ENERGY EFFICIENCY
IN ELECTRIC MOTOR SYSTEMS

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ABSTRACT

Motors account for about 70 percent of the electricity consumed in the manufacturing sector. A recent study by ACEEE (Elliott, 1994) estimates 18-49 percent of this energy could be saved through improved motor management practices and orderly change-out of equipment at time of equipment failure, modernization, or new construction. This savings is realized from both the motor-drive system and from more efficient motor-driven equipment. The specific opportunities will vary by industry because of different end-use profiles. Pumps, fans, and compressors represent the greatest opportunities for efficiency improvements in motor-driven equipment.

INTRODUCTION

Electricity end-use can be grouped into three broad categories: direct process, motor, and lighting loads. Motors represent the largest end-use category at 70 percent, with process and lighting comprising 23 and 7 percent respectively (Figure 1). These estimates agree with the electricity end-use estimates reported in the *1991 Manufacturing Energy Consumption Survey* (MECS) (Energy Information Administration, 1994).

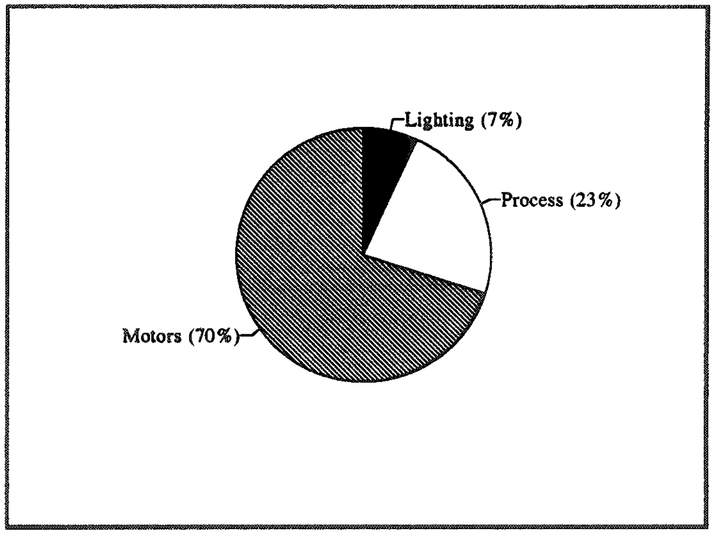

Figure 1 Estimated Electricity End-Use Consumption in Manufacturing (Source: Resource Dynamics, 1988 & 1992).

Beginning with the 1991 MECS, estimates of end-use energy consumption were reported (Table 1.). To obtain the motor end-use fraction some assumptions must be made. Motor end-use consumption is embedded in a number of the disaggregated categories. Based on previous research, the author has made estimates of motor end-use fractions for each reported category (boiler fuel and "end use not reported" categories are withheld). For total reported end-use consumption, motors represent 70 percent and lighting represents 7 percent of electricity consumption for all industry groups.

A recent study by ACEEE (Elliott, 1994) 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 the study did not consider process optimization or redesign that would significantly increase the conservation potential. Similar studies support this estimate (Jaccard, 1993, Heidell & King, 1990, Faruqui, 1990, Fuller, 1992, Miller, et al., 1989, ASE, 1991).

Table 1
1991 Estimates of Electricity End Use Consumption for All Industry

End-Use Categories	Net Electricity (million kWh)	Motor End-Use Fraction[1]	Motor End-Use[1] (million kWh)
TOTAL INPUTS	694,702	70%[2]	465,442
Boiler Fuel	W		
Total Process Uses	546,382	77%	419,185
Process Heating	68,853	40%	27,541
Process Cooling and Refrigeration	36,330	90%	32,697
Machine Drive	347,899	100%	347,899
Electro-Chemical Processes	89,005	10%	8,901
Other Process Use	4,295	50%	2,148
Total Non-Process Uses	116,156	40%	46,256
Facility Heating, Ventila- tion, and Air Conditioning	56,165	70%	39,316
Facility Lighting	47,309	0%	0
Facility Support	10,537	60%	6,322
Onsite Transportation	1,114	0%	0
Conventional Electricity Generation	NA		
Other Non-Process Use	1,031	60%	619
End Use Not Reported	W		

