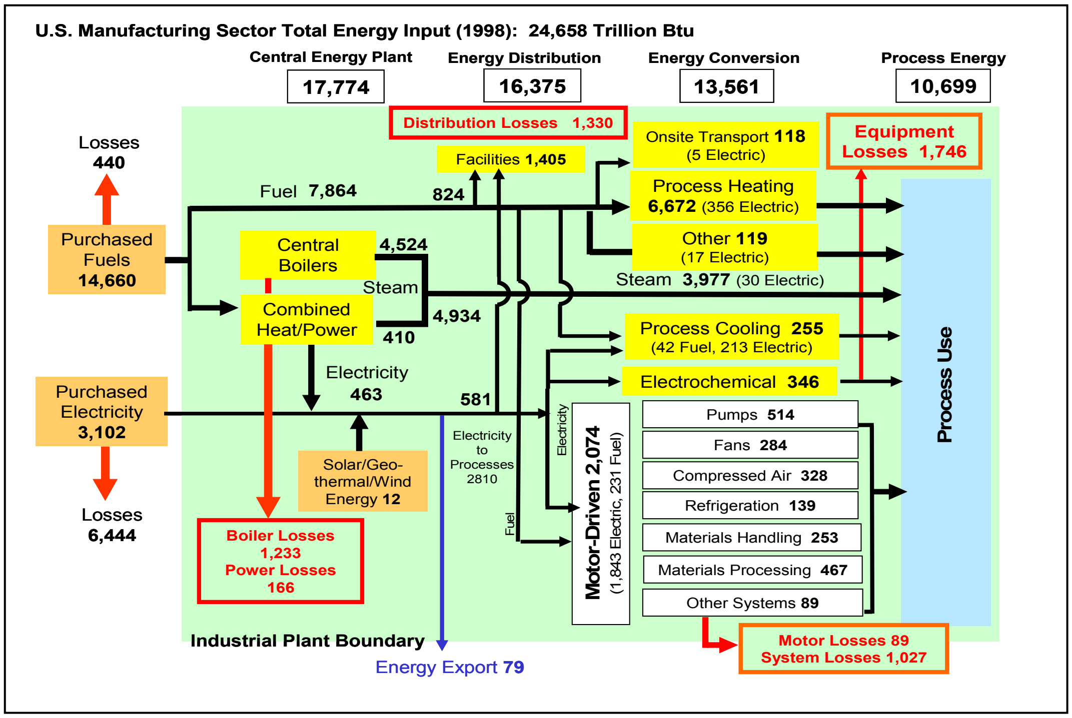
Study Results: Industrial Energy Use and Losses

The results of the study are presented for all of manufacturing and mining. However, the complete report contains detailed analysis of six individual industries, as well as detailed energy footprints for all sixteen industries. For a comprehensive description of the assumptions, calculations, and references used for all industries, please consult the original report, which is available at http://www.eere.energy.gov/industry/energy_systems/tools.html.

Overview of Manufacturing and Mining Energy Use and Losses

Energy footprint. The detailed energy footprint for U.S. manufacturing (mining has a separate footprint) is shown in Figure 3. The footprint shows that about 6.9 quads (quadrillion Btu) of energy losses are associated with industry purchases of offsite-produced energy, or about 28% of total energy. Of the energy that is delivered to the plant (17.8 quads), another 5.6 quads is lost due to system inefficiencies prior to reaching the process (another 23%). Thus, when offsite losses are included, over 50% of the energy associated with manufacturing and mining is lost prior to reaching the process. Note that facilities energy (1.4 quads) and energy export (0.08 quads) are also subtracted from energy going to processes (17.8 – 5.6 – 1.5 = 10.7 quads).

Figure 3. Energy Footprint for U.S. Manufacturing and Mining



Primary energy. From the standpoint of energy loss reduction, primary energy is the best way to look at industrial energy use. Primary energy use includes fuels and power as well as offsite losses at utilities from which energy is purchased. It represents all the processing energy associated with an industry, *both external and internal to the plant boundary*. It does not, however, include feedstock energy (energy used as a raw material). As Figure 4 illustrates, the heavy industries (chemicals, forest products, petroleum, iron and steel) consume the most primary energy.

