Electricity Consumption and the Potential for Electric Energy Savings in the Manufacturing Sector

R. Neal Elliott

April 1994

American Council for an Energy-Efficient Economy
1001 Connecticut Avenue NW, Suite 801, Washington, DC 20036
2140 Shattuck Ave, Suite 202, Berkeley, CA 94704

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The author would like to acknowledge and thank a number of individuals and organizations who provided assistance during the course of this study. This project was funded by the Pew Charitable Trust.

The following individuals provided helpful comments on various drafts and additional information which improved the content of this report: Howard Geller and Steve Nadel, ACEEE; Marc Ross, University of Michigan; Eric Larson, Princeton University; Stu Slote, Vermont Department of Public Service; Denise Flora and Ziba Kellum, Industrial Electrotechnology Laboratory; Ammi Amarnath and Gene Eckhart, Electric Power Research Institute; and Fred Gordon, Pacific Energy Associates.

Neither the individuals nor the organizations acknowledged here necessarily endorse the analysis or the conclusions expressed in this report. The author assumes full responsibility for all information presented.

EXECUTIVE SUMMARY

This report provides an overview of electricity consumption in manufacturing industries, how electricity is used, what opportunities exist for improving efficiency of electricity use in those industries, and how much electricity can be saved through these efficiency improvements. Manufacturing industries consumed slightly over 15 Quads of all forms of energy in 1991, of which 16 percent (almost 695 billion kWh) was electricity (excluding inefficiencies in power generation and transmission). Manufacturing accounts for about a quarter of total national electricity consumption. Electricity purchases by manufacturing in 1991 totaled over $55 billion that represents almost two-thirds of the total manufacturing energy purchases. In spite of the size of the electricity expenditure, it only represents an average of 1.2 percent of the value of manufactured goods. In a few industries like aluminum and industrial gases, electricity purchases are more than 20 percent of the value of the manufactured products, but in many other industries like food processing, transportation equipment and apparel, electricity purchases are less than 1 percent of the value of shipments.

Electricity end-use can be grouped into three broad categories: process, motor, and lighting loads. Motors represent the largest group at 70 percent, with process and lighting comprising 23 and 7 percent respectively (*Figure I*). This study estimates that 14-38 percent of total electricity consumption can be saved through an orderly change-out of equipment at the time of equipment failure, process modernization or new construction. This estimate is conservative since this study does not consider process optimization or redesign that would significantly increase the conservation potential. Similar studies surveyed in the report support this estimate.

How electricity is used varies among the different industry groups and industries. The report estimates electricity end-use in all the manufacturing industry groups (SIC 20-39). The six most electricity intensive industry groups (chemical, pulp and paper, food, metals fabrication, industrial machinery, and transportation equipment) along with two primary metals industries, steel and aluminum are also addressed in greater detail. The motor fraction of electricity consumed varies from a low of 33 percent in primary metals to a high of 95 percent in pulp and paper. The process consumption of electricity varies from a high of 56 percent in primary metals to 2 percent or less in seven industry groups. While savings can be realized through programs that promote efficient lighting and motors to all manufacturing industries, it is necessary to understand the electricity end-use and the corresponding conservation opportunities within each industry if large savings are to be realized.

Over 80 percent of the available electricity savings come from electric motor systems improvements with lighting and process each contributing slighting less than 10 percent (*Figure I*). Within motor systems, ten specific measures are identified. Over a third of the motor system conservation opportunity is estimated to be in the application of adjustable speed drives, with another quarter coming from improved drivetrain, electricity supply and maintenance practices. Another sixth of the motor system conservation opportunity is estimated to come from the selection of more efficient motors.

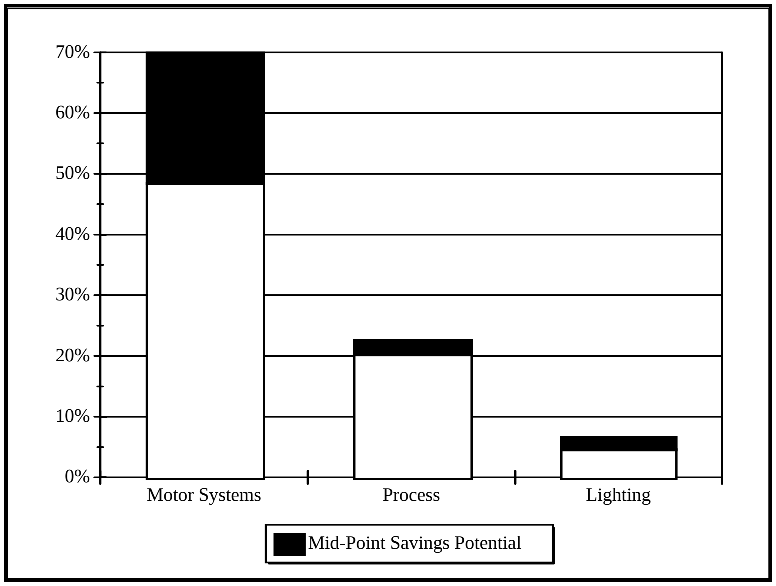

Figure I Electricity Consumption and Conservation Potential for Manufacturing Industries by End-Use

Though the lighting fraction of total electricity conservation potential is modest, lighting represents one of the easiest was to improve industrial electricity. The overall savings potential as a fraction of end use is 20-40 percent, and lighting represents over 15 percent of total electricity consumption in some industry groups like textiles, printing, apparel and furniture.

Clearly many opportunities still exist for improving the electrical energy efficiency of manufacturing industries as a whole. Given concerns such as competition from low-wage nations, maintaining a strong manufacturing base, and emissions of greenhouse gases and other power plant pollutants, efforts need to be directed at realizing this savings potential. Improved efficiency will benefit many parties: manufacturing companies through decreased operating costs, electric utilities through reduced demand growth and need to build additional capacity, the economy through improved resource utilization and increased productivity, and the environment through reduced pollutant emissions.

I. INTRODUCTION

This report provides an overview of electricity consumption by manufacturing industries, how electricity is used, what opportunities exist for improving the efficiency of electricity use in those industries, and how much electricity can be saved through efficiency improvements.

This report is restricted to manufacturing industries. For purposes of this report, the manufacturing sector consists of those establishments classified as Standard Industrial Classification codes (SIC) 20 through 39. Agricultural production, forestry, fishing, mining and construction are excluded from this categorization. All electric energy values are end-use consumption. No attempt has been made to project primary energy consumption or savings potential.

While this report discusses some specific electrical processes and opportunities for efficiency improvements, the site-specific nature of these opportunities make them difficult to quantify on a broad basis. Also, this report is based on many different sources of information that use different methodologies and assumptions. Some in fact are not self-consistent, although the author has endeavored to reconcile these differences to the best extent possible. As a result, the estimates of overall energy savings potential in this report are approximate rather than precise figures.

This report also considers only end-use consumption of electricity. Significant efficiencies can be realized from on-site generation of electricity, especially when the electrical generation system is part of a cogeneration system that also provides a source of direct process heat. However, it is important when sizing an on-site generation system that electricity conservation opportunities are considered as part of the design process.

Significant net energy savings can also be realized with the substitution of some electrical technologies for fossil fuel and steam processes. In some cases, as in radio frequency drying of textile products, a reduction in electrical consumption can also be realized (Cato, 1991). While some of these opportunities will be identified in this report, no systematic attempt is made to quantify the net savings potential from fuel switching.

II. ELECTRIC ENERGY CONSUMPTION BY MANUFACTURING SECTOR

Manufacturing industries consumed slightly over 15 Quads (one Quad = 10^{15} Btu) of all energy forms in 1991 on an end-use basis (i.e., not including energy lost in electricity generation and transmission), the latest year for which detailed statistics are available. This represents about 25 percent of the national end-use energy (61 Quads) (EIA, 1993a). As *Figure 1* shows, four industry groups accounted for almost three quarters of this energy consumption: Chemicals (SIC-28), Petroleum and Coal (SIC-29), Pulp and Paper (SIC-26), and Primary Metals (SIC-33) (EIA, 1993b).

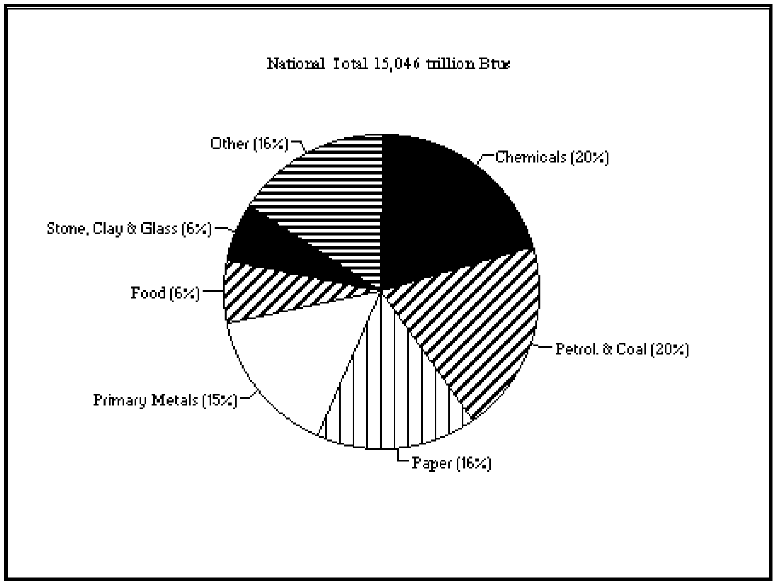

Figure 1 Manufacturing Industries 1991 Total Energy Consumption (Source: EIA, 1993b).

Total manufacturing industry purchases of fuel and electricity in 1991 were over 55 billion dollars. Electricity accounted for almost two-thirds of these energy purchases even though it represents only 16 percent of industrial energy consumption on a end-use basis (*Figure 2*). Electricity purchases exceeded fuel purchases in all industry groups except petroleum refining, and stone, clay and glass (*Figure 3*)(Census, 1992).

Manufacturing electricity consumption in 1991 was almost 695 billion kWh including both purchased and self-generated electricity, which is over a quarter of the almost 2,700 billion kWh national total (EIA, 1993a). The primary metals (SIC 33), chemicals (SIC 28), paper (SIC 26) and food (SIC 20) industry groups account for 55 percent of the electrical consumption *Figure 4*). Steel (SIC 3312) and primary aluminum (SIC 3334) account for almost three quarters of the electricity consumed in the primary metals group. In the chemical group, industrial inorganic chemicals (SIC 2819) account for almost 29 percent of the industry group's electric consumption, with industrial gases (SIC 2813), plastics and resins (SIC 2821), and industrial organic chemicals (SIC 2869) accounting for between 11 and 14 percent each. In the paper group, integrated paper mills (SIC 2621) account for over half of the electric energy consumption (EIA, 1993b).

Based on Bureau of the Census estimates for value of 1991 shipments for each industry group (Census, 1993), an average electric energy intensity (kWh per dollar of shipment) can be calculated; these data are shown in *Figure 5*. (Values are reported in *Table A-I* in the Appendix.) The average intensity for all industries is about 0.25 kWh per dollar shipped. The most electrically intensive industry group is primary metals at 1.10 kilowatt-hour per dollar of shipments. Within primary metals, all industries exceed the industry average. Primary aluminum production (SIC 3334) at 10.9 kWh per dollar shipped is the most electricity intensive, and is also the most intensive of all industries by a factor of two. Electrometalurgical steel production (SIC 3133) is a the next most intensive at 3.7 kWh per dollar shipped, though it accounts for less than 3 percent of the industry group's electricity consumption.

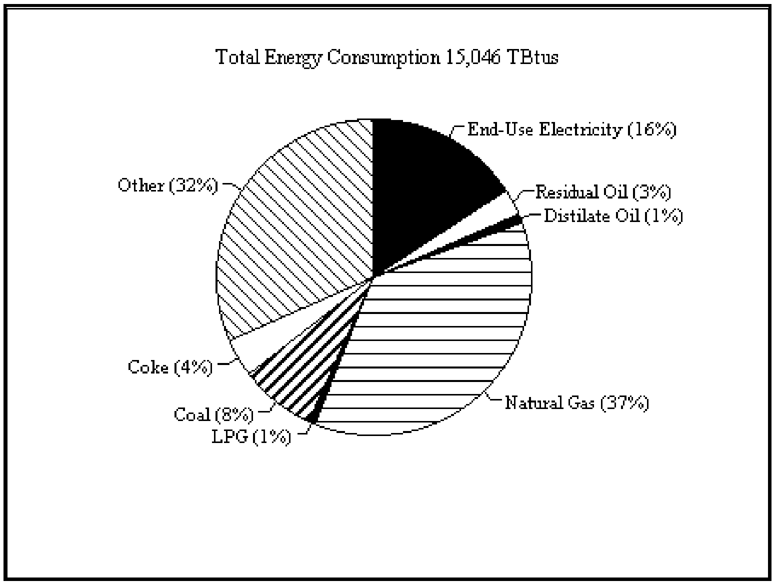

Figure 2 Total Manufacturing Energy Consumption by Fuel Type (Source: EIA, 1993b).

The chemicals group has an intensity of 0.94 kWh per dollar of shipments. Three industries within this group are very intensive: alkalies and chlorine (SIC 2812), industrial gases (SIC 2813) and inorganic chemicals (SIC 2869) at 3.9, 5.6 and 2.1 kWh per dollar shipped respectively. The remaining four industries considered in the chemicals group are less electricity intensive, though they are still more electricity intensive than the industry average.

Four other industry groups exceed the average electricity intensity: pulp and paper; rubber and plastics; stone, clay and glass; and textiles. Within these industry groups, the most intensive industries are hydraulic cement production (SIC 3241) and container glass (SIC 3221) at 2.5 and 0.8 kwh per dollar shipped respectively. All the industries considered within the paper group are energy intensive, with paper mills (SIC 2621) the highest at almost 1 kWh per dollar shipped.

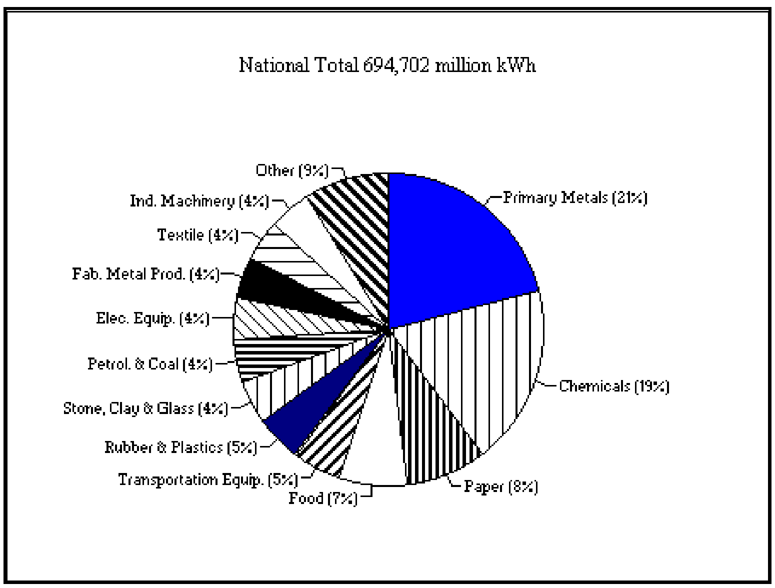

Figure 3 Total 1991 Electricity Consumption by Manufacturing Industries (Source: EIA, 1993b).

While the food group (SIC 20) is not very intensive overall, it is a large industry group and includes some intensive industries. Wet corn milling accounts for about 8 percent of the group's electricity consumption and uses about 0.6 kwh per dollar shipped.

An important observation is that electricity purchases are not a large part of manufacturing costs. In the electricity-intensive primary metals and chemicals groups, electricity costs are 4 percent of manufactured value. The average electric cost for all manufacturing industries is about 1.2 percent. While food industries consume over seven percent of industrial electricity, electricity costs represent only

Figure 4 Electrical Intensity of Selected Manufacturing Industries and Industry Groups (Source: EIA, 1993 & Census, 1993).

Figure 5 Purchased Electricity and Fuel, and Production Labor Costs as a Fraction of Wholesale Value of Shipments for Selected Manufacturing Industries and Industry Groups (Source: Census, 1992).

0.6 percent of manufactured value. For most manufacturers, other costs like labor represent a much larger share of operational cost as is shown in *Figure 5* (Census, February 1993). There are a few notable exceptions. Electricity purchases in both primary aluminum production (SIC 3334) and industrial gases (SIC 2813) exceed 20 percent of manufactured value, and exceed 10 percent in alkalies and chlorine (SIC 2812), and hydraulic cement (SIC 3242).

Since electricity purchases account for a small fraction of production cost in most manufacturing industries, most firms will not be highly motivated by the cost savings potential from electrical savings options alone.   Additional co-benefits, such as emissions reduction or productivity enhancements, will be necessary to motivate changes in energy use behavior in many cases. If a program is to encourage more efficient use of electricity, it must be structured so as to look at energy as a part of the manufacturing process, rather than look at it in isolation. It is fortunate that many process-related efficiency improvements also offer these co-benefits.