Source: Energy Information Administration, 1994 and ACEEE assumptions
W - data withheld by EIA
[1] estimates made by ACEEE
[2] fraction of total reported end use consumption

How electricity is used varies among the different industries. 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 (Figure 2). The ACEEE (Elliott, 1994) study estimates that over 80 percent of the available electricity savings comes from electric motor systems improvements with lighting and process each contributing slightly less than 10 percent.

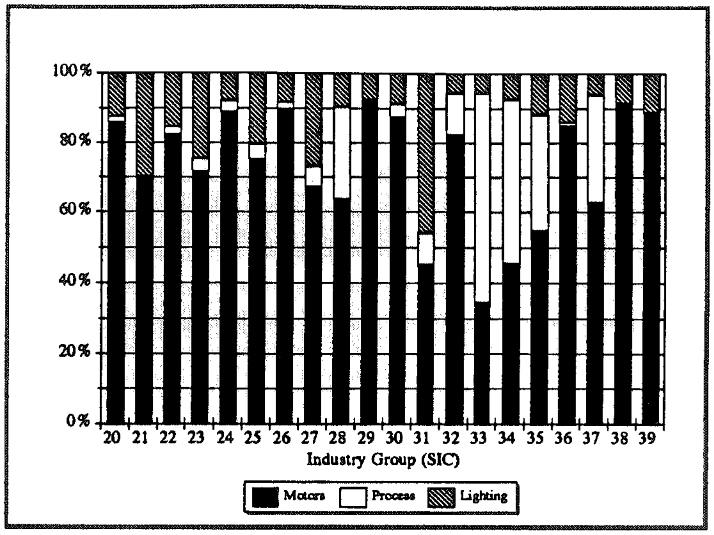

Figure 2 Electricity Consumption in Manufacturing Industry Groups by End-Use (Derived from Resource Dynamics, 1988 and 1992).

This report discusses specific motor system efficiency measures. 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.

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. However, this figure is misleading since the greatest efficiency opportunity for most generic applications is to modify the process to use less of what is produced (e.g., shaft horse power or compressed air). In this paper, motor use and conservation potential in motor systems will be discussed.

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.

ELECTRIC MOTOR SYSTEMS

Motors account on average for about two-thirds of all the electricity used in manufacturing. As can be seen in Figure 2, the motor load fraction varies by 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).

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 the process load requirements to the motor driven device through proper component sizing, multi-speed motors, variable speed drives, and system controls. The latter approach is often referred to as system integration or optimization, and looks at the entire system and attempts to account for interactions between components

Electric motor systems are comprised of several components: theelectric motor itself; the electric supply system that provides electric energy to the motor; and the drive mechanism that connects the motor to the load. Each component has energy losses associated with it, and the first approach noted above 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 report unless otherwise noted.

Energy-Efficient Motors

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

Motors with a range of efficiencies have always been available in the market (Figure 3). After the mid-1950s, motor efficiency declined as greater emphasis was placed on reduced first cost. Beginning in the 1970s, a new class of products was introduced: what we now call "premium efficiency" motors. The efficiency of these products has increased with time causing the range of available efficiencies to increase. The Energy Policy Act (EPAct) of 1992 mandated, minimum efficiency levels for all new poly-phase, general purpose NEMA design B motors between 1 and 200 horsepower (HP). The nominal efficiencies from NEMA MG-1 Table 12-10 are listed in the Act as the minimum efficiency levels. This regulation covers about half of all industrial motors sold, and goes into effect in 1997 and covers all applicable motors sold or imported into the United States (Van Son, 1994).