Fuels and electricity. Table 3 compares and ranks the total use of power and fuels among different industrial sectors. This comparison identifies industries that are highly electricity- or fuel-intensive, and helps to pinpoint industries that could potentially benefit from the use of onsite cogeneration technology. As Table 3 illustrates, the top users of fuel and electricity are the most energy-intensive heavy industries (e.g., chemicals, forest products, iron and steel), metal fabricators, and end-users (e.g., transportation equipment, food).

Figure 4. Primary Energy Use in Manufacturing and Mining

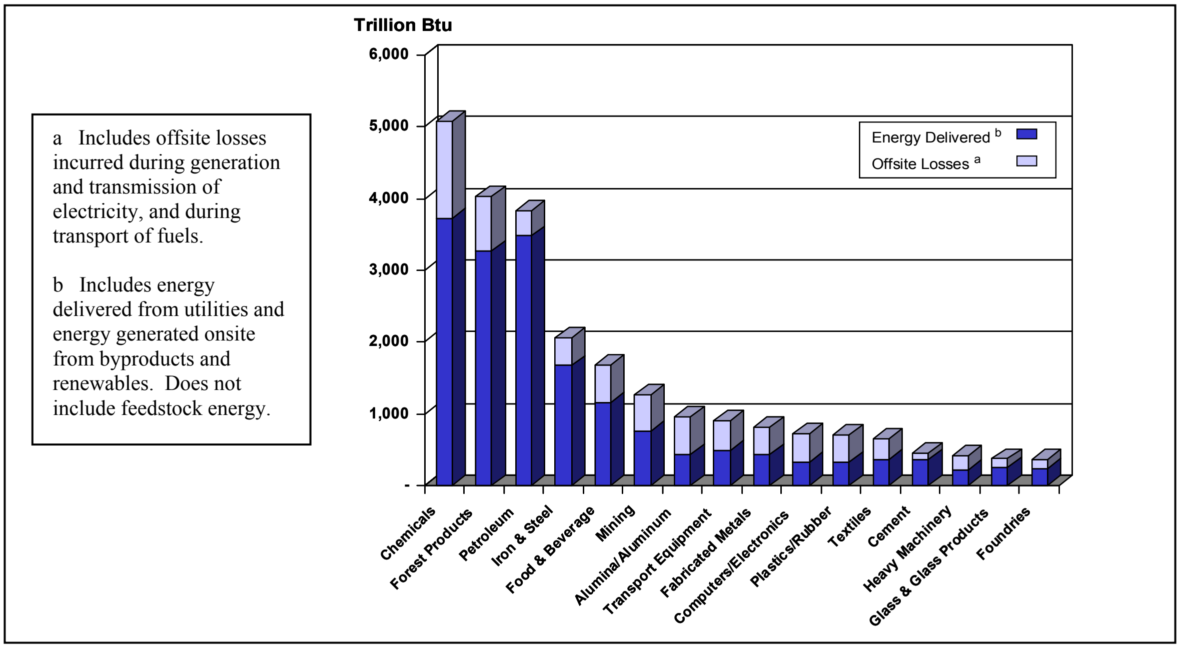


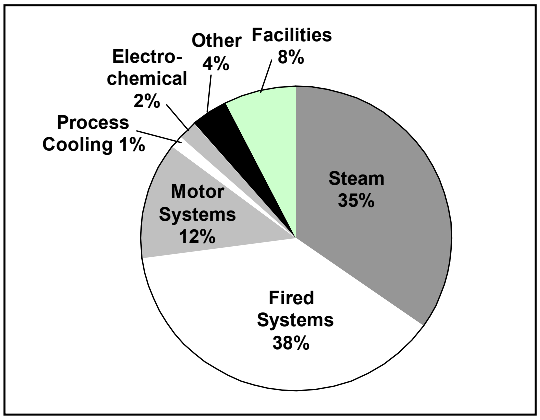
Table 3. Comparison of Fuel and Electricity Use By Sector