III. HOW ELECTRICITY IS USED IN MANUFACTURING

Electric energy use in manufacturing can be grouped into three broad categories: lighting, process, and motor loads. Motor loads are the largest group accounting for over two-thirds of the consumption (*Figure 6*). Lighting accounts for about 7 percent of overall industrial electrical consumption. But lighting accounts for over 10 percent of electricity consumption in nine of the twenty industry groups, and accounts for more than 15 percent of electrical consumption in six of the industry groups: textiles, printing, apparel, furniture, tobacco, and leather. Direct process energy use accounts for the remaining quarter of electricity consumption. This category includes electrolytic processes (of which aluminum refining is the largest consumer) and various process heating requirements such as drying, curing, melting and heating. Five industry groups account for most of the process energy consumption: chemicals (SIC-28), primary metals (SIC-33), fabricated metal products (SIC-34), industrial machinery (SIC-35) and transportation equipment (SIC-37).

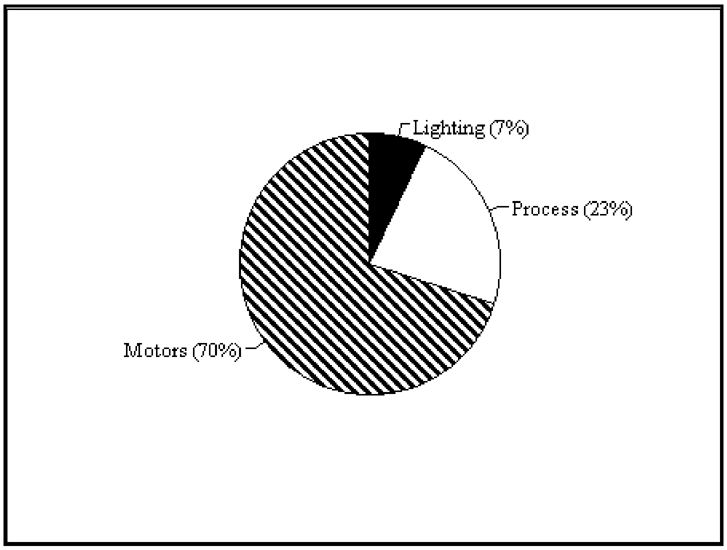

Figure 6 Estimated Electricity End-Use Consumption in Manufacturing Industries (Source: Resource Dynamics, 1988 & 1992).

In general, electricity use can be grouped into two broad classes: process-specific and generic. In process-specific applications like electrolytic and heating processes the electricity is consumed directly by the process. In generic applications like motors, lighting, and the generation of compressed air the energy use is once removed from the process. Over two-thirds of the electricity consumed by industry goes to these generic applications. This figure is misleading since the greatest efficiency opportunity for most generic applications is to modify the process to use less of what is produces (e.g., shaft horse power or compressed air).

In the next section, seven individual industry groups will be discussed in detail because of their high process usage or large fraction of manufacturing electric consumption. Since motors account for such a large fraction of the electrical consumption in most industry groups, motor use and conservation potential in motor systems will be discussed in a following section. Likewise, lighting use and conservation opportunities have many common characteristics across industry groups and will be discussed last.

As will be shown, a significant electricity conservation potential still exists from efficiency improvements to existing systems in all these industry groups despite the efforts made by industry in the last two decades. Additional energy savings can be achieved through the re-engineering of processes to ensure that the minimum amount of energy is used to accomplish the necessary tasks.

A. Electric Consumption in Specific Manufacturing Industry groups

1. Primary Metals (SIC 33)

Primary metals manufacturing is the industry group that consumes the most energy, both electric and total. Primary aluminum and steel production are the dominant electricity consumers accounting for almost three-quarters of the electricity consumed by this industry group. Each industry would independently rank in the top five industry groups for electricity consumption. Unlike most other industry groups, most of the electric energy in primary metals goes directly into the process. Only a third of the electricity goes to motor drives, with only 20 percent of that going to fans, pumps and compressors. Half of the motor energy goes to materials processing of which 40 percent is used in forming and 32 percent in crushing and grinding operations. The remaining 30 percent of the motor load is consumed by materials handling systems (Resource Dynamics, 1992).

<u>Steel Mills</u> (SIC 3312)

Steel making accounts for over two thirds of the total energy consumed in the primary metals industry group, and slightly over a quarter of the electricity (EIA, 1993). The steel industry has undergone major dislocations in the last twenty years due to changing technology, material use patterns and world markets. Primary steel production (i.e., production of steel from iron ore) peaked in the U.S. in 1978 at slightly over 137 million tons before falling to a low of about 75 million tons in 1982. The industry rebounded in the late

1980s to almost the 100 million ton level before the recession of 1991 caused production to drop below 90 million tons. 1992 and 1993 have seen a rebound in the industry with production expected to move back up to a sustained level of slightly over 90 million ton by the mid-1990s. The advent of low-cost minimills, such as Nucor, who operate on scrap, has shaken the market. Once thought only a threat in the structural steel market (e.g., rebar, beams and girders), Nucor is now producing rolled stock (e.g., sheet steel)(International Trade Administration, 1993 and 1994).

The steel industry can be divided into three market groups: integrated steel production from iron ore (primary steel production), secondary production from scrap, and specialty steel production (e.g., stainless and tool steels). The feedstocks and technologies used in each sector are different, and to a large extent the markets for their products are also different. Steel is produced by three major processes: open hearth, basic oxygen and electric arc furnaces. Primary steel making produces the greatest tonnage nationally, and is in general dominated by the basic oxygen technology with some older, open hearth capacity. The secondary and specialty markets use electric arc furnaces (EAF) almost exclusively. Minimills account for about two-fifths of the operating EAFs and an even greater share of the total tonnage. Though specialty steels have a high value, they account for only a third of the EAF and tonnage is small compared with minimills steel (McIntyre and Landry, 1992). *Table I* reports the average electrical and total energy intensity of these three process estimated in 1982 by Argonne National Laboratory. In addition, the market share of each technology in 1980 and 1989 is reported along with a projection for the year 2000 (Energetics, 1988).

Steel making is a multi-step process. In integrated mills, ore is combined in a blast furnace with coke produced in coke ovens to produce pig iron. The iron is then refined into steel in a steel making process. Finally the steel is annealed in furnaces. *Table II* shows the fuel utilized in 1983 in each step.

Table II
Electric Intensity and Market
Share of Steel Making Processes

Steel Making Process	Electrical Intensity 1982 (kWh/ton)[a]	Market Share 1980[b]	Market Share 1989[b]	Projected Market Share 2000[c]
Open Hearth	15	12%	4%	0%
Basic Oxygen Furnace	30	60%	61%	60%
Electric Arc Furnace	596	28%	36%	40%

a - Argonne National Lab, 1982
b - *Industry Brief*, 1991b
c - Azimi, 1988

While there is now some use of EAF in integrated mills, it remains small . The newest technology in primary steel production is direct steel making in which the iron and steel production steps are combined. Several technologies offer the potential to reduce total energy intensity at integrated mills through switching from fossil fuels to electric energy, particularly in the iron making process (Energetics, 1988). Induction and vacuum arc melting both offer reduced net energy requirements while also providing improved process yield and product quality (Resource Dynamics/Battelle, 1988).

Table IIII
Fuel Use by Steel Making Process for 1983

Fuel (TBtu)	Total	Coke Oven	Blast Furnace	Steel-making Furnace	Annealing Furnaces	Other
Coal	859.9	800.6				59.3
Fuel Oil	64.6	2.5	18.5	9.6	12.7	21.4
Nat. Gas	379.1	14.8	19.0	19.3	216.5	109.6
Electricity	445.1	7.6	12.9	184.3		240.4
Coke	686.5		686.5			
Other	331.3	83.0	63.8	1.8	54.1	128.3
Total	2,766.5	908.5	800.7	215.0	283.3	559.0

Source: Energetics, 1988

In integrated steel making, much of the electricity is consumed by motors. The major end uses are for blowers, fans and compressors. The most electricity intensive use is the production of oxygen, a process discussed in the following section on chemicals. Additional electricity is consumed by the motors in the materials handling systems (Energetics, 1988). Information on the distribution of these end-use motor loads is not readily available. The opportunities for improvements in these electricity uses are discussed in the section on electric motor systems.

In the secondary market, post-consumer scrap is refined in an EAF, eliminating the coking oven and blast furnace operations. As can be seen, the majority of electricity in steel making is consumed by the arc furnaces used predominately by minimills. A survey of arc furnaces by Energetics (Azimi, 1988) reported the intensity ranged from 380 to 613 kWh per ton, with the variation coming from product mix and level of technology implemented. Many of the older facilities are more electricity intensive, with the newer facilities already realizing some of the efficiency opportunities. While facilities may shed load for demand control (i.e., shutting off furnaces for brief periods of time), it is rarely attractive to reduce the rate of power consumption because power input is a factor in EAF efficiency. Most of the focus on electricity use will be on increasing rate of production for a given power input (i.e., decreased intensity).

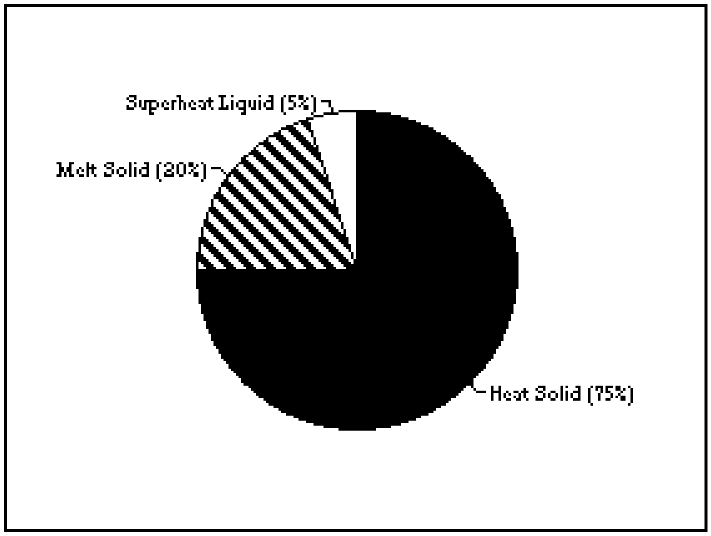

Figure 7 Distribution to Energy Input to EAF (Source McIntyre and Landry, 1992).

Electric power input can be reduced by the use of supplemental heat, but requires careful balancing of the different energy costs. About three-quarters of the energy input to an EAF goes to heat the solid material (*Figure 7*). Three types of supplemental heating can be used to decrease the amount of electricity used in furnaces: scrap pre-heating with furnace exhaust gas, use of supplemental fuels, and increased use of oxygen lances. Both scrap preheating and supplemental fuels reduce electricity required to heat the solid. Scrap preheating uses furnace off gases to reheat the charge to the EAF. This technology offers a reduction in heating requirements of 100 kWh per ton or approximately 15 percent of total 1982 electric energy. While seeing significant use in Japan, this technology has just begun to enter the U.S. market (see Case Study) (Energetic, 1988 and McIntyre and Landry, 1992).

The use of supplemental fossil fuel burners can be used to reduce the time required to heat the solid. These burners can be temporary or permanently installed, but their benefits decline as the solid temperature increases (Energetic, 1988 and McIntyre and Landry, 1992).

The use of oxygen lances can also reduce the electricity input to the EAF by 50-100 kWh per ton of steel and reduce tap-to-tap times by 5-8 minutes. The normal range for oxygen use is 500-1,000 cu. ft. per ton of steel. Rates above 1100 cu; ft. per ton exceed the available oxidizable materials in the melt, thus reducing overall efficiency by oxidizing the iron. The improved performance from increased oxygen use must be weighed against the cost of the oxygen (McIntyre and Landry, 1992).

Both scrap preheating and increased oxygen use result in increased capital and operating costs associated with pollution control equipment due to increased gas volumes and fines. These costs can limit the applicability of these technologies at some sites (McIntyre and Landry, 1992).

Other technologies also offer potential for increased efficiency. Ultra high power transformers, bottom tap vessels, sustained foaming slag, and water cooled furnace panels each offer reductions in the 1 to 5 percent range. One study estimates that the energy savings in electric arc furnaces could be as high as 23 percent over the 1983 base case. As noted previously, some of this potential has already been realized at new facilities built in the last 10 years, but it appears that about 13 of the 23 percent still remains to be realized by 2000 (Energetics, 1988).

Because of the complexity of the structure of the steel industry and lack of disaggregated electricity end-use data, it is difficult to make estimates of the conservation or efficiency potential on a end-use basis. Because of the magnitude of electricity consumption and the trend for increased electricity intensity, this topic represents an area for future research.

Application of Scrap Preheating at Florida Steel

Florida Steel in Charlotte, NC is a minimill steel producer using a 75 ton EAF. As part of a demonstration project, they installed a CONSTEEL scrap feeding and preheating system in 1989. Hot waste gases represent about 25 percent of the energy input to the furnace. The system involves a vibratory conveyor and preheater using both waste gas from the EAF and supplemental fuel burners. The preheating portion is a 80 foot long refractory-lined tunnel. Hot furnace gases pass out of the EAF side opening, through the preheater (countercurrent to the scrap charge) and into ductwork leading to the baghouse. Sixty natural gas burners are located in the roof of the preheater to supply supplemental heat.

In normal operation, a "heat" is started with 30-35 tons of melted steel in the furnace. Scrap is added at about 1500 lb/min until the full heat of 70 tons is reached. The system is designed to be operated with a continuous foaming slag on top of the melt. The furnace is also equipped for both carbon and oxygen injection.

Several problems were encountered with the system. Because the EAF was operated with the furnace door open, waste gas was diluted resulting in reduced gas temperatures and reduced heating. The increased gas volumes also entrained some of the additives added with the scrap. In addition, consistent foaming slag operation was not maintained resulting in increased electrode consumption.

Scrap preheating reduced processing time from 83 to 60 minute tap-to-tap, resulting in an average productivity increase from 33 to 44 billet tons per hour. While electricity consumption did not change significantly, with the use of scrap preheating, total energy input (i.e., electricity, oxygen and natural gas) did decrease from about 522 to 486 kWh/ton. While measured temperatures indicate a equivalent reduction in total energy of 90 kWh/ton, actual energy consumption numbers do not show savings this large. It is suggested that this results from limited heat transfer from the waste gases to the incoming scrap.

The overall economics of the system are very attractive with the cost of production going from about $23.30/ton for conventional top charge operations to about $21.55/ton with scrap preheating.

Source: Bosley, et al., 1991.

<u>Primary Aluminum</u> (SIC 3334)

The primary aluminum industry involves the production of pure aluminum from bauxite and alumina (Al_2O_3). It is the single most electricity-intensive industry accounting for almost 10 percent of manufacturing consumption, and almost half of the primary metals group. Its consumption of electricity exceeds all other industry groups except chemicals. As a result of its intensive electric energy use, aluminum processing plants are concentrated in areas of low electricity cost such as the Pacific Northwest, western New York and Tennessee Valley where hydropower is plentiful.

About 84 percent of the electricity is consumed in the aluminum production process. Three primary steps are involved in aluminum production: extraction of alumina from bauxite by the Bayer process; reduction of the alumina in electrolytic cells to produce aluminum in the Hall-Heroult process; and remelting of scrap with smelted metal followed by purification, alloying and casting. As can be seen in *Table III*, the reduction step consumes most of the energy (Energetics, 1990a). The industry currently consumes about 7.25 kWh of electricity to produce a pound of aluminum. No current alternative processes to the Hall-Heroult cell show strong commercial potential, so the potential for improvement appears to lie in improved control of the existing process. The theoretical efficacy of the Hall-Heroult process is 2.85 kWh per pound of aluminum so significant theoretical potential to improve efficiency exists. Control of anode/cathode distance through new cathode materials, reduced heat loss from cells and improvements in electrolyte all offer significant potential for energy savings (*Industry Brief*, 1991a). The potential impact of these technology improvements has been projected to be between 10 to 30 percent for the reduction process (Arthur D. Little, 1990). A recent Congressional Office of Technology Assessment (1993) report estimated current energy intensity at 7.3 kWh/ton, and projected that by 2010 intensity could be reduced to 6.5 kWh/ton using state-of-the-art technologies and further to 6.0 kWh/ton with advanced technologies.

Table IIIIII
Electric Consumption in Primary Aluminum by Process Step

Process	Percent of Electrical Consumption
Bauxite to Alumina with Bayer Process	3%
Alumina to Aluminum with Hall-Heroult Electrolysis	96%
Holding, casting, melting, alloying, and scrap remelting	1%

Source: Energetics, 1990.