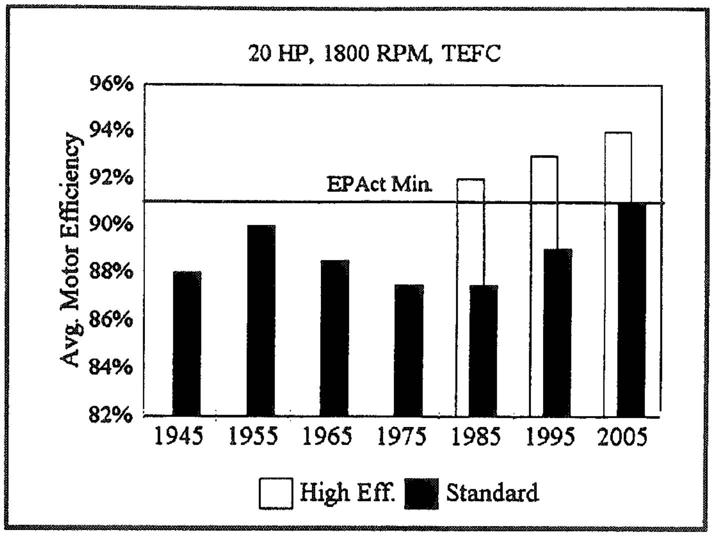

Figure 3 Standard and High Efficiency Motor Trends (source: Van Son, 1994).

With the passage of EPAct, the efficiency of the standard motors began rising in anticipation of the minimum-efficiency regulation. The average efficiency of motors available in the marketplace in the future will be higher, though a range of efficiencies will continue to exist (Van Son, 1994).

EEMs have become more widely accepted in the industrial market place. In 1987, EEMs accounted for an estimated 20 percent of all new motor sales. Today, manufacturers estimate that EEMs account for about 40 percent of new motor sales (Atkins, 1995). While there is significant variation among industries as reported in a survey of motors in Wisconsin manufacturing facilities (Table 2), EEMs 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 at time of failure. More motors over 5 HP are repaired annually than are sold new. A recent study estimated that 2.8 million motors 5-500 HP were repaired in 1993 (Schueler, et al., 1994).

A motor is frequently repaired one or more times to extend its useful life. Motors have a technical life of 15-30 years, but average motor life is less usually less, as was reported in a 1980 study (Table 3). Repair or reconditioning is often incorrectly equated with rewinding, which involves the replacement of the stator windings and may also include other service such as clearing and bearing replacement. However, motors are frequently repaired or reconditioned (including bearing replacement) without having their windings replaced. A recent study found that repair was usually more cost effective than a new motor purchase, but it was usually more cost effective to purchase a new EEMs than to rewind a motor smaller than 50 HP (Cheek, et al., 1995).

There is great dispute as to the impact rewinding has on motor life and efficiency. A recent report asserts that a motor *can* be rewound without any loss of efficiency. The study, however, found no comprehensive studies of the efficiency impact of rewinding. Those studies that were available found a decrease in full load efficiency between 0.5 and 2.5 percent for an initial rewind. The average decrease in efficiency was reported to be about 1 percent for the initial rewind. One study suggested that efficiency decreases might be less for premium efficiency motors. It is unclear what impact subsequent rewindings of motors has on efficiency (Schueler, et al., 1994).

Table 2
Stock Saturation of Energy Efficient Motors

Industry group	HP-Weighted % EEMs
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 as cited in Nadel, et al., 1992.

There are several interrelated source of the efficiency losses during repair. These include high temperature burnout of core, improper bearing replacement, use of a smaller wire size, and changes in stator winding patterns. It is unclear which are the most important (Schueler, et al., 1994). One recent test did find that on average rewound motors operate 10°C hotter than new, high-efficiency motors. These increased temperatures result in a significant shortening of the motor life (Kellum, 1993).

It is difficult in most cases to justify replacing operating motors with EEMs (Cheek, et al., 1995). It is more reasonable to replace existing motors when they fail with EEMs. Motors are routinely rewound, which can involve an outage of a day or more. With proper planning, a new EEMs 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).