	Total		Fuel Use		Electricity	
Sector	**TBtu**	**Rank**	**TBtu**	**Rank**	**TBtu**	**Rank**
Chemicals	3,729	1	3,127	2	602	1
Petroleum Refining	3,478	2	3,355	1	123	12
Forest Products	3,263	3	2,936	3	327	2
Iron & Steel Mills	1,672	4	1,509	4	163	10
Food & Beverage	1,156	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

Source: Pellegrino et al. 2004

Functional energy use. When manufacturing and mining are combined, total delivered energy totals more than 18.5 quads of fuel and electricity (excluding any offsite energy losses) (see Figure 5). Steam and fired systems systems dominate industrial energy use at 73% of the total. Motor- driven systems account for the next substantial share of energy use at 12%. Note that the distribution shown in Figure 5 is an industry aggregate and may not reflect individual industry energy use. Foundries and cement, for example, use virtually no steam. In aluminum, electrochemical processes account for 40% of energy use. Tables 4 and 5 provide a comparison of individual industries by their use of steam and fired systems, and illustrate the diversity of functional energy use among sectors. Forest products, while ranked first in steam use, is only ranked at eight for fired systems. Petroleum refining and chemicals manufacture are heavy users of both steam and fired systems, and are ranked among the top three in both categories.

Figure 5. Functional Energy Use in Manufacturing and Mining (18.5 quads)



Combined heat and power (CHP). Figure 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 produced onsite (over 95%) is generated using cogeneration systems which also provide high-temperature steam. As large steam and electricity users, chemicals, forest products, petroleum refining, iron and steel, and food processors are large cogenerators.

Energy losses. *Offsite energy 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). Even though the industrial facility does not incur these losses, including them is provides a total picture of the energy associated with an individual industry's use of electricity. *Onsite losses* are incurred within a plant boundary. 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 targeting efficiency improvements, it is important to define the source of onsite losses. An overall breakdown of onsite losses in the manufacturing and mining sectors is shown in Figure 6. 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 (dotted line in Figure 7). In typical plants, plant engineers often cite downstream losses on the order of 30%.

The components of onsite energy losses identified through the energy footprint analysis are illustrated in Figure 8 and Table 6. The bulk of energy losses occur in process heating and cooling, 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 account for another 1.3 quads, or about 18% of energy inputs to those systems. Motor system losses, which include losses in motor windings and mechanical losses, amount to 1.3 quads or 55% of motor system energy inputs. The assumptions used in loss calculations are found in Table 2, and are described in more detail in the main report (Pellegrino et al. 2004).

Table 4. Industry Rank by Steam

Sector	Steam Use	
	Tbtu	Rank
Forest Products	2,442	1
Chemicals	1,645	2
Petroleum Refining	1,061	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

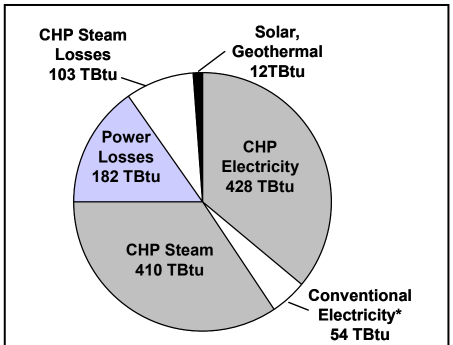
Source: Pellegrino et al. 2004

Table 5. Industry Rank by Fired Systems

Sector	Fired Systems	
	Tbtu	Rank
Petroleum Refining	2,156	1
Iron & Steel Mills	1,372	2
Chemicals	1,207	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

Source: Pellegrino et al. 2004

Figure 6. Onsite Power Generation and Loss Profile for Manufacturing and Mining



* Onsite power systems producing only electricity.

Potential downstream process losses are denoted in Figure 8 for fired systems. As discussed earlier these losses, which include energy embodied in waste heat, exit gases, waste steam, hot water, or other sources, can be as much or more than those incurred prior to the process. Looking at fired systems, for example (if just distribution and conversion losses are considered), it appears these systems are roughly 80% efficient. In reality, as much as 50% of the energy to fired systems could potentially be lost. Steam losses downstream (low quality waste steam, contaminated waste steam) could be similar. Table 6 also shows carbon emissions associated with energy losses in the U.S. manufacturing and mining sectors. These total nearly

104 MMTCE, which represents about 7% of carbon emissions in the United States from anthropogenic (manmade) sources. Carbon emissions are based on combustion of fuels.