The use of recycled feedstocks, or secondary processing, has major impact on the energy use in aluminum production. Since the electrically-intensive reduction step is not required, only 5 percent of the energy is consumed in secondary processing from scrap as compared with the primary production from alumina (Energetics, 1990). Total production costs per unit production are comparable between primary and secondary processing, though the distribution of costs differs significantly as shown in *Figure 7*.

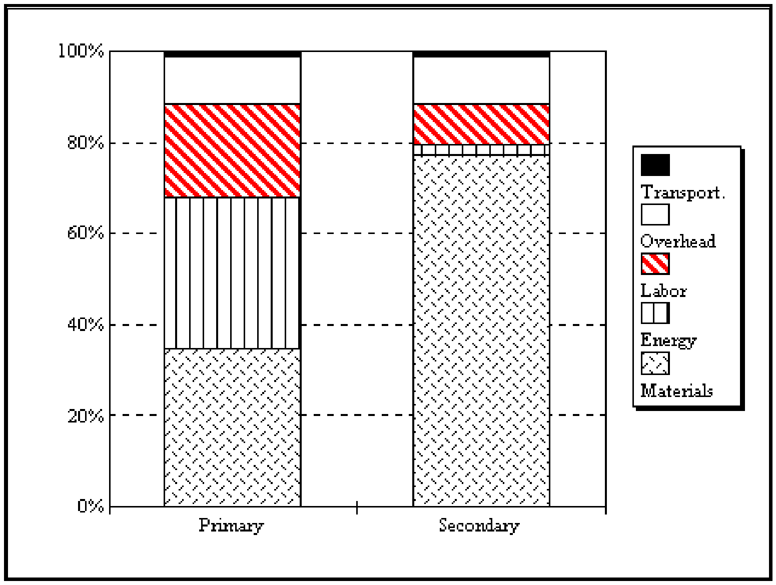

Figure 7 Aluminum Production Costs (as distributed in primary and secondary processing) (Source: Energetics, 1990)

Secondary processing has played an important role in U.S. primary aluminum production since the early 1900's. During World War II, the war-inspired recycling effort saw over 35 percent of the total production coming from recycled sources. The level fell to less than 15 percent by the late-1950s from which we have seen a steady rise since then (Energetics, 1990). Today about one-third of aluminum production comes from secondary processing (Elliott, 1993). As has been seen with steel minimills, dedicated secondary aluminum mills are now producing materials that have traditionally been the preserve of primary mills. The new Golden Aluminum mill in Lupton, CO is designed to use 95 percent recycled feedstock to produce sheet for beverage cans which have traditionally required at least half virgin material (Charlier, 1993). Greater use of recycled feedstock could result in significant energy savings. While production from scrap has traditionally been done by dedicated secondary plants, in recent years primary production facilities have used increasing quantities of scrap in their production (*Industry Brief*, 1991a).

When looking at the aluminum industry, it is important to remember that it is a global industry and not constrained by national boundaries. International market considerations and electricity prices dictate which processing operations are carried out domestically. The last five years has seen a steady increase in the importation of primary aluminum while domestic production has remained flat. These trends are projected to continue for the remainder of the decade (International Trade Administration, 1993). The recent wave of low-cost Russian aluminum and the global recession have created a glut in the international aluminum market, resulting in a decrease of domestic production capacity. U.S. aluminum producers have already mothballed about 15 percent of domestic capacity. Reduced Russian exports, a recovering economy and expanded markets for aluminum however could create global shortages by the end of the century with corresponding changes in the global production picture (Aeppel, 1993).

Table IVIV
Electricity End-Use and Conservation Potential in the Aluminum Production Industry

Electricity End-Use	End-Use Fraction of Electricity Consumpt.	Savings Potential as % of End-Use Fraction (d)
Process	84% (a)	10-30% (c)
Motors	13% (b)	13-40% (d)
Lighting	3% (b)	20-40% (d)

Source: (a) Energetics, 1990a
(b) estimates made by author as described in text.
(c) A.D. Little, 1990 and OTA, 1993.
(d) See sections on Electric Motor System and Lighting for conservation assumptions.

Although most of the electricity is used directly in the production process, the remainder used by motors and lighting is still very large since total consumption by the industry is so great. No data on distribution of electricity for these end-uses is available, so the author has made order of magnitude estimates of lighting and motor consumption as reported in *Table IV*.

2. Chemicals (SIC 28)

The chemical and allied products industry group produces a diverse group of products ranging from organic and inorganic industrial chemicals to synthetic materials and drugs. The chemicals industry group is the largest industrial energy consumer accounting for over 20 percent of total energy consumed by the manufacturing sector in 1991, not including the substantial energy value of their feedstocks. In electrical consumption, the chemical industry group ranks second to primary metals at almost 19 percent of manufacturing electricity consumption (EIA, 1993). Motors account for the largest fraction of the electrical load at 66 percent with lighting at about 7 percent and process about 27 percent. Almost all the process electric use is in electrolytic separation processes such as chlorine and alkalies production (SIC 2819). Three quarters of the motor load goes to pumps, fans and compressors with over 37 percent going to pumps, and 27 percent going to compressors (Resource Dynamics, 1988 and 1992).

Five industries account for three quarters of the electric consumption within the chemicals industry group. Industrial inorganic chemicals industry (SIC-2819) (which produces acids, bases and salts) is the largest electricity consumer of these industries accounting for about 29 percent of the whole industry group's consumption. Industrial gases (SIC-2813) (often referred as the air separation industry which produces liquid oxygen and nitrogen) is next with about 14 percent. Organic chemicals (SIC-2869), and plastics and resins (SIC-2821) each account for between 11 and 12 percent, and alkalies and chlorine (SIC-2812) for about 8 percent of the industry groups electricity consumption (EIA, 1993).

The industrial inorganic chemicals industries (which include SIC-2812, 2813, and 2819) are the major consumer of direct process electricity. The co-production of chlorine and sodium by electrolysis (SIC-2812) is the major process use, consuming 8.3 percent of the chemical industry group's electric energy (EIA, September 1993), of which 90 percent is used in the electrolysis process. This industry represents over a quarter of the electrolytic process consumption for the chemical industry group (Resource Dynamics, 1988). Diaphragm cells account for 77 percent of the production, with 14 percent used in the older mercury process and 6 percent in the newer membrane cells (Cascon, 1993). A shift from diaphragm cells to membrane cells could reduce electrical intensity of this process by 25 percent (Resource Dynamics/Battelle, 1988). This process change represents an average savings potential in the process of about 20 percent. Absent data on other processes we assume this savings potential extends to other electrolytic processes in the chemical industries group.

Cryogenic air separation of industrial gases (SIC-2313) is very electricity-intensive with electrical purchases accounting for 80 percent of the energy used, and 21 percent of manufacturing costs (as discussed earlier). This industry consumes 13.8 percent of the electricity in the chemicals industry group (EIA, 1993). Compressors consume ninety-five percent of the electricity in compressing air and cooling the liquid so that it can be distilled into its various components (Cascon, 1993). An alternative to cryogenic separation, the Miltox process, offers the potential for a 40 percent reduction in process intensity, though the technology is not yet commercial (Resource Dynamics/Battelle, 1988).

Table VV
Electricity End-Use and Conservation
Potential in Chemicals Industries

Electricity End-Use	End-Use Fraction of Electricity Consumpt.	Savings Potential as % of End-Use Fraction (c)
Direct Process Electricity	26% (a)	(No estimate made)
- electrolytics	25% (a)	~20%
Motors	63% (a)	14-51%
- Conveyors	10% (b)	(included in motors estimates above)
- Pumps	23% (b)	2-10%
- Fans	7% (b)	2-10%
- Compressors	17% (b)	20-40%
- Materials Processing	6% (b)	(Not Available)
Lighting	7% (a)	20-40%

Source: (a) Resource Dynamics, 1988
(b) Resource Dynamics, 1992.
(c) See text and sections on Electric Motor System and Lighting for conservation assumptions.

Production of plastics, resins, synthetic fibers and other organic chemicals (SIC 282 and 286) begin with petroleum feedstocks which are refined and recombined in multi-step processes to produce various products. Most of the electricity in these industry groups is used by motors driving pumps, fan and compressors.

In addition to the process innovations mentioned above, electric motor systems offer large savings opportunities in this industry group (*Table V*). The motor savings are particularly great because of the high fraction of pumps, fans and compressors. These savings opportunities are summarized in *Table V*, and will be discussed in the Electric Motor System section.

Overcoming Barriers to Industrial Energy Efficiency at the Louisiana Division of the Dow Chemical Company

An inspiring tale of how to realize improved energy efficiency through corporate culture-change is told by Ken Nelson recently retired from the Dow Chemical Company. The Louisiana Division began an annual Energy Contest in 1981 conducted by an energy committee organized by Nelson. Plant employees were encouraged to make energy efficiency suggestions with a capital cost of less than $200,000 and a return on investment (ROI) of 100 percent (about a one year payback). Twenty seven project passed a review with a capital cost of $1.7 million and an average

ROI of 173 percent. Over the next years the number and savings of the proposed projects increased, with 140 projects meeting requirements in 1993 for an annual savings of $28.4 million of which 16 percent came from direct energy savings (*Table VI*).

Table VIVI
Dollar Summary of Winning Contest Projects
Having ROIs Above the ROI Cut-off

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Cost, $Million	1.7	2.2	4.0	7.1	7.1	10.6	9.3	7.5	13.1	8.6	6.4	9.1
Savings, $Mill/yr:												
Fuel Gas	2,970	7,650	6,903	7,533	7,136	5,530	4,171	3,050	5,113	2,109	5,167	4,586
Yield & Cap.	83	-63	1,506	2,498	798	3,747	13,368	32,735	8,656	17,909	11,645	20,311
Maintenance	10	45	-59	187	357	2206	583	1,121	1,675	2,358	2,947	2,756
Miscellaneous	0	0	0	0	0	19	-98	154	2,130	5,270	518	788
Total Annual Savings, $Mill./yr	3,063	7,632	8,350	10,218	8,291	11,502	18,024	37,060	17,575	27,647	20,277	28,440

Most of the proposed projects were process improvements which yielded production savings even greater that the energy reductions. The Dow Energy Committee that ran the program circumvented any threats to management by only exerting influence, not attempting to control staff and money. The project were proposed and implemented within the existing system. The program "empowered" the plant engineers to make their plants more efficient. The contest offered no cash rewards, since this competed with the system by setting up a parallel system that competes with loyalty to the boss. Rewards were recognized as part of the employees job review.

The program was a bottoms-up program. Nelson remarks that he never received full support from management, but rather their tolerance. This situation benefitted the persistence of the program by isolating it from changes in top management. It was allowed to survive because it showed profitability, which made top management look good.

Source: Nelson, 1994

3. Pulp and Paper (SIC 26)

The pulp and paper industry in the U.S. can be divided into three broad categories: manufacture of pulp from wood; production of paper and paperboard from wood pulp; and production of finished products from paper and paperboard (eg., boxes, cartons, drums). Pulp production is grouped into two categories: pulp produced at an integrated mill and consumed internally; and pulp produced at a dedicated facility for resale. The majority of pulp (86 percent) is produced at integrated mills. The market pulp category (SIC 2611) is relatively small, but the measures applicable to the pulp portion of integrated mills are also applicable to the dedicated mills (*Industry Brief*, 1991c). The output from paper (SIC 2621) and paperboard mills (SIC 2631) are usually grouped together and the data combined. These three categories combined account for over three-quarters of the electric consumption by the industry group as a whole (see *Table A-I* in the Appendix) (EIA, 1993).

Almost all of the electricity in this industry group is consumed by motors. Motors loads are about evenly distributed among centrifugal loads (i.e., pumps, fans and compressors), materials handling, and process loads. Pumps account for two-thirds of the centrifugal loads. Of the process loads, about 35 percent each involve cutting and mixing, and 20 percent is crushing operations (Resource Dynamics, 1992).

Pulp manufacturing falls into two major categories: chemical production and mechanical production. Chemical pulp accounts for nearly 90 percent of the U.S. production with the Kraft process being dominant. The wood chips are softened in a caustic sulfide cooking liquor and require only small amounts of mechanical action to separate fibers. The waste liquor is then sent to a recovery process to recover the chemicals in a special furnace. This furnace is the single most capital-intensive item in the pulp mill. These furnaces generate steam which is used to generate electricity and to provide heat to the process. Most pulping operations generate more electricity than is required in the pulping process with the excess being consumed by the papermaking processes.

Mechanical pulps are produced by forcing chips between counter-rotating disks which convert the wood into pulp. This process is very electricity intensive requiring about 1,500 kWh per ton of pulp (*Industry Brief*, 1991c). Mechanical pulps do not have the excellent strength or color of bleached kraft pulps. The paper made from mechanical pulp has limited applications. It is principally used for printing where its high opacity is desirable.

After the pulp is produced, it is bleached to remove the color from the lignins and extractives. Chemical pulps require less bleaching than mechanical pulps since much of the lignin is removed in the pulping process. Electricity consumption in the bleaching of kraft pulps can be as low as 80 kWh/ton bleaching, while bleaching may consume upwards of 170 kWh/ton in mechanical pulping operations (Elaahi & Lowitt, 1988 and Larson, 1992).

Paper and paperboard are made in two steps: stock preparation and paper making. In stock preparation the pulp slurry is subjected to mechanical action to evenly hydrate the fibers. This step requires about 5 percent of the energy consumed in the paper making process and is a major electric energy consumer. The refining operation, which requires 200-420 kWh of electricity and 1.1-2.4 million Btu of thermal energy per ton of paper, requires most of the electricity. The electricity is consumed in the mechanical agitation of the pulp slurry.

The paper machine removes water from the pulp slurry and dries the paper. This water removal occurs in three phases, each more energy and capital intensive than the previous. First water is allowed to drain from the slurry on porous belts. Next water is mechanically extracted by pressing the web. Finally the paper is dried by evaporation. The paper machine consumes 300-400 kWh of electricity and 6.5-12.5 million Btu of thermal energy per ton of paper. Most of the thermal energy is used in drying and is an area of active research. While thermal energy reductions of up to 50 percent are projected for the application of impulse and infrared drying, these are offset in part by increased electric consumption of up to 200 kWh per ton. These technologies

Table VIIVII
Electricity Use in Pulp and Paper Processes

Unit Process	Market Fraction [b]	Electric Consumption kWh/ton paper[*]			Fraction of Total Consumpt	Motor Load Fraction[C]	Fraction Pump/Fan of Motor Load[C]
		Low	High	Avg			
Wood Preparation		41	60	51	4.1%	98%	0%
Pulping				508	41.6%	98%	55%
Mechanical							
stone groundwood	2%	1,260	1,450	1,355		98%	0%
refiner	2%	NA	NA	1,771		98%	5%
thermomechanical	3%	1,200	2,000	1,800		98%	5%
Chemical							
kraft	63%	325[a]	470[a]	400[a]		98%	80%
sulfite	2%	NA	NA	400[a]		98%	80%
Semichemical	6%	250[a]	550[a]	400		98%	40%
Waste paper	22%	381	552	467		98%	5%
Bleaching		80	500	237[e]	19.4%	95%	95%
Chemical Recovery		0	166[d]	104[e]	8.5%	98%	95%
Papermaking and Drying				364	29.8%	95%[*]	10%[*]
Other (lighting, etc.)				66	5.0%	50%	75%
Total				1,221		95%	48%

NA - not available

Source: * - Elaahi & Lowitt, 1988 unless otherwise noted.
a - F.T. Sparrow, 1990
b - Energetics, 1990
c - estimates made by ACEEE unless otherwise noted.
d - Larson, 1992
e - weighted average reflecting predominance of kraft pulping.

have seen only modest penetrations at this time due to the high cost of making modifications to existing process lines. The major opportunity for electrical conservation is in the application of energy-efficient electric motor systems, including energy-efficient motors, drives and variable speed drives (*Industry Brief*, 1991d).

Table VII summarizes the electrical energy consumption by unit process. The major area of variation between the different paper production processes is in pulping, where mechanical techniques require approximately four times the electrical energy of chemical processes. Industry averages and market fractions of the different types of pulping are used to estimate a weighted average for the generic categories.

Table VIIIVIII
Electricity End-Use and Conservation Potential in Pulp and Paper Industries

Electricity End-Use	End-Use Fraction of Electricity Consumpt.	Savings Potential as % of End-Use Fraction (c)
Direct Process Electricity	2% (a)	(No estimate made)
Motors	95% (c)	10-44%
- Conveyors	23% (b)	(included in motors estimates above)
- Pumps	38% (c)	2-10%
- Fans	10% (c)	2-10%
- Compressors	6% (b)	20-40%
- Materials Processing	23% (b)	(No estimate made)
Lighting	3% (a)	20-40%

Source: (a) derived from Resource Dynamics, 1988
(b) derived from Resource Dynamics, 1992.
(c) See text and sections on Electric Motor System and Lighting for conservation assumptions.
(d) See text and *Table VII*

As mentioned, motors account for almost all of the electricity consumption (*Table VIII*), with the remainder used for miscellaneous applications, predominately lighting. Chemical pulping and bleaching are the unit processes with very high fan and pump loads. In addition, the chemical recovery process is also a large consumer of electricity for pumps and fans associated with the operation of the chemical recovery boilers. Since chemical pulping is the predominate pulping method, this weights the motor load average toward pumps and fans. Direct motor drives account for most of the load in mechanical pulping. With 95 percent of the electrical load consumed by motors and 48 percent of the motors being used by pumps and fans, motor measures represent the greatest opportunity for electricity savings as described in *Table VIII*.