Table 3
Average Electric Motor Life

HP Range	(years)	
	Average Life	Life Range
1-5	17.1	13-19
5.1-20	19.4	16-20
21-50	21.8	18-26
51-125	28.5	24-33
Greater than 125	29.3	25-38

Source: Schueler, et al., 1995

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 HP motor operating at 50 percent of its rated load were replaced with a 20 HP motor operating at 75 percent of it rated load (i.e., a 15 HP load), an energy savings of 2-3 percent would be realized due to the difference in efficiencies at these operating points. (This estimate is based on the average part-load efficiencies for 1800 rpm, T-frame motors listed in the *Motor Master Database* [Washington State Energy Office, 1991], and assumes that there is no difference in operating speed between the two motors.) 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 and 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 1-5 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 opportunities to increase energy exist 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 belt. About one third of motor transmissions in industry uses belts. While V-belts are the most common type, three other types are available that can offer greater efficiency (Table 4). The cogged V-belts are 1-4 percent more efficient and can be used with the same sheaves and pulleys while lasting twice as long and requiring less frequent adjustments. Efficiencies with cogged V-belts are greatest when used with the smallest appropriate pulley. Likewise flat and synchronous belts can offer improved efficiency when their unique operating characteristics are taken into consideration (De Almeida and Greenberg, 1994).

While V-belts are rated at 90-98 percent efficiency when properly installed and maintained, in practice many operate well below the 90 percent efficiency level. 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 1-5 months (Howe, et al., 1993). Similar savings are reported in a 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 3-20 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 energy used by motors. 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 that eliminated repainting of motors because painting was resulting in increased motor temperature. E-Source estimates that optimal O&M practices could save 3-10 percent of all drive power (Howe, et al., 1993).

Table 4
Comparison of Belt Drive Characteristics

	Typical Efficiency Range (%)	Suitable for Shock Loads	Periodic Maintenance Required	Change of Pulleys Required	Special Features
V- Belts	90-98	Yes	Yes	No	Low first cost.
Cogged V-Belts	95-98	Yes	Yes	No	Easy to retrofit. Reduced slip.
Flat Belts	97-99	Yes	No	Yes, but low cost	Medium-high speed applications. Low noise. Low slip.
Synchronous Belts	97-99	No	No	Yes, with higher cost	Low-medium speed applications. No slip. Noisy.

Source: De Almeida and Greenberg, 1994

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 3-7 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 (ASDs) represent one of the easiest ways to accomplish this task. ASD installations in all industry groups yield on average 15-40 percent energy reductions, with energy savings at some sites even higher. ACEEE estimated that 20-40 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 25-75 percent of pump, fan, compressor and materials-handling motor loads.

MOTOR-DRIVEN EQUIPMENT

While many pieces of motor-driven 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 4. 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. Figure 5 shows that pumps alone consume a fifth of the motor energy (Resource Dynamics, 1992).

The distribution of fan, pump, and compressor loads varies widely with industry, as shown in Figure 6, 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).

In pumping operations, opportunities exist for conservation from improved pumps and from optimizing the design of the fluid-flow system. High-efficiency pumps can improve pump efficiency by 2-10 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 a larger pipe size, and operating the system at a lower pressure. While the implementation of some of these 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.

A recent study of agricultural ventilation fans showed that their efficiencies vary by a factor of two (Ford, 1991). It is not realistic to