Figure 7. Onsite Energy Loss Profile for Manufacturing and Mining

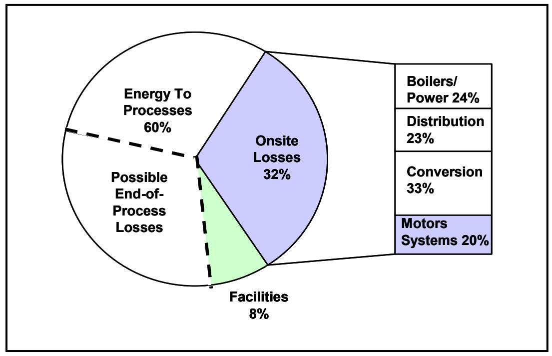


Figure 8. Energy End Use and Loss Distributions in Manufacturing and Mining

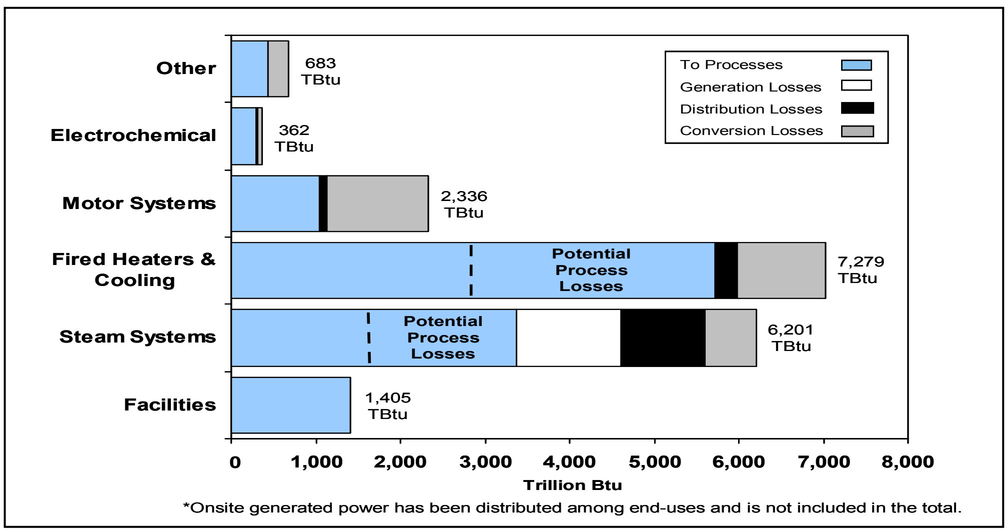


Table 6. Manufacturing Energy Use and Losses (Trillion Btus)

	To Process/ End-use	Generation Losses	Distribution Losses	Conversion Losses	Total Onsite Losses	Total Energy	Associated Carbon (MMTCE)**
Facilities	1,405	na	na	na	na	1,405	Na
Steam Systems	3,382	1,234	987	598	2,819	6,201	49.3
Fired Systems/Cooling	5,983	na	256	1,040	1,296	7,279	20.9
Motor Systems	1,047	na	85	1,204	1,289	2,336	24.2
Electrochemical	295	na	15	52	67	362	1.3
Other Uses	434	na	Na	249	249	683	1.2
Onsite Power	*(482)	182	Na	na	182	182	3.6
Export of Power	79	na	Na	na	na	79	0
TOTALS	12,625	1,416	1,343	3,143	5,902	18,527	103.9

*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).

Source: Pellegrino et al. 2004

Opportunities Analysis

Analysis was conducted at the process level for six major industries to better pinpoint targets of opportunity for reducing energy losses downstream of the process (exit or flared gases, waste steam, etc.). Table 7 shows the energy savings identified by that analysis for four of the industries – these represent the bulk of post-process energy savings identified. Table 8 shows savings grouped by categories based on the source of the energy losses, discussions with industry experts on potential loss recovery/reduction options, and industry priorities as set in various technology roadmaps. As Table 8 shows, there are over 5 quads of lost energy that could potentially be recovered.