Recycling has a major impact on energy consumption in the paper industry. While 60 percent less energy is required to make paper from recycled feedstocks in an integrated chemical pulp and paper plant, the bark, reject chips, and waste liquor are no longer available for use as a fuel so they must be replaced with purchased fuels. In addition, recycled pulps are produced using mechanical rather than chemical processes which shifts the fuel distribution toward electricity due to the predominance of motor drives.

4. Food (SIC 20)

Food processing is a diverse and widely dispersed manufacturing industry group consisting of over 30,000 facilities and employing over 1.5 million workers. Products range from chocolate to flour to meat to wine. The distribution of facilities tends to vary by region with 80 percent of the value added coming from twenty states. Food processing is also a low profit margin industry averaging about 4 percent, almost 2 percent lower than other non-durable goods manufacturing industries. It is also a dynamic industry, constantly changing due to market dynamics and intense competition.

Table IXIX
Energy Consumption in Food Processing Industries

	Energy Consumption 1980		Energy Consumption 1985	
	(TBtu)	Fraction	(TBtu)	Fraction
Electricity	147.7		163.7	
Lighting	16.7	11%	18.5	11%
Process Heat	0.3	0%	3.1	2%
Motor Drives	130.7	88%	142.1	87%
Pumps, fans and compressors	57.5	39%	62.5	38%
Materials handling	37.0	25%	40.2	25%
Materials processing	36.2	25%	39.3	24%
Purchased Fuels	807.8		865.7	
Space Heating	14.8	2%	11.7	1%
Cogeneration Fuels	26.4	3%	38.7	4%
Process Heat Fuels	766.6	95%	815.3	94%
Natural gas	447.3	55%	299.4	35%
Fuel oil	105.1	13%	99.3	11%
Coal	119.1	15%	207.2	24%
LPG & other fuels	95.1	12%	209.1	24%

Source: Resource Dynamics, 1990

The processes employed by the food industry are as diverse as the products. These processes can be grouped into two categories: preservation and non-preservation techniques. Preservation processes involve the heating, cooling, curing or drying of a product to maintain or enhance its food value. Non-preservation processes change the form (e.g., grain milling) or extract a product (eg., oil extraction). *Table IX* shows a distribution of energy use in the industry group for 1980 and 1985. Electricity accounts for about 16 percent of the total energy. Of this electrical consumption, over 85 percent is motors and about 11 percent lighting as seen in *Table IX* (Resource Dynamics, 1990). As can be seen from the table, the use of electric process heating is increasing, and the literature indicates that this trend has been accelerating.

This report assumes that the process heating fraction has doubled to 4 percent by 1991. ACEEE's *Energy-Efficient Motor Systems* indicates that about half of this motor load goes to refrigeration (Nadel, et al., 1992), which is higher than reported in an recent EPRI study (Resource Dynamics, 1992). Based on the increase in process heat and the higher refrigeration fraction, an estimated end-use breakdown is presented in *Table X*.

Table XX
Electricity End-Use and Conservation
Potential in Food Processing Industries

Electricity End-Use	End-Use Fraction of Electricity Consumpt.	Savings Potential as % of End-Use Fraction (d)
Process Heat	4% (a)	(Not Available)
Motors	86% (a)	14-45%
- Refrigeration	43% (c)	5%
- Conveyors	19% (b)	(included in motors estimates above)
- Pumps	14% (b)	2-10%
- Fans	6% (b)	2-10%
- Compressed Air	4% (b)	20-40%
Lighting	10% (a)	20-40%

Source: (a) Derived from Resource Dynamics, 1990
(b) Resource Dynamics, 1992.
(c) Nadel, et al., 1992.
(d) See sections on Electric Motor System and Lighting for conservation assumptions.

The major opportunities for electrical conservation are motors, motor loads, and lighting as discussed in subsequent sections. The savings potential for this industry group is reported in *Table X*. Technologies such as freeze concentration, membrane processes, infrared and dielectric heating can achieve net energy savings by replacing steam or direct-fired processes with electrotechnologies. In many cases these processes can also provide other benefits in addition to the energy savings such as reduced processing times, better process control, improved product quality and in some cases, new products (Resource Dynamics, 1988).

Many food processing facilities are also candidates for waste water heat recovery because of the large volume of hotwater that is discharged from clean-up necessitated by sanitary regulations (Resource Dynamics, 1988 and *Industry Brief*, 1991e).

The Breyers Company
Framingham, MA

One of the most talked about energy efficiency projects in the food industry has been The Breyers Company ice cream plant in Framingham, MA. This 120,000 square foot facility built in 1963 produces about 20 million gallons of ice cream and frozen desserts each year. In the late 1980s the facility's production costs had risen to a level that made the facility uncompetitive with other manufacturing facilities. Increased electricity costs were a part of the problem.

In cooperation with Boston Edison, the facility underwent a sixteen day audit focusing on cooling, storage, manufacturing, packaging and sanitation systems by two engineering firms. They identified 6 million kWh of annual savings opportunities. These measures included:

1. new refrigeration system with automated controls
2. new air handling equipment in the freezer
3 new lighting system with T-8 fluorescent lights, reflectors and electronic ballasts,
4. high-efficiency motors for some process equipment, and
5. installation of a heat recovery system.

Installation of the improvements was completed in March 1990. Beginning in June 1991, a two year savings verification process was undertaken. Lighting system changes resulted in a 30 percent overall savings, and the replacement of forty motors in the 5 to 40 hp range resulted in approximately a 10 percent increase in efficiency. The refrigeration system savings were estimated at about 50 percent, while at the same time handling increased production. Actually electricity savings for the two year period were 12.5 million kWh, or 112 percent of estimated electricity reduction .

The largest portion of the savings, 64 percent, was achieved from the refrigeration system upgrade, with 32 percent coming from the air handler retrofit. The lighting system improvements yielded 2.5 percent of the savings and motors replacement produced 1.5 percent of the savings. This savings distribution is consistent with the observation that the greatest conservation potential lies modifying processes.

Since the measures were implemented, electricity (kWh per gallon of ice cream) has been reduced 25 percent and electric costs per gallon decreased 2 cents compared to 1988. An additional, unexpected benefit was realized with an improvement in productivity due to a change in the corporate culture at Breyers. Production line efficiency improved over 10 percent from the start of the verification period.

Source: Crowley and Donoghue, 1993 and Donoghue, 1993.

5. Metals Fabrication Industries (SIC 34, 35, and 37)

Three metals fabrication industries, Fabricated Metal Products (SIC-34), Industrial Machinery (SIC-35), and Transportation Equipment (SIC-37) share similar manufacturing processes and energy use characteristics. Electrical use is about balanced between motor load, which varies from 42 to 62 percent (Resource Dynamics, 1992), and process energy with load varying from 30 to 42 percent (Resource Dynamics, 1990). Process energy use is primarily in the area of materials heating. In Industrial Machinery, the heating load is distributed as shown in *Table XI*. Because of the similarity in processes between these industry groups, a similar distribution can be assumed for the other two industries.

Materials can be joined with mechanical fasteners, welding, brazing/soldering, and adhesives. Welding offers the strongest bond. However, welding is a resource-intensive operation. Electricity is consumed at a rate of between 10 to 15 kWh per foot of weld. Labor costs vary from $25 to $90 per foot, and materials costs from $5 to $10 per foot. Thus energy is a very small fraction (less than 1 percent) of the total cost of this operation. The requirements for joining vary with the specific applications. In some cases, adhesive bonding can be substituted for welding in applications requiring less strength with resulting savings in both materials and energy costs. Adhesive curing times can be lengthy, so the joint can be heated to accelerate curing if time is critical (Resource Dynamics/Battelle, 1988). We

Table XIXI
Electric Use for Heating Processes
in Industrial Machinery Manufacturing

Heating Process	Energy Fraction
Welding	40%
Heat Treating	40%
Casting	20%

Source: Resource Dynamics/Battelle, 1988.

estimate that 10 percent of the welds can be replaced with adhesive bonds for a 50 percent electric energy savings at no net additional material and labor cost.

The electricity used in heat treating is consumed in two operations: direct induction heating in which a current is passed through the product and indirect resistance furnaces in which a resistance element is heated and in turn transfers heat to the product. Heat treating is used to relieve residual stresses in metal parts resulting from manufacturing operations and to control the material properties of metals (e.g., hardness, ductility). Both these technologies compete with fossil fuel ovens which in general offer lower initial and operating costs, but less control. While electric heating is more costly, it is generally more efficient and so may offer some opportunities for fuel switching. In addition, electrotechnologies such as powder coatings and infrared drying do offer opportunities in these industry groups for net energy savings over fossil-fueled thermal processes (Resource Dynamics/Battelle, 1988).

The casting process involves melting metal and then introducing it into a mold to produce components such as engine or machine parts. Electricity is used in some casting processes which require very high quality components and for metals that would degrade in the presence of combustion products. Electricity is used to melt the metal by three processes: electroslag casting (ESC), vacuum-arc melting (VAR) and induction melting. ESC and VAR are directly competing technologies for producing very high quality castings. Capital cost for the two technologies are similar, though energy and operating costs appear lower for the ESC than for VAR. ESC uses between 50 and 90 percent of the energy of a VAR. In addition, ESC has the potential to produce very high quality castings which can substitute for forged components reducing or eliminating subsequent processing (Resource Dynamics/Battelle, 1988). VAR is the dominate technology. While no distribution of energy use by each technology is available, we estimate a conservation potential of 5-20 percent.

Induction casting is used for high quality castings because of its high quality, yield, flexibility and energy efficiency. The technology competes with coke fueled cupolas. Capital cost for the two technologies are comparable. The induction furnace is more energy efficient and has a lower operating cost. This technology represents a conservation opportunity from fuel switching (Resource Dynamics/Battelle, 1988).

Electrogalvinization is an important electricity using process in the fabricated metals industries group (SIC-34) accounting for almost 8 percent of the total electricity consumption. This process deposits a corrosion inhibiting layer of zinc on steel by electrolysis. Electricity consumption accounts for 15-35 percent of the total production cost in this process. Because all the new equipment used in this process is patented, operating data is not publicly available. Reduced electricity consumption must be considered with increased capital costs since electrogalvinization equipment is very expensive. Processing lines cost $50-150 million, with the more expensive equipment generally being more energy efficient (Resource Dynamics/Battelle, 1988).

While pumps fans and compressors account for about a third of the motor load in transportation equipment (SIC-37), they account for only a fifth in fabricated metals products (SIC-34) and industrial equipment (SIC-35). Materials processing equipment consumes between 35 and 50 percent of the motor load. Of this load between 40 and 45 percent is used in forming operations such as stamping and forging. Most of the remainder of the process load goes to cutting operations. As discussed in the accompanying sidebar, many of these processing operations represent significant compressed air loads which offer significant potential for reduced air use (Price and Ross, 1989). The energy savings opportunities also exist from the use of more efficient fans, pumps and compressors, and from more efficient motor system in materials handling systems.

Very attractive opportunities exist in this industry group for the application of electro-technologies to coatings. Many of the products produced in these industry groups have a coating applied (e.g., paint). These coatings have traditionally been solvent based and are either air dried or dried in fossil fueled convection ovens to accelerate drying time. Infrared drying can be used to replace the convection ovens for decreased capital cost and improved speed. The applications of infrared and ultraviolet technologies have spawned new types of coatings, such as electrostatic powders, which have no solvents eliminating a major environmental compliance problem for many facilities. These coatings can also reduce materials cost, increase production speed and improve product quality.

Table XIIXII
Electricity End Use and Conservation
Potential in Metal Fabrication Industries

Electricity End-Use	End-Use Fraction of Electricity Consumption			Savings Potential as % of End-Use Fraction
	Fabricated Metal Prod.	Industrial Machinery	Transport. Equipment	
Electrolytics	8% (c)	<1% (c)	<1% (c)	(not available)
Process Heat	34% (c)	31% (c)	30% (c)	(included below)
- Welding	14% (a)	12% (c)	11% (c)	~5% (a)
- Other Process Heating	20% (a)	19% (c)	16% (c)	5-20% (d)
Motors	42% (c)	53% (c)	62% (c)	13-42% (d)
- Pumps	2% (c)	3% (c)	6% (c)	2-10% (d)
- Fans	2% (c)	1% (c)	2% (c)	2-10% (d)
- Compressed Air	3% (c)	6% (c)	10-30% (b)	20-40% (d)
- Conveyors	13% (c)	22% (c)	17% (c)	(included in motors estimates above)
Lighting	3% (c)	6% (c)	3% (c)	20-40% (d)

Source: (a) Resource Dynamics/Battelle, 1988.
(b) Price and Ross, 1989.
(c) Derived from Resource Dynamics, 1988 and 1992.
(d) see sections on Electric Motor System and Lighting for conservation assumptions.

The opportunities for electricity savings in the three fabricated metals industries are summarized in *Table XII*.

The Electricity Conservation Potential at Ford Motor Company

Ford Motor Company has evaluated the opportunities for reduced electricity use within their manufacturing facilities to be about 25 percent. The electricity conservation potential is grouped into five categories (see *Table XIII*). Some of the measures are "house keeping" types. Others require a change in process equipment. While retrofit of these latter opportunities can not be justified in most cases, these opportunities are cost effective when selecting new equipment. Opportunities offering ancillary benefits, such as increased reliability, improved working conditions and reduced maintenance requirements help motivate measure implementation at Ford.

Table XIIIXIII
Estimate of Electricity Use Reduction Anticipated in the Automotive Industry

Measure	Reduction in Electricity Use (percent)
Shutdown Controls	4 - 8
Motor systems	5 - 10
Compressed Air	3 - 5
Lighting	3 - 4
Heating and ventilating	1 - 5
Total	16 - 32

Source: Price and Ross, 1989.

Shutdown Controls

In 1987, Ford performed a comparison of electricity use at three automobile manufacturing plants during a holiday shut-down. Plant one had an energy management system controlling lighting, heating and ventilation systems, and a more controllable compressed air system. These systems were installed in 1970's due to high off-peak electric rates. The other facilities lacked these controls. The ratio of shut-down electricity use to operating electricity at plant one was 6:1, while plants two and three were 3:1 and 2.5:1 respectively.

A Canadian plant installed department sub-metering with weekly summary reports provided to department supervisors. A 5% reduction in electricity was realized after three years. Reduction was achieved largely in non-production hours and during periods of low production.

Motor Systems

At one Ford engine plant, ASD's were installed on machining coolant pumps which allowed precise pressure and flow control. Coolant flow could be turned off at a station to allow the workpiece to be changed without affecting other stations. Pressures were reduced from 64 psi to 45 psi, flows were cut in half and electricity usage was reduced by over 50 percent. The reduced pressure and flow resulted in an ancillary benefit of reduced coolant "misting" which reduced ventilation and clean-up requirements.

Replacement of vee belts with cogged belts have shown 2 to 10 percent reduction in motor load, with a reduction in total plant electricity load of 1 percent.

Compressed Air

Compressed air represents 10 to 30 percent to total plant electrical load in the automobile industry where it is used for many applications ranging from handtools to pneumatic cushions in stamping presses. Leak rates approach 50 percent. Well maintained systems require 20 to 30 percent of full load to maintain system pressure during non-production periods. Leak detection programs at Ford have achieved 10 to 25 percent reduction in compressed air demand. The results of a one-year program were effective for at least two years, but an ongoing program was necessary to achieve a lasting result.

Pneumatic die cushions in large stamping presses are used to support the lower die. Historically these cushions have been pneumatic cylinders pressurized with plant air. These cylinders develop leaks in as little as three months, which at a plant with 200 presses translates into 20,000 cfm of compressed air, requiring about 4 MW electricity. The replacement of these cylinders with air actuators (heavy-walled rubber air bags supporting a metal plate) can all but eliminate these leaks. Some actuators have been in place longer than 5 years with little or no air leakage. At one Michigan stamping plant, a reduction in compressed air requirements of 25 percent was achieved by converting to this technology in half of the presses. It is estimated that a complete switch to this technology at stamping plants would reduce plant electricity use by 10 to 15 percent, where 25 percent of the electricity is used by air compressor drives.

Lighting

Lighting consumes an average of 10 percent in automobile manufacturing facilities, and is another area of proven conservation potential. A manufacturing facility converted from florescent lighting to metal halide reducing energy levels from 2 to 1 watts per square foot while improving light levels.