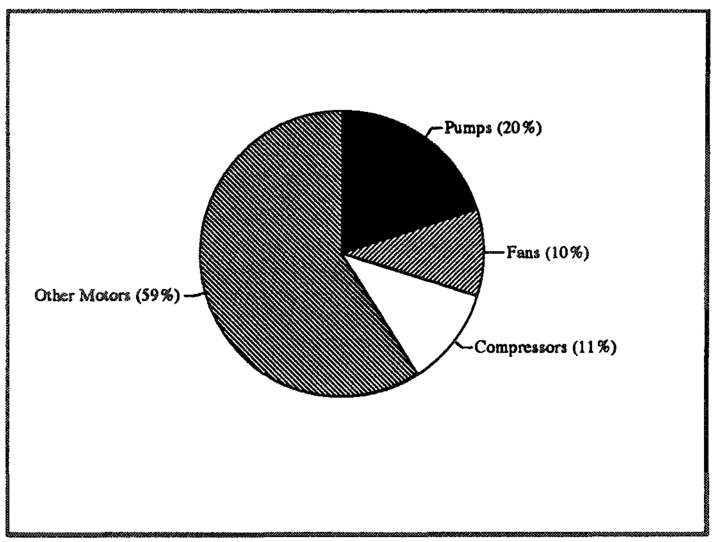

Figure 5 Distribution of Industrial Motor Load by End-Use (Source: Resource Dynamics, 1992).

assume that this level of conservation is available with industrial fans since they are more closely optimized to their application. A draft study of industrial fans and blowers reports a 3-10 percentage point difference among backward-inclined fans. Among different types of fans, the most efficient designs can be 30 percent more efficient than the least efficient designs (Easton, 1994b). In addition, air-handling design optimization can also yield similar savings to those of pump-driven systems. In a study of variable airflow in lumber drykilns, a 50 percent energy savings was achieved by varying fan speed to match the drying requirements (Kellum, 1992).

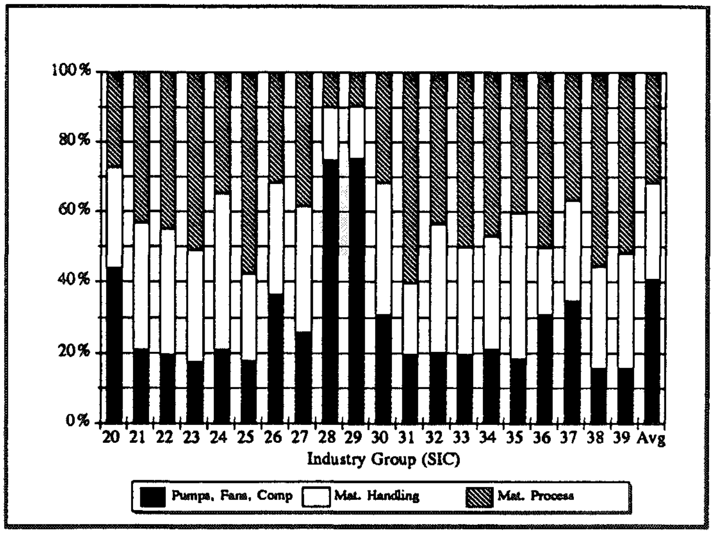

Figure 4 Distribution of Motor Load in Manufacturing Industry Groups by End-Use (Source: Resource Dynamics, 1992)

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 that 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 considerations do not dictate the choice, selection of a different type of compressor or a mix of compressors can reduce energy consumption (Scales, 1993). A recent study by Easton Consultants (Easton, 1994a) identified compressor energy savings across all types of 15-25 percent.

Within each type of compressor, the potential also exists for purchasing a unit that is 5-20 percent more efficient. For example: a premium 100 HP reciprocating compressor is approximately 10 percent more efficient at full load than a standard unit. These units command a price premium of 10-30 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 10-15 percent premium that will significantly decrease part-load power consumption (Scales, 1993). Easton (1994a) indicated that most of the savings within compressor types comes from controls and ancillary components such as filters, separators, dryers and aftercoolers. For purposes of this analysis it is assumed that about half of this potential could be realized with more efficient compressors, i.e., savings potential of 2-10 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 percent (Nadel, et al., 1992).