Table 7. Potential Energy Loss Reductions for Selected Industries and Processes

Industry/Process	Main Source of Energy Loss	Savings (Trillion Btu/year)
Chemicals (combined steam and fired systems losses)		
Ethylene Chain	Waste gases	25.5
Propylene Chain	Flared gases, waste gases, solvent vapors	5.3
Benzene-Toluene-Xylene (BTX)	Vent gases, boiler waste heat, flue gases	15.3
Agricultural Chemicals	Reformer waste heat, waste steam, drying heat	33.4
Chlor-Alkali	Heater flue gases	15.3
TOTAL		*94.8*
Petroleum Refining (steam losses)		
Atmospheric Distillation	Contaminated waste steam	60.0
Vacuum Distillation	Contaminated waste steam, reboiler losses	11.0
Catalytic Hydrotreating	Contaminated waste steam	25.0
Catalytic Reforming	Contaminated waste steam	14.0
Alkylation	Contaminated waste steam	17.0
Other	Contaminated waste steam	9.0
TOTAL		*136.0*
Petroleum Refining (fired system losses)		
Atmospheric Distillation	Hot flue gases and coolers	96.2
Vacuum Distillation	Hot flue gases and coolers	29.9
Delayed Coking	Hot flue gases, coke drum cooling, oil cooler	14.3
Fluid Catalytic Cracking	Hot flue gases	42.9
Catalytic Hydrotreating	Hot flue gases	70.3
Catalytic Reforming	Hot flue gases and coolers	47.4
Alkylation	Cooling water	29.8
Other	Hot flue gases	29.2
TOTAL		*360.0*
Forest Products (steam)		
Pulping	Waste steam	24.0
Bleaching	Waste steam	14.0
Chemical Recovery	Exit gases, radiation losses, waste steam	17.0
Pulp Drying	Exit gases	3.0
Paper Drying	Hot water, exit gases, waste steam	138.0
Lime Reburning (fired system)	Exit gases	23.0
TOTAL		*220.0*
Iron and Steel (combined steam and fired system losses)		
Blast Oven Furnace Ironmaking	Waste gases	97.0
Electric Arc Furnace Steelmaking	Waste gases	79.0
Ingot	Waste water	11.0
Slab Reheating Furnace	Waste gases	51.0
Cleaning/annealing	Waste water	18.0
Other		13.0
TOTAL		*269.0*

Table 8. Opportunity Energy Savings Summarized by Broad Categories

Category	Combined Savings (Trillion Btu)
Waste Heat and Energy Recovery	1,831
Improvements to Boilers, Fired Systems, Process Heating/Cooling	907
Energy System Integration and Best Practices	1,438
Energy Source Flexibility and Combined Heat and Power	828
Sensors, Controls, Automation	191
Total	**5,195**

Conclusions

The energy use, loss and opportunities study develops energy footprints for sixteen industrial sectors, and identifies areas of energy losses. Estimates are included for onsite losses occurring during energy generation, distribution, and conversion prior to process use, as well as offsite losses incurred at utilities and in fuel transport. Comparisons of use and loss across sectors reveals that five industries – petroleum refining, chemicals, forest products, petroleum, iron and steel, and food processing – consume the most energy, exhibit the greatest losses, and are the heaviest users of steam and fired systems.

There are significant opportunities to reduce industrial energy use through recovery or reduction of the energy lost to equipment inefficiencies. As shown, these losses are substantial, about 5.9 quads within the plant boundaries of U.S. industry. While some losses are due to process irreversibilities or other technical limitations and can never be recovered, there is some portion that could be addressed through advances in technology or implementation of better energy management practices. Overall, the study identifies over 5.2 quads of lost energy that could potentially be recoverable. About 1.8 quads of this could be recovered through increased recovery of waste heat and byproduct energy, and nearly 1 quad could be recovered through improvements to boilers, fired systems, and other process heating and cooling equipment. Energy loss reduction through best energy management practices is about 1.4 quads.

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