Heating and Ventilation

Many space heating and ventilation systems are at least 30 years old. An Ohio plant had a mixture of steam and direct-fired gas heaters with a total motor load of over 2000 horse-power. In 1987 the system was replaced with a new computer-controlled, direct-fired gas system with an installed motor load of 800 hp. The system improved ventilation and reduced total plant electricity usage by about 5 percent.

Source: Price and Ross, 1989.

B. Electric Motor Systems

Motors account on average for about two-thirds of all the electricity used in manufacturing. As can be seen in *Figure 9*, the motor load fraction varies with industry group from about 33 percent in primary metals to about 90 percent in paper, petroleum refining, rubber, and wood products. In some individual industries, like primary aluminum, the fraction can fall to less than 2 percent, while in paper making and some textile facilities the fraction can exceed 90 percent (Resource Dynamics, 1988 and 1992).

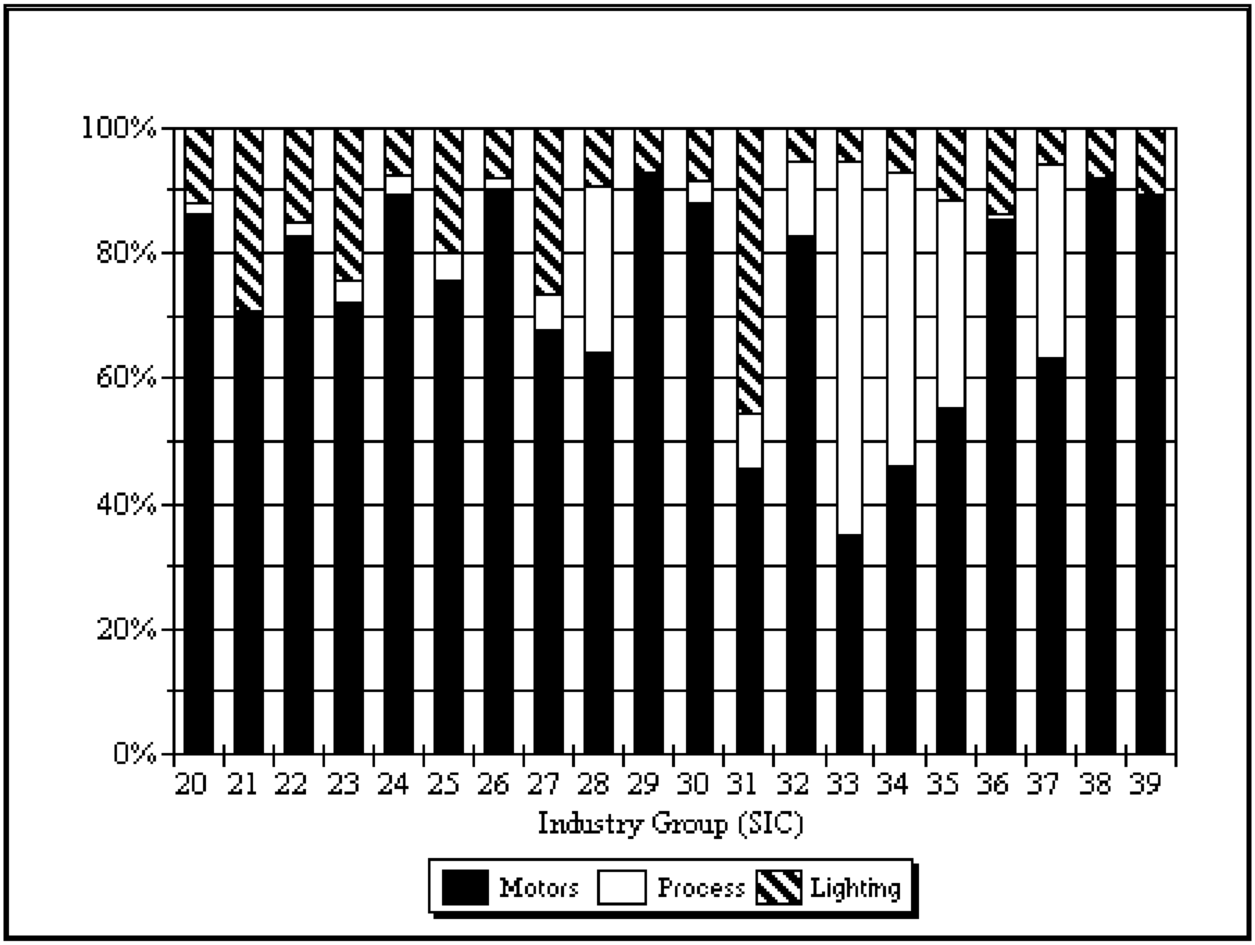

Figure 9 Electricity Consumption in Manufacturing Industry Groups by End-Use (Derived from Resource Dynamics, 1988 and 1992).

There are two approaches to improving the energy efficiency of electric motor systems (EMS): 1) reduce the EMS losses through more efficient equipment; and 2) more closely match load to the process requirements of the motor driven device through variable speed drives and other controls.

Electric motor systems are comprised of several components: the electric motor itself; the electric supply system that provides electric energy to the motor; and the drive mechanism which connects the motor to the load. Each component has energy losses associated with it, and the first approach is to minimize these losses. ACEEE has prepared a book discussing this topic in depth (Nadel, et al., 1992), and it is used as the source for this section unless otherwise noted.

Energy-Efficient Motors

Approximately 96 percent of the motor load is consumed by AC induction motors. Testing has confirmed that *energy-efficient motors* (EEM) are more efficient than *standard* motors, particularly at part load. The efficiency difference varies with motor size, with the greatest difference in the smaller sizes. A recent study, which conducted laboratory testing of over 100 motors from one to 200 horsepower, reported that EMM are on average 5 percent more efficient than the installed base of all motors. The existing motors were initially less efficient than high efficiency motor and have experienced additional loss of efficiency due to wear and repair (Kellum, 1993). ACEEE estimates a range of improved efficiency of 1 to 9 percent, varying with motor size. On average EEM cost 3 to 30 percent more than standard motors though motor purchasing practices can reduce this difference. EEM also maintain their higher efficiency at part load which is particularly important since most motors operate at a fraction of their full load.

EEM have become more widely accepted in the industrial market place. In 1987, EEM accounted for an estimated 20 percent of all new motor sales. While there is significant variation among industries as reported in a survey of motors in Wisconsin manufacturing facilities (*Table XIV*), EEM still account for less than 5 percent of the existing motor population (Howe, et al., 1993). The efficiency of the installed motor base is not likely to improve significantly in the near future. The average industrial motor has a life of 15 years, and in all likelihood will be repaired (commonly referred to as rewinding) at time of failure. While there is great dispute as to the impact rewinding has on motor life and efficiency, recent testing indicates that some loss of efficiency does occur, and that on average rewound motors operate 10 degrees C hotter than new, high-efficiency motors. These increased temperatures result in a significant shortening of the motor life (Kellum, 1993).

Table XIVXIV
Stock Saturation of Energy Efficient Motors
In Wisconsin Industries in 1989

Industry group	HP-Weighted % EEM
Paper Mills	7.9
Motor Vehicles	0.6
Iron/Steel Foundries	0.0
Beverages	0.0
Engines and Turbines	1.3
Commercial Printing	3.1
Construction./Mining Equipment	1.0
Elec. Ind. Apparatus	0.2
Misc. Plastic Products	10.1
Nonferrous Foundries	17.4
Dairy Products	8.5
Converted Paperboard	0.1
Gen. Ind. Machinery/Equipment	3.3
Ind. Inorganic Chem.	0.0
Metal Forging/Stamping	0.0
Nondurable Goods	0.0
Durable Goods	0.0
Average	**3.0**

Source: Xenergy, 1989 as cited in Nadel, et al., 1992.

It is difficult in most cases to justify replacing operating motors with EEM. It is more reasonable to replace existing motors when they fail with EEM. Motors are routinely rewound, which can involve an outage of a day or more. With proper planning, a new EEM can be installed in a matter of hours and at a very low premium compared to rewinding. In addition to being more efficient, the new motor will likely be more reliable than a repaired motor (Kellum, 1993).

Available data indicate that half of all motors operate at less that 60 percent of rated load and a third at below 50 percent. As long as the motor is operated above 60 percent of rated load, the efficiency generally does not vary significantly. However below 40 percent rated load the efficiency declines rapidly. While it is impractical to eliminate all oversizing of motors due to high starting loads, uncertainty about actual loads and other use specific considerations, the correction of gross oversizing does offer potential for significant energy savings. For example, if a 30 horsepower motor operating at 50 percent of its rated load were replaced with a 20 horsepower motor operating at 75 percent of it rated load (i.e., a 15 horsepower load), an energy savings of 2 to 3 percent would be realized due to the difference in efficiencies at these operating points.[1] Replacing a motor operating at a lower part load would achieve even greater savings (Nadel, et al., 1992).

Electric Supply System

The system that supplies electricity to motor systems can cause energy losses and adversely affect the reliability and life of the motor. Ideally, the electricity driving a motor should be at the design voltage, design frequency and have a sinusoidal wave form. Unfortunately in the real world these conditions frequently are not met. System deficiencies fall into three categories: voltage imbalances in three-phase systems, low system voltage, and low power factor. One solution to many undervoltage conditions is to increase the size of cabling. In addition to reducing voltage drops in the cable, the increased conductor diameter has the added benefit of reducing line losses. Low power factor can be corrected by using capacitors connected to the motor or at the point of electricity distribution. Improving system power factor yields electricity savings by reducing line currents, which in turn reduce cable and transformer losses. It can also result in significant electricity bill savings by reducing utility charges for low power factor (Dorhofer and Heffington, 1994).

ACEEE has estimated that improvements to electric supply systems can result in a 1 to 5 percent savings in motor loads, along with improved reliability and extended motor life. Many of these improvements will also result in additional energy savings and improved reliability in non-motor electrical loads.

Drivetrain, Lubrication, and Maintenance

Additional energy-efficiency opportunities exist through reduction in power transmission system losses, improved equipment lubrication and better maintenance. Most motors are connected to their loads through a transmission system, most frequently a V-belt. While V-belts are rated at 90-96 percent efficiency when properly installed and maintained, in practice many operate well below the 90 percent efficiency level. Cogged V-belts are 1 to 3 percent more efficient and can be used with the same sheaves and

---

[1] Based on the average part-load efficiencies for 1800 rpm, T-frame motors listed in the *Motor Master Database* (Washington State Energy Office, 1991). Assumes that there is no difference in operating speed between the two motors.

pulleys while lasting twice as long. A recent review by E-Source of five studies in which V-belts were replaced with cogged V-belts reported savings of between 0.4 and 10 percent with a median savings of 4.1 percent. At the 4.1 percent savings level, the payback from energy-savings alone ranges from 1 to 5 months (Howe, et al., 1993). Similar savings are reported in the Ford Motor Company Case-Study (Price and Ross, 1989). Likewise the selection of efficient gear drives can result in similar savings.

The selection of premium lubricants can also reduce losses in various motor processes and devices. Savings of 3 to 20 percent have been realized in wire-drawing, gear reducers, compressors and motors. In many cases, the additional cost can be more than justified on longer lubricant life alone.

Better operating and maintenance (O&M) practices can also save motor energy. Proper motor-shaft alignment reduces motor load while extending bearing life. Better practices can also take the form of less "bad" maintenance, as in the case of Southwire Company which eliminated repainting of motors because painting was resulting in increased motor temperature. E-Source estimates that optimal O&M practices could save 3 to 10 percent of all drive power (Howe, et al., 1993).

Because of the diverse nature of all these measures and a lack of well-documented data, a good estimate of the overall savings potential from these measures is difficult. ACEEE has estimated that drive and maintenance measures taken together could conservatively yield 3 to 7 percent savings at a very modest cost.

Variable Speed Drives and Controls

While incremental savings can be achieved through reductions in EMS losses, the largest conservation potential exists in better matching and controlling the motor load to meet process requirements. Adjustable speed drives (ASD) represent one of the easiest ways to accomplish this task. ASD installations in all industry groups average 15 to 40 percent energy reductions, with energy savings at some sites even higher. ACEEE's **Energy-Efficient Motor Systems** estimated that 20 to 40 percent of the motor load in all industry groups are potential sites for ASD application. The installed base of ASDs is estimated to be only 10 percent of these potential sites. In the industrial sector there are more opportunities. Many fans, pumps, compressors and materials-handling systems are appropriate applications of ASDs. In addition some of the process motors also can benefit from ASDs. For the purposes of this analysis, the range of potential sites is assumed to be 25 to 75 percent of pump, fan, compressor and materials-handling motor loads.

Variable Air Flow in Lumber Dry Kilns

The N.C. Alternative Energy Corp., in cooperation with the furniture industry and the state's electric utilities, undertook a project to demonstrate the potential of controlling airflow in hardwood lumber dry kilns. The first step was to understand the physics of the lumber drying process. The process involves three distinct phases: release of the mechanical or chemical bonds that hold the water in the wood; transport of the water to the surface; and transport of the water away from the surface by air flow. In furniture grade lumber, especially some hardwoods like oak, it is important that the moisture gradients within the wood be limited to minimize drying stresses that result in degrading of lumber quality. Since the first two phases of the drying process are driven by the wood temperature and the relative humidity at the surface, the amount of water requiring transport away from the surface will vary during the drying process. In conventional operations, the maximum air flow required is estimated and the requisite fan capacity is installed (usually with some excess for good measure). The drying rate is controlled by regulating the kiln temperature and recirculating air to control relative humidity. This means that the fan capacity installed is required for only a short period of the drying cycle.

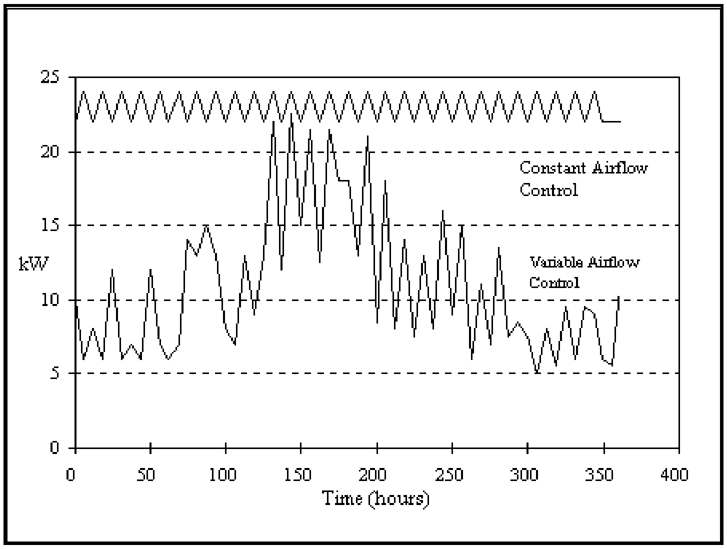

Figure 10 Energy Savings from Variable Air-flow Control in Hardwood Dry Kilns. Source: IEL, 1992.

An AEC study indicated that the required rate of air flow could be determined by measuring the wet bulb depression in the air immediately after it had passed through the lumber stack. Using this reading as an indicator, a control strategy was developed by AEC to vary the fan speed. Field trials with two industrial cooperators confirmed that varying the air flow resulted in at least as good a lumber quality with no effect on production rates. Though tests were not conclusive, the operators felt that lumber quality was better with the variable air, particularly on difficult woods to dry like oak. The total energy required for a kiln charge was reduced by about half as shown in the accompanying Figure. Paybacks for the fan control systems vary from 2.4 to 8.7 years depending upon motor size and kiln configuration.

Source: IEL, 1992

Motor Loads (Pumps, Fans and Compressors)

While many pieces of equipment are unique to the application, much of the energy is consumed by generic equipment such as pumps, fans, and compressors. Resource Dynamics has made estimates of the electrical consumption in 1985 for motors and the primary end-use motor loads as shown in *Figure 11*. Savings realized from improvements to these loads are independent of and in addition to improvements to the drive source. As the figure shows, over 40 percent of the motor electrical load is consumed by these end-uses. As *Figure 12* shows, pumps alone consume a fifth of the motor energy (Resource Dynamics, June 1992).