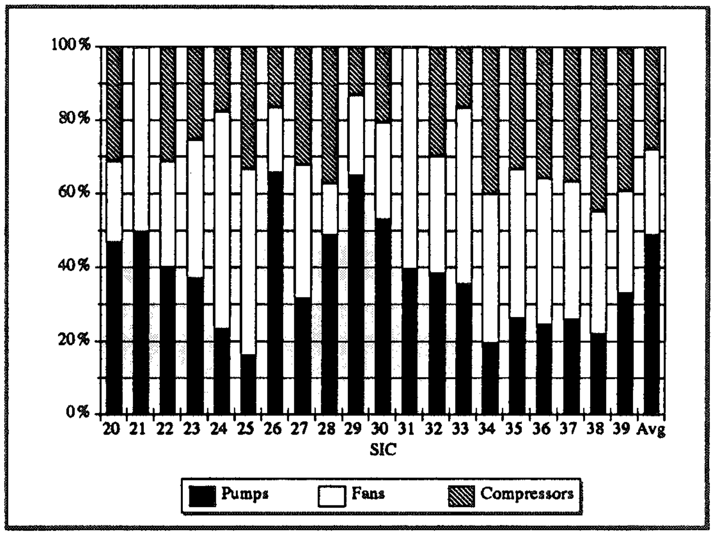

Figure 6 Distribution of Pump, Fan and Compressor Motor Load in Manufacturing Industry Groups (Source: Resource Dynamics, 1992).

Reduction of compressed-air systems leaks represents the largest opportunity for electricity savings in compressors. ACEEE 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 50-75 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, Johnston, 1993). The impact of the leaks can be minimized through the design of the compressed-air distribution system as was discussed in a study of energy efficiency at Ford Motor Company. 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 percent 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 1.3-4 ¢ per kWh saved (Houghton, et al., 1992).

EMS CONSERVATION POTENTIAL

The potential for electricity savings from each EMS and motor-driven equipment measure is summarized in Table 5. Based on analysis discussed in the preceding section, an overall motor system conservation potential of 18-49 percent of motor load is estimated. The chemicals (SIC-28), food (SIC-20), and petroleum (SIC-29) industry groups all have a potential savings level greater than 50 percent in part due to their high pump loads (Figure 7). 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 EEMs upgrades offer a maximum potential of about 8 percent.

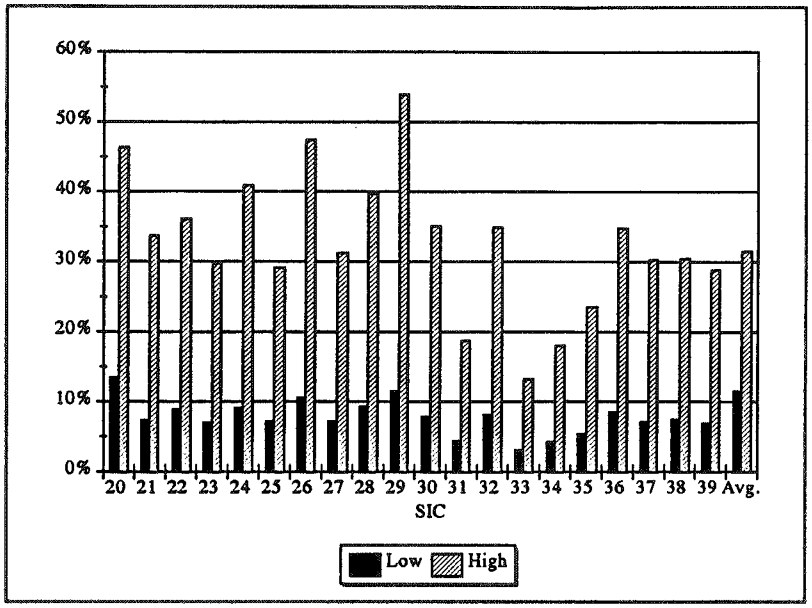

Figure 7 Estimate of Motor System Conservation Potential by Industry Group

Four other recent studies have projected similar EMS conservation potentials as shown in Figure 8. The most aggressive estimates of 28-60 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 16-40 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 24-38 percent were technically and economically achievable (Faruqui, et al., 1990). The average savings range for these five studies is 30-48 percent.

SUMMARY AND CONCLUSIONS

This study shows that significant potential exists for electricity conservation in all manufacturing industries. EMS and reduction of motor-driven loads are the areas of greatest

Table 5
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	
Adjustable Speed Drives	15-40% for applicable motors	25-75% of pump, fans, compressor, and conveyor loads are applicable sites
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
Compressor Controls	3-7% for compressor load	
Air Compressor Efficiency	4-20% for applicable load	50% of compressor load is applicable for equipment efficiency improvement
Refrigeration Equipment Efficiency	10% for refrigeration load	

opportunity, representing over 80 percent of the manufacturing electricity conservation potential identified in a recent ACEEE study (Elliott, 1994). High-efficiency motors alone represent at most 17 percent of the electricity savings potential from EMS (Figure 9). 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. The greatest savings potential comes from the application of adjustable speed drives.

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. 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 would be a resource-intensive process, it would also yield benefits in addition to energy-cost reductions, such as waste minimization, improved product quality

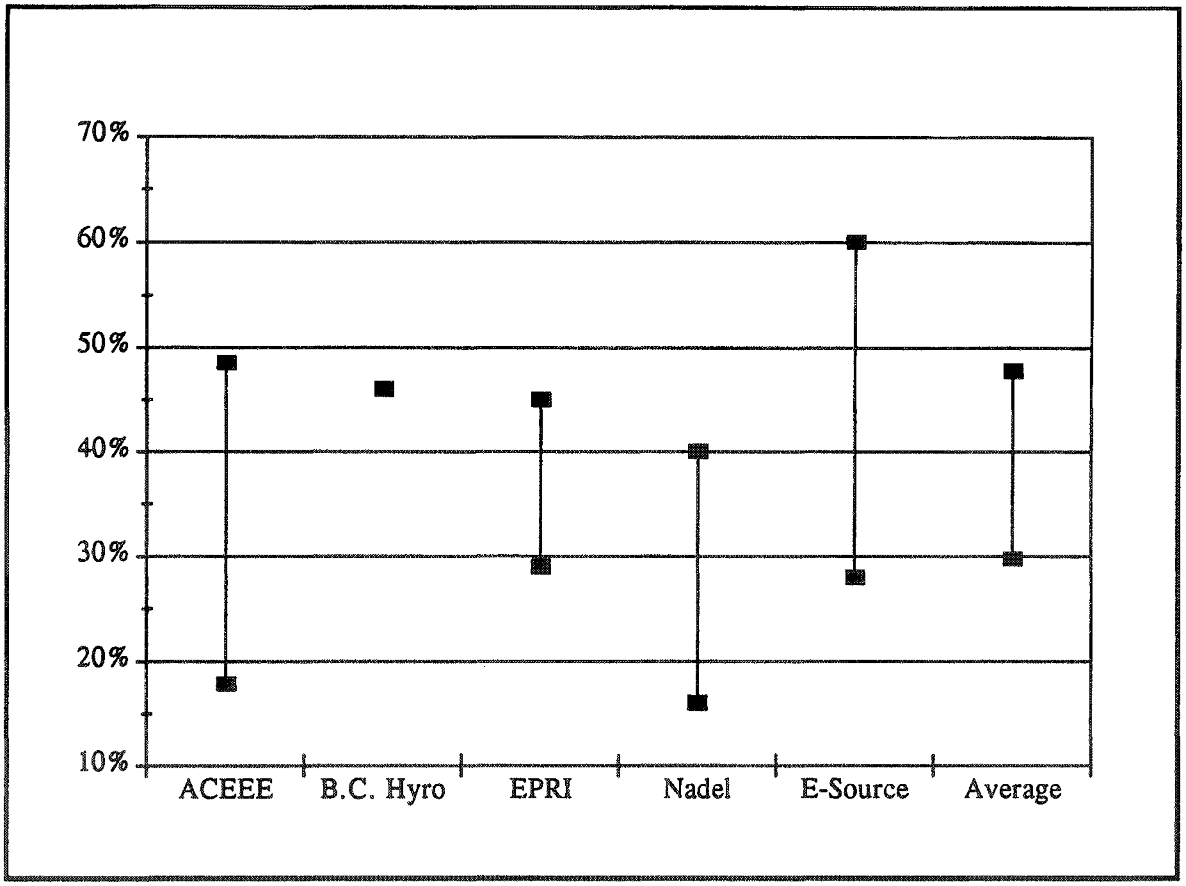

Figure 8 Estimates of Motor System Electricity Conservation Potential from Recent Studies

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. The inclusion of end use data in the MECS is a valuable step. U.S. DOE has proposed a study to characterize the U.S. industrial base of motor systems that should provide very valuable information (U.S Department of Energy, 1995). 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

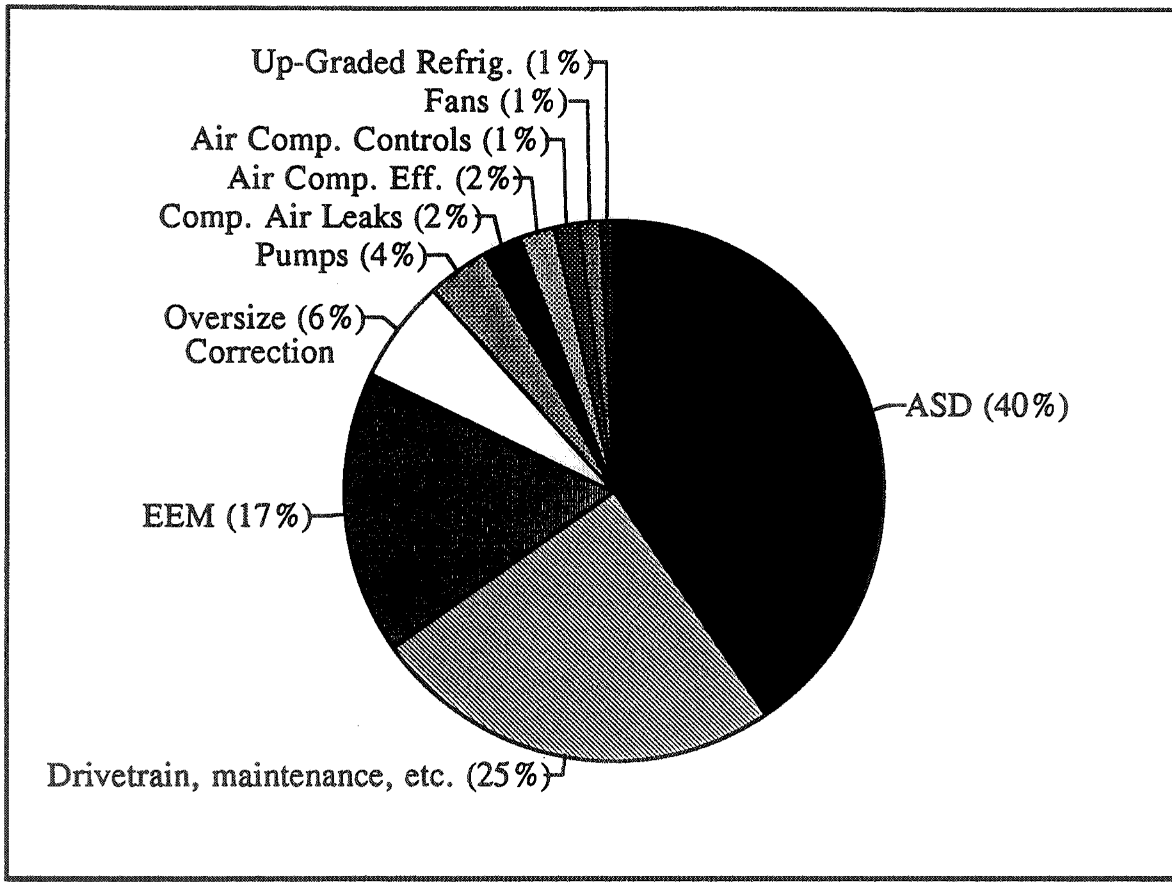

Figure 9 Distribution of Maximum Electric Motor System Conservation Potential (EMS Maximum Conservation Potential is 48.5% of Motor Load).

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.

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