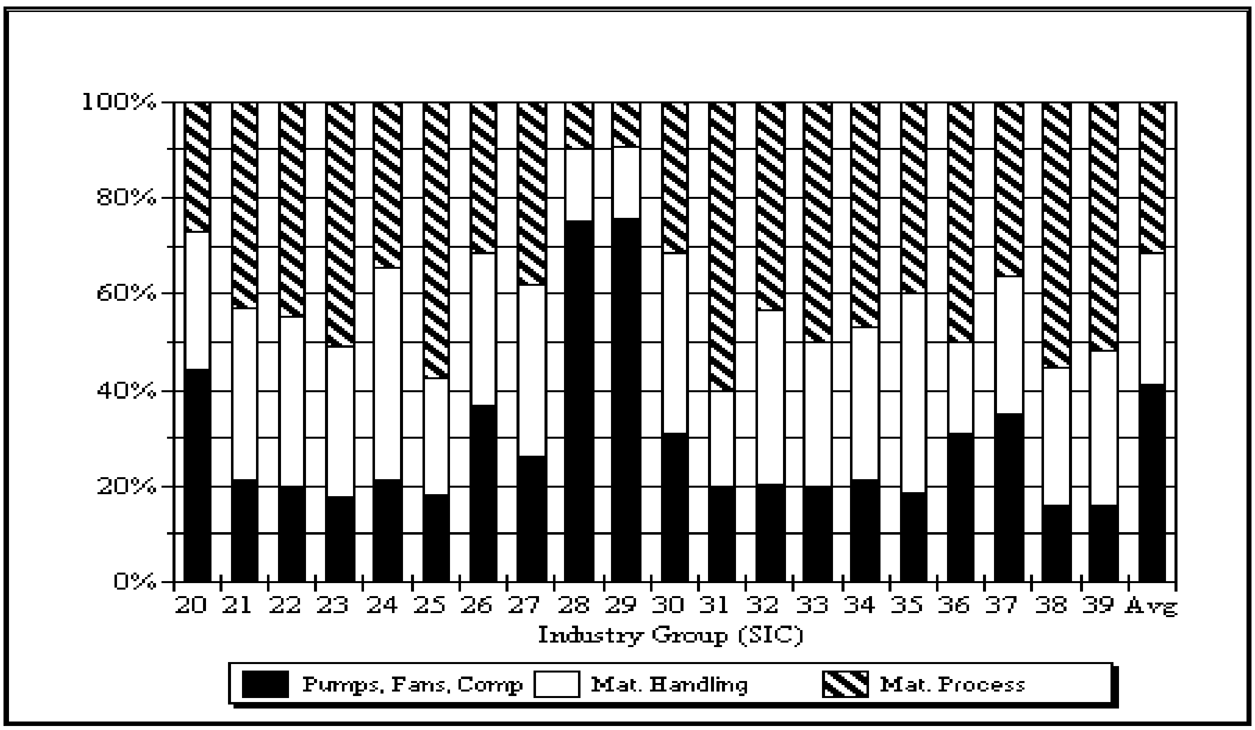

Figure 11 Distribution of Motor Load in Manufacturing Industry Groups by End-Use (Source: Resource Dynamics, 1992)

The distribution of fan, pump and compressor load varies widely with industry, as shown in *Figure 13*, due to differences in the manufacturing processes used in each industry group. In paper (SIC-26) and petroleum refining (SIC-29) pumps account for about 65 percent of the load, while fans account for half the load in wood products (SIC-24).

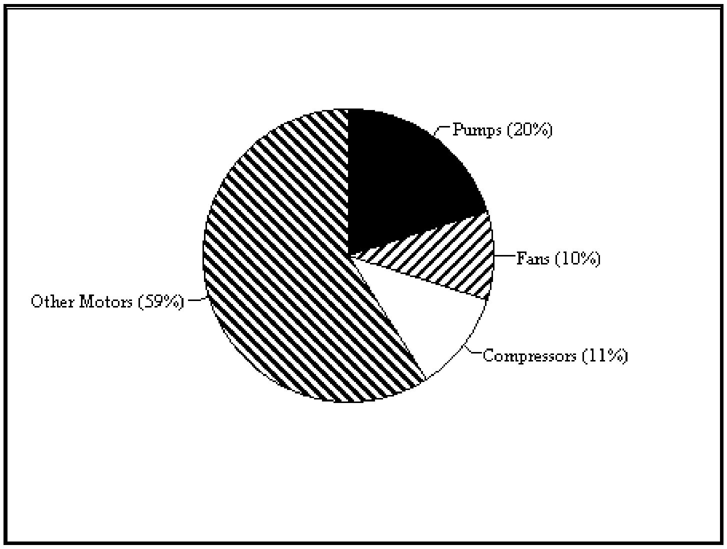

Figure 12 Distribution of Industrial Motor Load by End-Use (Source: Resource Dynamics, 1992).

In pumping operations, opportunities exist for conservation with improved pumps and with optimizing the design of the fluid-flow system. High-efficiency pumps can improve pump efficiency by 2 to 10 percent (Arthur D. Little, 1980). In designing a fluid-flow system, the energy losses can be minimized by matching flow to actual process requirements, reducing restrictions in the system by using large a larger pipe size, and operating the system at a lower pressure. While the implementation of some of these

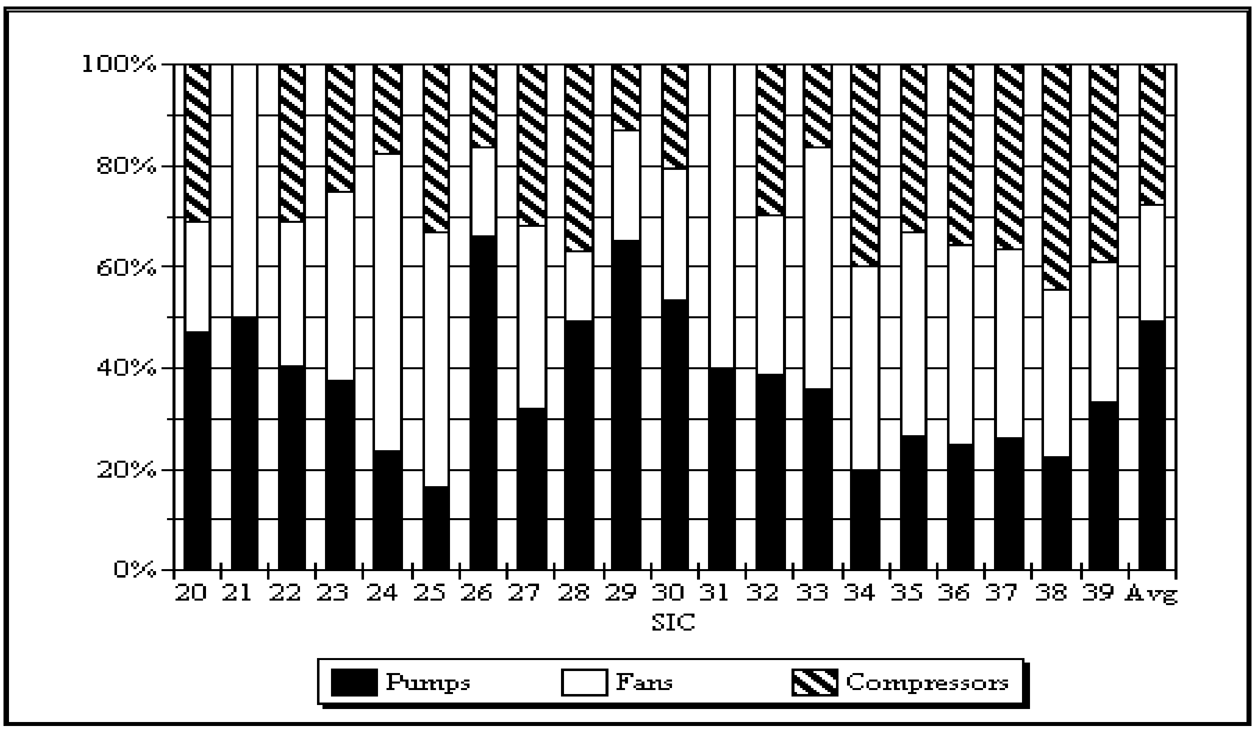

Figure 13 Distribution of Pump, Fan and Compressor Motor Load in Manufacturing Industry Groups (Source: Resource Dynamics, 1992).

opportunities are cost effective only in new construction, flow control with an ASD and reductions in operating pressure can often be implemented in existing systems. Also, specifying a larger size when replacing existing piping will reduce energy consumption.

Fan efficiency numbers do not appear to be available. However a recent study of agricultural ventilation fans showed that their efficiency vary by a factor of two (Ford, 1991). It is not realistic to assume that this level of conservation is available with industrial fans since they are more closely optimized to their application, so it is assumed for this analysis that a similar potential exists for fans as for pumps. In addition, air-handling design optimization can also yield similar savings to those of pump-driven systems. In the lumber drykiln example on page 32, a 50 percent energy savings was achieved by varying fan speed to match the drying requirements.

With compressors, three main areas exist for improvements: selection of more efficient compressors, compressor control improvements, and reductions in compressed-air system leaks. There are several different kinds of compressors, each with its own unique operating characteristics which in part can dictate selection. Each type also has a different full load efficiency and part load efficiency curve. For example, reciprocating compressors are about 10 percent more efficient than comparable screw compressors at full load. At part load the screw's efficiency declines rapidly. When operating consideration do not dictate the choice, selection of a different type of compressor or a mix of compressors can reduce energy consumption (Scales, 1993).

Within each type of compressor, a potential also exists for purchasing a unit that is 5 to 20 percent more efficient. For example: a premium 100 horse power reciprocating compressor is approximately 10 percent more efficient at full load than a standard unit. These units command a price premium of 10 to 30 percent. As with motors, part load efficiencies are equally important. Screw compressors have particularly bad part load performance. An internally compensated design can be purchased for a 10 to 15 percent premium which will significantly decrease part-load power consumption (Scales, 1993). For purposes of this analysis it is assumed that about half of this potential could be realized with more efficient compressors, so a savings potential of 2 to 10 percent of the compressor motor load. By optimizing the selection of compressor type even more savings is possible.

Improved controls can operate compressors in the most efficient manner, minimizing short cycling and optimizing loading of multiple compressor system. As an example, lead-lag control on air compressors typically save 3-7% (Nadel, et al., 1992).

Reduction of compressed-air systems leaks represents the largest opportunity for electricity savings in compressors. It is estimated that 15 percent of the energy used to generate compressed air is lost to leaks. Because of the nature of air leaks it is impractical to eliminate all of them, however a 50 to 75 percent reduction is reasonable. Elimination of this loss is unfortunately not a one-time effort; leaks will reoccur if a preventive maintenance program is not implemented (Price and Ross, 1989 and Johnston, 1993). The impact of the leaks can be minimized through the design of the compressed-air distribution system as discussed in the Ford Motor Company Case Study. By segmenting the system and providing satellite compressors, portions of a plant's compressed-air system can be shut down when not required. At one Ford plant this reduced electricity consumption for compressed-air production by 80 percent (Price and Ross, 1989).

The other major use of compressors is in chiller and refrigeration systems. Refrigeration controls can save about 10 percent, and refrigeration represents 50% of SIC 20 motor load (Nadel et al., 1992). New water-cooled centrifugal chillers have an average efficiency of 0.63 kW/ton. One recent analysis projects that the efficiency could be improved to approximately 0.49 kW/ton, a 20 percent reduction, for between 1.3 and 4 ¢ per kWh saved (Houghton, et al., 1992).

EMS Conservation Potential

Table XVXV
Summary of Electric Motor System
Efficiency Opportunities

Measure	Saving Potential as % of Motor End-Use Fraction	Assumptions
Energy-Efficient Motors	1-9% for applicable motors	96% of motor load has energy-efficient replacements available
Correction of Motor Oversizing	6-9% for oversized motors	one-third of motor load operates a less than 50% load
Improved Drivetrains, Lubrication and Maintenance	3-7% for all motor load	
Improved Electric Supply	1-5% for all motor load	
Increases Installation of Adjustable Speed Drives	15-40% for applicable motors	25-75% of pump, fans, compressor and conveyor loads are applicable sites
Improved Pump and Fan Efficiency	2-10% for end-use motor load	
Reduced Compressed Air Leaks	50-75% reduction in leaks	compressed air leaks are 15% of compressor load
Improved Compressor Controls	3-7% for compressor load	
Improved Air Compressor Efficiency	4-20% for applicable load	50% of compressor load is applicable for equipment efficiency improvement
Improved Refrigeration Equipment Efficiency	10% for refrigeration load	

The potential for electricity savings from each EMS and motor-driven equipment measure are summarized in *Table XV*. Based on analysis discussed in the preceding section, an overall motor system conservation potential of 18 to 49 percent of motor load is estimated. *Table A-III* in the appendix lists the potential by industry group and measure. The chemicals, food and petroleum industry groups all have a potential savings level greater than 50 percent in part due to their high pump loads. As many other studies have found, ASDs offer the greatest potential for savings, with an average of almost 20 percent of motor energy use. Electric supply system upgrades, drivetrain, lubrication, and maintenance are the next largest measure group with up to 12 percent savings, and EEM upgrades offer a maximum potential of about 8 percent.

Four other recent studies have projected similar EMS conservation potentials as shown in *Figure 14*. The most aggressive estimates of 28 to 60 percent have been made by E-Source (Howe, et.al., 1993). This estimate is for the motor population as a whole. Nadel, et al. (1992) made a more conservative estimate of 16 to 40 percent but did not address the potential from fan, pump and compressor savings. A study prepared for B.C. Hydro estimated a potential of up to 46 percent reduction in motor electric consumption, with pumps, fans and compressors representing the greatest end-use savings. The authors projected that about half the savings potential in motor driven machinery comes from the EMS and half from process modifications reducing the need for motor input. In the case of pumps, they project a 30 percent reduction from system efficiency improvements and 39 percent from process re-engineering (Jaccard, et al., 1993). EPRI estimated that industrial motor savings of 24 to 38 percent were technically and economically achievable (Faruqui, et al., 1990). The average savings range for these five studies is 30 to 48 percent.

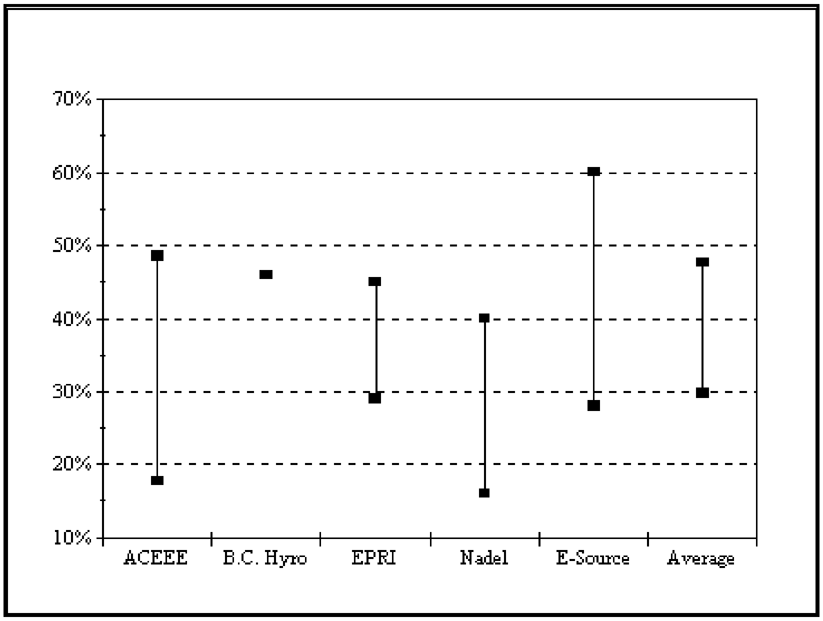

Figure 14 Estimates of Motor System Electricity Conservation Potential from Recent Studies

C. Lighting

Lighting is an obvious target for electricity savings in all sectors of the economy. However, industrial lighting is less well understood than commercial and residential lighting. While lighting design practice for the commercial sector has evolved very rapidly over the last few years, the Illumination Engineering Society's industrial lighting standards were last revised in the 1930's. It is even difficult to determine exactly how much electricity is consumed for lighting. Overall industrial lighting end-use has been reported to range from 2 to 20 percent of total industrial electricity consumption (International Energy Agency, 1989) (Lovins, 1988). Resource Dynamics (1988) estimated that electricity consumed for industrial lighting and other miscellaneous uses in 1985 is 8.8 percent of total industrial electricity use. Included in this number were lighting, electric resistance space heating, computers, controls and instrumentation. The report estimated widely varying lighting end-use fractions of 5-50 percent for different industry groups . For purposes of this analysis we assume an overall lighting use of about 7 percent.

The conservation potential for improved lighting practices also vary. ACEEE has estimated that 36 percent of industrial electricity use from lighting could be saved through substitution of more efficient equipment at a levelized cost of less than $0.07/kWh (Miller, Eto, and Geller, 1989). One practitioner indicates that based on his experience, a conservation potential of 10 to 25 percent exists, assuming that acceptable quality of lighting already exists (Johnston, 1993). EPRI has made several studies of industrial lighting savings potential in industry. One projected a savings potential of 37 to 50 percent (Barakat & Chamberlin, 1990) while another projected 17 to 37 percent (Faruqui, et al., 1990). A project involving 24 industrial facilities in the Portland area achieved a 50 percent reduction in lighting energy, even after increasing light levels to correct for inadequate lighting. These savings were realized at less than a nine year payback (Wolfe, 1989).

In many industrial facilities, the first priority should be to improve the quality of lighting rather than reduce energy use. The Portland survey found uniformly substandard lighting levels (Wolfe, 1989). The concept of task lighting offers great potential for improving lighting quality while also reducing energy consumption. For example, a recent retrofit of a textile mill in South Carolina replaced a high-output fluorescent lighting system with a fluorescent task lighting system. The level of task illumination increased from 40 to over 70 foot-candles while energy consumption was reduced 38 percent (Hubner, 1993). Based on these disparate results, we estimate an energy-savings opportunity of 20-40 percent.

Though the lighting fraction of end-use is relatively modest, it can represent one of the easiest industrial electricity efficiency opportunities to implement. Lighting efficiency improvements can be achieved with relatively short paybacks, modest capital investments, and are perceived as being less involved with the manufacturing process than other measures. Some utility industrial DSM programs have used lighting programs as a means of gaining customer confidence, laying the groundwork for the pursuit of other industrial efficiency measures (Jordan and Nadel, 1993).

IV. OVERALL ELECTRICITY CONSERVATION POTENTIAL

A. Summary of Findings

The previous sections of the report have summarized the electricity conservation potential for the most electricity intensive industry groups and industries, and for two major end-use categories, electric motor systems and lighting. These estimates are based on the existing equipment base. Based on these industry- and end-use specific estimates, the estimated electricity conservation potential for the manufacturing sector from all measures is 14-38 percent. This estimates does not assume wholesale replacements of operating equipment, but what can be achieved through an orderly change-out of equipment. This change-out could occur at the time of equipment failure, process modernization, or new construction over the next seven to twenty years. As mentioned in the introduction, many of the numbers upon which these estimates are based are rough estimates. The range of conservation potential reflects the uncertainty associated with both the consumption by electricity by end-use and the savings that could be realized from each measure.

It is important to note that, as *Table XVI* and *Figure 15* show, all the manufacturing industry groups (as identified by their SIC codes) have significant electricity conservation potentials. The average projection of maximum savings is 38 percent. For eighteen of the industry groups, the high estimate of conservation potential exceeds 30 percent, with food and petroleum refining offering more than 50 percent savings at an upper bound. More that half of the industry groups have a minimum potential of at least 10 percent, with 14 percent being the average for all industries.

The two largest electricity consuming industry groups, chemical and primary metals, also offer the largest absolute energy savings potentials (*Figure 16*). These savings estimates are based on 1991 electricity consumption. No attempt has been made to project future increases in each industry group's electricity consumption. Other industries that offer maximum savings in excess of 10 TWh include: food; transportation equipment; rubber and plastics; stone, clay and glass; petroleum refining; electrical equipment; and textiles.

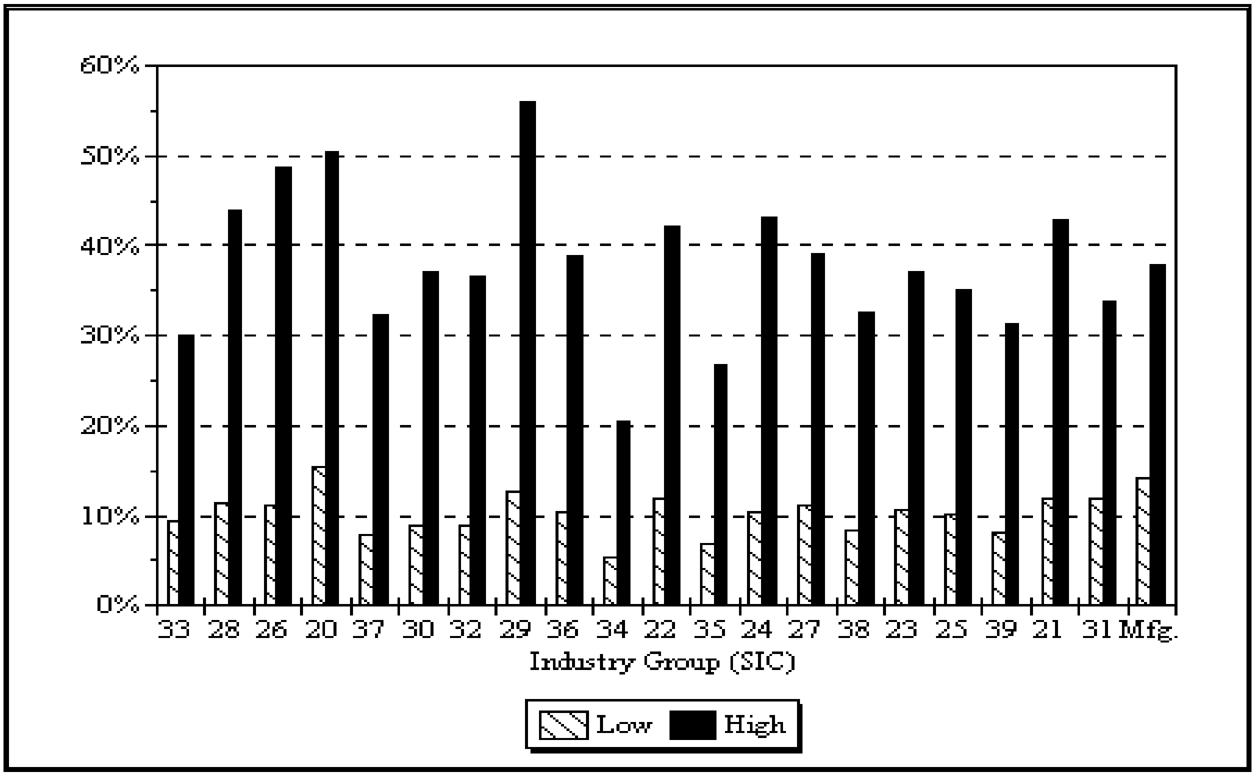

Figure 15 Electricity Conservation Potential for Manufacturing Industry Groups

Over 80 percent of the end-use electricity conservation comes from motor loads. A breakdown of this end-use potential in each industry group appears in *Figure 17* with details reported in *Table A-IV* in the Appendix. Electric motor systems are the largest end-use. The conservation potentials as a fraction of total consumption for process and lighting are similar, even though process energy consumption is more than three times lighting consumption.

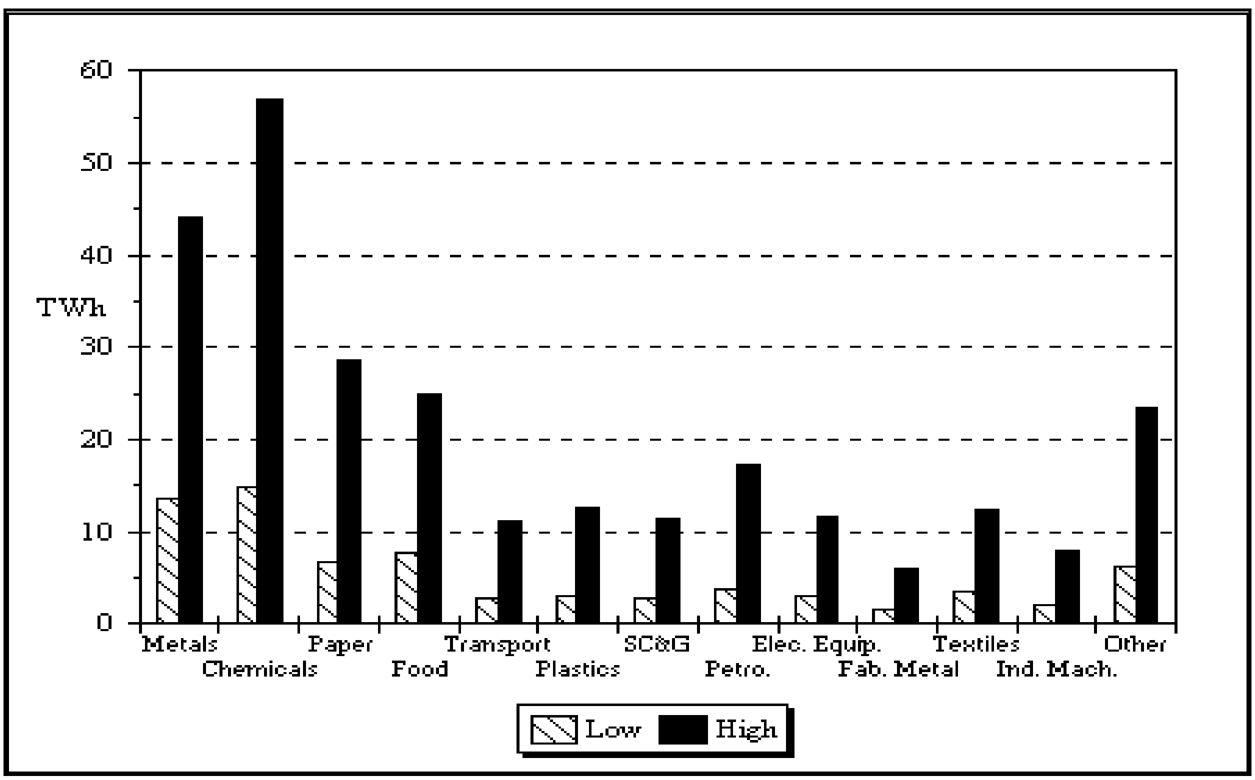

Figure 16 Electricity Savings Potential in Manufacturing Industry Groups

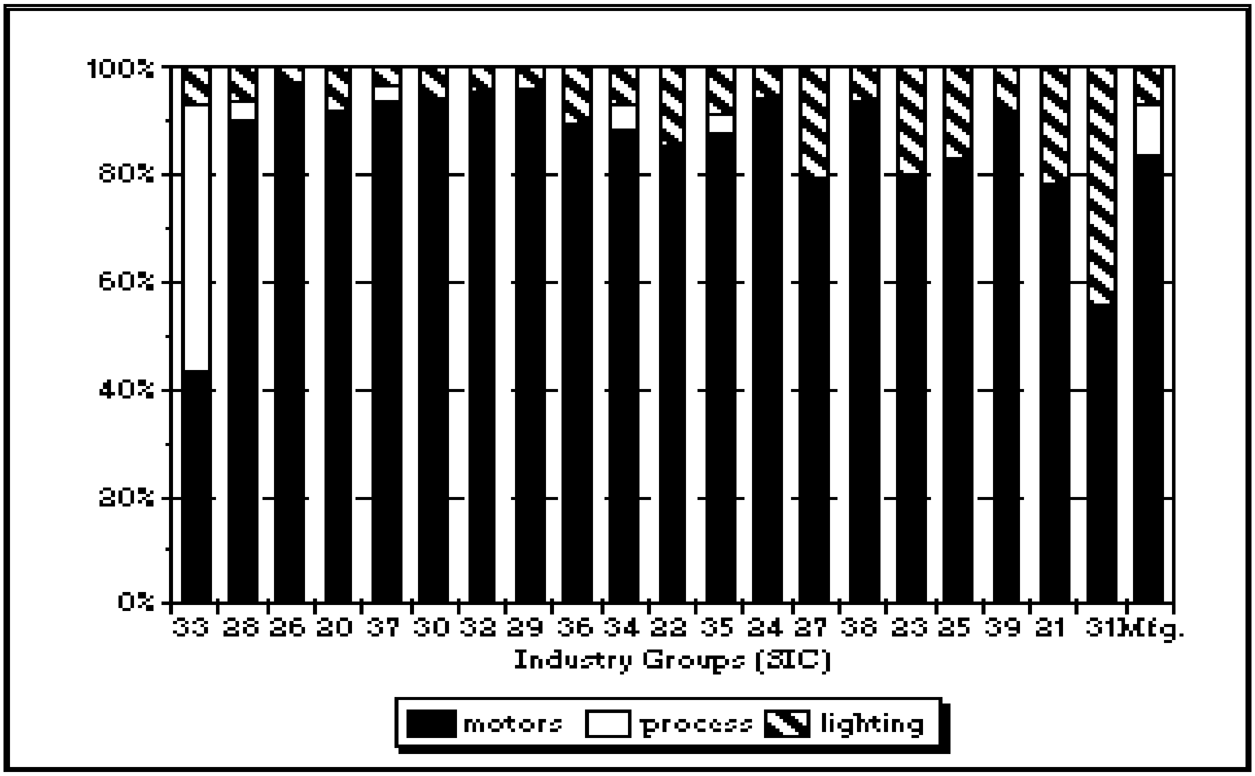

Figure 17 Distribution of Electricity Conservation Potential by End-Use for Manufacturing Industry Groups

These estimates of electricity conservation potential do not include measures related to process optimization. If energy demands of the process are reduced, even more substantial savings could be achieved than are shown here. For example, the electric motor system conservation estimates assume no change in the process-related motor load. If the process requirements are reduced, as the lumber dry kiln example on page 32 shows, very substantial savings can be achieved.

Table XVIXVI
Summary of Electricity Conservation Potential Estimates

SIC	Industry	Total Conservation Potential		Total Electricity Savings Potential Based on 1991 Consumption (TWh)	
		Low	High	Low	High
33	Primary Metals	9%	30%	13.64	44.08
28	Chemicals	11%	44%	14.72	56.79
26	Paper	11%	49%	6.59	28.64
20	Food	16%	50%	7.69	24.95
37	Transportation Equip.	8%	32%	2.78	11.24
30	Rubber & Plastics	9%	37%	3.04	12.62
32	Stone, Clay & Glass	9%	37%	2.75	11.27
29	Petroleum & Coal	13%	56%	3.88	17.22
36	Electrical Equipment	10%	39%	3.13	11.64
34	Fabricated Metal Products	5%	20%	1.58	6.07
22	Textile	12%	42%	3.52	12.43
35	Industrial Machinery	7%	27%	2.02	7.88
24	Wood Products	10%	43%	1.84	7.74
27	Printing	11%	39%	1.75	6.13
38	Instruments	8%	32%	1.04	4.02
23	Apparel	11%	37%	0.60	2.09
25	Furniture	10%	35%	0.50	1.73
39	Misc. Manufacturing	8%	31%	0.30	1.15
21	Tobacco	12%	43%	0.12	0.43
31	Leather	12%	34%	0.09	0.27
Total		**14%**	**38%**	**98.24**	**262.25**

N.B.: All percentages in this table are reported as percent of total electricity consumed.

B. Comparison of Estimates with Other Studies

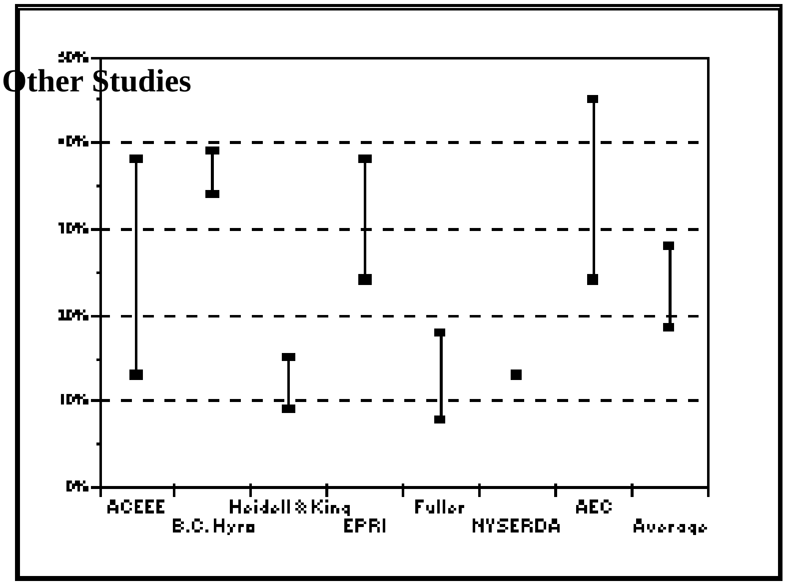

Figure 18 Estimates of Industrial Electricity Conservation Potential Made in Recent Studies.

A number of other estimates of electricity conservation potential have been made. All of these studies consider currently available efficiency measures Cost effectiveness is used as a screening criterion in most but not all of the studies. Most of these confirm EMS are the major area of end-use potential. Estimates of total electricity savings potential from seven studies (including this study) are presented in *Table XVII* and summarized in *Figure 18*. The assumptions, scope and time periods vary widely among the studies. The estimates and assumptions for each of these studies are discussed below.

A recent study initiated by B.C. Hydro looked at the technical and economic potential for electricity conservation in industry in British Columbia. This study extended the usual estimation of the potential for energy-efficient motors and adjustable-speed drives by also considering alternative process equipment and configurations, and the relationship between auxiliary technologies and major production process steps. The study projected an average conservation potential in 2010 of 37 percent relative to the existing technology mix with a range of 34-39 percent savings potential. A disaggregation of the savings potential found significant variation between industry groups with pulp and paper the highest at over 42 percent, chemicals at 23 percent, wood products at 19 percent, and other industries at 40 percent. EMS and motor-driven equipment were identified as the areas with the greatest potential (Jaccard, et.al., 1993).

Heidell and King (1990) modeled the electricity conservation potential for the industrial sector served by six major U.S. and Canadian utilities. The study projected a conservation potential of 9 to 15 percent depending upon the utility. The study focused on equipment replacement and did included the full range of EMS measures considered in this study or any major process changes. In addition, the study focused exclusively on "short term" measures with a high likelihood for acceptance by industrial customers in the next five years.

In 1990, EPRI estimated the maximum electric energy savings potential for all sectors of the economy for the year 2000. For the manufacturing sector, the study considered adjustable speed drives, energy-efficient motors, waste heat recovery, high efficiency lighting, and advanced membrane and electrolytic technologies. Other process measures were not considered. The overall electricity savings potential was projected to be 24-38 percent. On an end-use basis, savings from EMS were projected to account for 29-45 percent, lighting 17-33 percent, electrolytics 19-30 percent and process heating 8-13 percent of the total savings potential (Faruqui, et.al., 1990).

Fuller (1992) estimated an electricity savings potential of 8-18 percent based on studies of more than 100 plants performed for a New England utility. Over half of these savings are obtained from lighting improvements with only 7 percent coming from EMS. The estimates were based only on measures that could be cost-effectively implemented on a retrofit basis. Equipment replacement measures were not considered. The study is less thorough and narrow in scope than most of the other studies reviewed in *Table XVII*.

Table XVIIXVII
Summary of Electricity Conservation Potential Estimates

Study	**Electricity**	
	Low	**High**
This study (ACEEE)	13	39
B.C. Hydro (Jaccard, et.al., 1993)	34	39
Heidell & King (1990)	9	15
EPRI, (Faruqui, et.al, 1990)	24	38
Fuller (1992)	8	18
NYSERDA (Miller, et.al., 1989)	13	
America's Energy Choices (AEC) (ASE, et.al, 1991)	24	45
Average of Studies	18	30

An assessment of electricity conservation potential in New York State's industries focused only on energy-efficient motors, adjustable speed drives and lighting measures. It projected a cost-effective electricity savings potential from the customer's perspective of about 13 percent (based on a 1986 baseline). No attempt was made to look at process savings potential or to look at EMS measures beyond energy-efficient motors and adjustable speed drives (Miller, et.al., 1989).

In the 1991 *America's Energy Choices* study, four public interest organizations considered various national energy scenarios. The electricity savings analysis for the industrial sector relied heavily upon maximum potential estimates made by EPRI. These estimates were based on calculations of the savings from energy-efficient motors and adjustable speed drives, improved process heating equipment, improved electrolytics, and improved lighting and space conditioning. The projected electricity savings potential in 2010 varied between 24 and 45 in three different high efficiency scenarios. The amount of the savings depended on the assumed fraction of the technical potential that is implemented. In the highest savings case all the potential was assumed to implemented by 2010 (Alliance to Save Energy, et.al., 1992).

V. CONCLUSIONS

This study shows that significant potential exists for electricity conservation in all manufacturing industries. We estimate that a savings potential of at least 10 percent exists in more than half of the manufacturing industry groups, and a maximum potential in all but two industry groups of more than 30 percent. Other studies support these estimates. EMS and reduction of motor-driven loads are the areas of greatest opportunity, representing over 80 percent of the manufacturing electricity conservation potential identified in this study. High-efficiency motors alone at most represent 17 percent of the electricity savings potential from EMS (*Figure 19*). Other measures such as better matching of motor size to the load, adjustable speed drives and improved efficiency of motor-driven processes offer equal or greater savings potential.

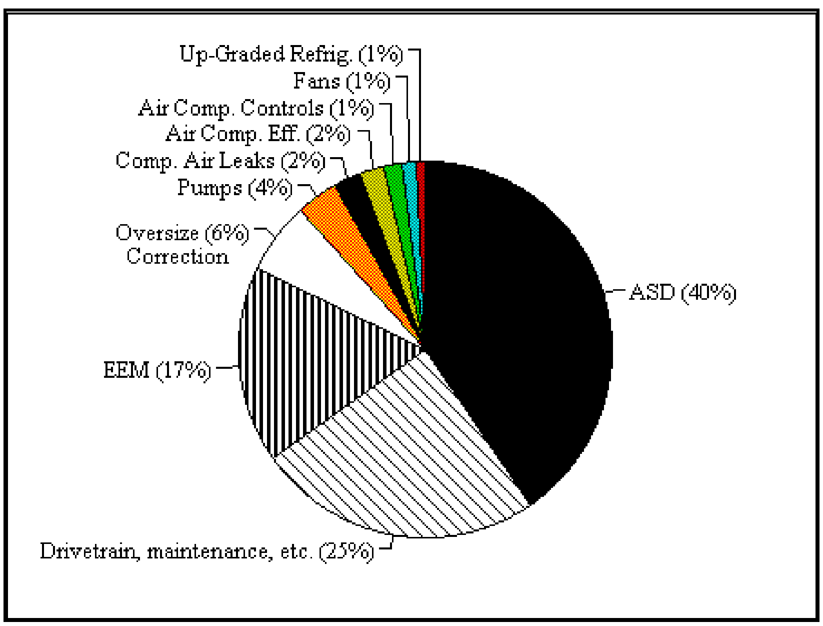

Figure 19 Distribution of Maximum Electric Motor System Conservation Potential (EMS Maximum Conservation Potential is 48.5% of Motor Load).

The highest absolute electricity savings potential is found manufacturing industries with the greatest consumption. In the cases of primary metals, petroleum refining and paper, a few, very large facilities account for the majority of the electricity consumption in these industry groups. In regions where these facilities are not located there is still significant conservation potential from other industry groups like chemicals, food, metals fabrication industries, and plastics which have many more widely distributed plants.

It is important to note that this study is inherently conservative. While this study did consider more end-use conservation measures for motor loads than have many other studies, only limited consideration was given to optimization of the motor load itself. This study also only considered six of the twenty manufacturing industry groups individually for savings opportunities from process improvements, and then only for a limited set of technologies for which consumption and savings data are available. Increasing recycled materials content (i.e., secondary production) was not considered, even though indications of significant energy savings are present (Elliott, 1994), since it involves issues outside of the manufacturing sector per se. Most importantly, major redesign of industrial processes was not considered.

To achieve the greatest total energy savings, energy use needs to be looked at on a fuel-blind, systems basis. Each process needs to be studied for its energy use and for its relation to the operation of the plant as a whole. While this is a resource-intensive process, it can also yield benefits in addition to energy-cost reductions, such as waste minimization, improved product quality and materials utilization, and improved productivity.

This study also suggests that there are several areas where further research is warranted. The information on end-use energy consumption on an industry group and industry basis is imperfect and incomplete. There is also a need for better data on the savings potential from higher efficiency motor-driven equipment (e.g., pumps, fans, and compressors) and opportunities for efficiency improvements related to this equipment. Additional work on process energy requirements in each industry group would also be useful, especially in diverse industry groups like chemicals and food.

It is clear that many opportunities still exist for improving the electrical energy efficiency of manufacturing industries as a whole. Given concerns such as competition from low-wage nations, maintaining a strong manufacturing base, and emissions of greenhouse gases and other pollutants from electricity generation, efforts need to be directed at realizing this savings potential. Improved efficiency will benefit many parties: manufacturing companies through decreased operating costs, electric utilities through reduced demand growth and need to build additional capacity, the economy through improved resource utilization and increased productivity, and the environment through reduced emissions of pollutants.

References:

Aeppel, Timothy, 1993. "U.S. Aluminum Makers Find World Market a Scary Place", *The Wall Street Journal*, pg. B4., November 8.

Alliance to Save Energy, et.al., 1992. *America's Energy Choices*, Union of Concerned Scientist, Cambridge, MA.

Argonne National Laboratory, 1982. *Energy and Materials Flows in Iron and steel Industry*, U.S. Department of Energy, Washington, DC.

Azimi, Sayed A,.and Howard Lowitt, 1988. *The U.S. Steel Industry: and Energy Perspective*, DOE/RL/01830-T55, U.S. Department of Energy, Washington, DC.

Badin, Joseph S. and Howard E. Lowitt, 1988. *The Textile Industry: an Energy Perspective*, U.S. Department of Energy, Washington, DC.

Barakat & Chamberlin, Inc., 1990. *Efficient Electricity Use: Estimates of Maximum Energy Savings*, CU-6746, Electric Power Research Institute, Palo Alto CA.

Bock, Marck, Gale Boyd, Stephen Karlson and Marc Ross, 1993. *Steel Minimills and Their Energy Use*, Office of Industrial Technologies, U.S. Department of Energy, Washington, DC.

Bosley, J., and D. Klesser, 1991. *The CONSTEEL Scrap Preheating Process*, Center for Materials Production, Carnegie Mellon Research Institute, Pittsburgh, PA.

Cascon, Ron, 1993, personal communication, ChemSystems, Tarrytown, NY.

Cato, M.J., et.al., 1991. *Handbook of Radio Frequency Drying of Textiles*, N.C. Alternative Energy Corporation, Research Triangle Park, NC.

U.S. Bureau of the Census (Census), 1993. *1991 Annual Survey of Manufacturers*, M91(AS)-3, U.S. Department of Commerce, Washington, DC.

Charlier, Marj, 1993. "ACX Strives to Become Aluminum's Low-Cost Producer", *The Wall Street Journal*, Pg. B4, November 29.

Crowley, Joseph C., and John P. Donoghue, 1993. "The Energy Efficiency Partnership: Kraft General Foods and Boston Edison", *Proceeding of Workshop on Partnership for Industrial Productivity through Energy Efficiency*, American Council for and Energy-Efficient Economy, Berkeley, CA.

Donoghue, John, 1993. Personal communication, Boston Edison, Boston, MA.

Dorhofer, F.J. and W.H. Heffington, 1994. "Electrical Energy Monitoring in an Industrial Plant," *Proceeding of the 16th National Industrial Energy Technology Conference*, Houston, TX.

Elliott, R. Neal, 1993. *Carbon Reduction Potential from Recycling in Primary Materials Manufacturing*, American Council for and Energy-Efficient Economy, Berkeley, CA.

Energetics, 1990a. *Industrial Profiles Final Report: Aluminum*, U.S. Dept. of Energy, Washington, DC.

Energetics, December 1990b. *Industrial Profiles - Final Report:Steel*, U.S. Department of Energy, Washington, DC.

Energy Information Administration (EIA), 1993a. *State Energy Data Report 1991*, U.S. Department of Energy, Washington, DC.

Energy Information Administration, 1993b. "Manufacturing Energy Consumption Survey: Preliminary Estimates, 1991", *Monthly Energy Review*, September .

Energy Information Administration, 1988. *Manufacturing Energy Consumption Survey: Consumption of Energy, 1985*, U.S. Department of Energy, Washington, DC.

Faruqui, A., C.W. Gellings, et.al., March 1990. *Efficient Electricity Use: Estimates of Maximum Energy Savings*, Electric Power Research Institute, Palo Alto, CA.

Ford, S.E., L.L. Christianson, A.J. Muehling and G.L. Riskowski, 1991. *Agricultural Ventilation Fans: Performance and Efficiencies*, Department of Agricultural Engineering, University of Illinois, Urbana-Champaign, IL.

Fuller, Winslow H., "Industrial DSM - What Works and What Doesn't", 1992. *Proceedings ACEEE 1992 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Berkeley, CA.

Heidell, James A., and Michael J. King, 1990. "The Industrial sector: A conservation Gold Mine or a Quagmire?", *Proceedings of ACEEE 1990 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Berkeley, CA.

Howe, Shepard, Lovins, Stickney and Houghton, 1993. *Drivepower* Technology Atlas, E-Source, Boulder, CO.

Houghton, Bishop, Lovins, Stickney, Newcomb, Sherpard and Davids, 1992. *State of the Art: Space Cooling and Air Handling*, E-Source, Boulder, CO.

Hubner, John, 1993. Personal communication, Mor-Lite, Inc., Greenville, SC.

Industry Brief, 1991a. "Aluminum Industry", Vol. 1, No. 24, Electric Power Research Institute, Palo Alto, CA..

Industry Brief, 1991e. "Bakery Products", Vol.1, No. 10, Electric Power Research Institute, Palo Alto, CA.

Industry Brief, 1991d. "Paper and Paperboard Mills", Vol. 1, No. 18, Electric Power Research Institute, Palo Alto, CA.

Industry Brief, 1991c. "Pulp Mills", Vol. 1, No. 17, Electric Power Research Institute, Palo Alto, CA.

Industry Brief, 1991b. "Steel Industry", Vol. 1, No. 23, Electric Power Research Institute, Palo Alto, CA.

Industrial Electrotechnology Laboratory (IEL), 1992. *ENERGY SAVERS: Variable Airflow Control to Cut Lumber Drying Costs*, Raleigh, NC 27695-8301.

International Energy Agency, 1989. *Electricity End-Use Efficiency*, OECD, Paris.

International Trade Administration, 1993. *U.S. Industrial Outlook 1993*, U.S. Department of Commerce, Washington, DC.

International Trade Administration, 1994. *U.S. Industrial Outlook 1994*, U.S. Department of Commerce, Washington, DC.

Jaccard, Mark, John Nyboer and Allan Fogwill, 1993. "How Big is the Electricity Conservation Potential in Industry?", *The Energy Journal*, Vol. 14, No. 2.

Johnston, Walter, Industrial Extension Service, 1993. Personal communication, N.C. State University, Raleigh, NC.

Jordan, Jennifer and Steven Nadel, 1993. *Industrial Demand-Side Management Programs: What's Happened, What Works, What's Needed*, American Council for and Energy-Efficient Economy, Washington, DC.

Kellum, Ziba, 1993. Personal communications, Industrial Electrotechnology Laboratory, Raleigh, NC.

Larson, E.D., 1992. "Biomass-Gasifier/Gas Turbine Cogeneration in the Pulp and Paper Industry," *Journal of Engineering for Gas Turbines and Power*, October, Vol. 144, pages 665-675.

Lewis, Michael, and David Morris, 1993. *Saving BTUS Through Recycling*, Institute for Local Self Reliance, Washington, DC.

Little, Arthur D., Inc., 1986. *Aluminum Industry Scoping Study*, CMP-86-2, Center for Materials Production, Pittsburgh, PA.

Little, Arthur D., Inc., 1980. *Classification and Evaluation of Electric Motors and Pumps*, DOE/CS-1047, U.S. Department of Energy, Washington, DC, February.

Lovins, Amory, and Robert Sardinsky, March 1988. *State of the Art: Lighting*, Rocky Mountain Institute, Snowmass, CO.

McIntyre, Edmund, H. and Edward R. Landry, 1992. *Electric Arc Furnace Efficiency*, EPRI Center for Materials Production, Carnegie Mellon Research Institute, Pittsburgh, PA.

Miller, Peter, Joseph Eto and Howard Geller, September 1989. *The Potential for Electricity Conservation Potential in New York State*, New York State Energy Research and Development Authority, Albany, NY.

Nadel, Steve M., Michael Shepard, Steve Greenberg and Anibal T. de Almeida, 1992. *Energy Efficient Motor Systems*, American Council for and Energy-Efficient Economy, Berkeley, CA.

Nelson, Kenneth, 1994. "Creating and Empowered Conservation Culture", *Workshop on Partnerships for Industrial Productivity through Energy Efficiency, Proceedings*, American Council for an Energy-Efficient Economy, Washington, DC.

Price, Alan C. and Marc H Ross, 1989. "Reducing Industrial Electricity Cost - an Automotive Case Study", *The Electricity Journal,* July.

Resource Dynamics Corp.and Battelle Columbus Institute, 1988. *TAG Technology Assessment Guide, Volume 2: Part 3: Industrial Electricity Use - 1987*, P-4463-SR Vol. 2 Prt. 3, Electric Power Research Institute, Palo Alto, CA.

Resource Dynamics Corp., 1992. *Electric Motors: Markets, Trends, and Applications*, TR-100423, Electric Power Research Institute, Palo Alto, CA.

Resource Dynamics Corp., 1988. *Electrotechnology Reference Guide, Revision 1*, EM-4527, Electric Power Research Institute, Palo Alto, CA.

Resource Dynamics Corp., 1990. *Food Industry Scoping Study*, CU-6755, Electric Power Research Institute, Palo Alto, CA.

Resource Dynamics Corp., 1998. *Textile Industry Scoping Study*, Electric Power Research Institute, Palo Alto, CA.

Scales, Bill,1993. Personal communication, Scales Air Compressor Company, Carle Place, NY.

Washington State Energy Office, 1991. *Motor Master Electric Motor Database*, Olympia, WA.

Wolfe, Patrick, and Larry McAllister, 1989. "The Industrial Lighting Incentive Program: Process and Impact Evaluation", *Proceeding of the 1989 Energy Program Evaluation Conference*, Chicago, IL, August 23-25.

Appendix: