OFFICE OF INDUSTRIAL TECHNOLOGIES

United States Industrial Electric Motor Systems Market Opportunities Assessment

Executive Summary

OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY
U.S. DEPARTMENT OF ENERGY

TABLE OF CONTENTS

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PREPARED FOR
THE U.S. DEPARTMENT OF ENERGY'S
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OAK RIDGE NATIONAL LABORATORY
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Executive Summary

PROJECT OBJECTIVES

This is the *Final Report of the United States Industrial Electric Motor System Market Opportunities Assessment.* The Market Assessment is one component of the United States Department of Energy's (DOE's) Motor Challenge Program*. Motor Challenge is an industry/government partnership designed to help industry capture significant energy and cost savings by increasing the efficiency of motor systems. DOE's primary strategy is to support plant managers in applying a systems approach to specifying, purchasing, and managing electric motors and related machines so as to minimize the electricity needed to achieve production goals. This Market Assessment is intended to serve as a blue print for the implementation of the Motor Challenge strategy.

The objectives of the Market Assessment are to:

- Develop a detailed profile of the current stock of motor-driven equipment in U.S. industrial facilities;
- Characterize and estimate the magnitude of opportunities to improve the energy efficiency of industrial motor systems;
- Develop a profile of current motor system purchase and maintenance practices;
- Develop and implement a procedure to update the detailed motor profile on a regular basis using readily available market information; and,
- Develop methods to estimate the energy savings and market effects attributable to the Motor Challenge Program.

In addition to serving DOE's program planning and evaluation needs, the Market Assessment is designed to be of value to manufacturers, distributors, engineers, and others in the supply channels for motor systems. It provides a detailed and highly differentiated portrait of their end-use markets. For factory managers, this study presents information they can use to identify motor system energy savings opportunities in their own facilities, and to benchmark their current motor system purchase and management procedures against concepts of best practice.

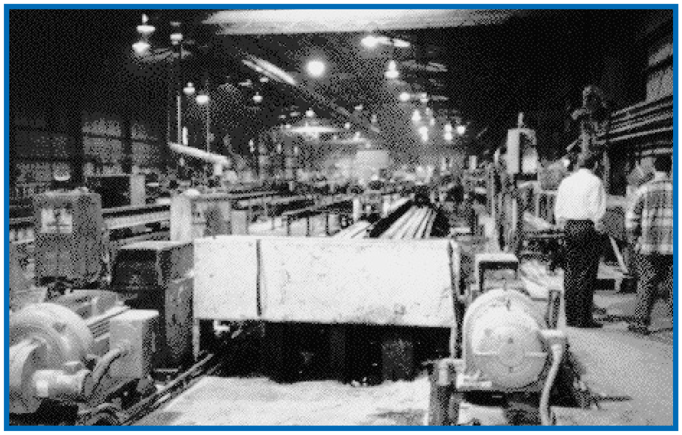
The Market Assessment was carried out by XENERGY Inc. under a subcontract with Oak Ridge National Laboratory (Lockheed Martin Energy Systems). The project was initiated in the autumn of 1995. Field data collection was carried out during most of calendar 1997. Many individuals and organizations contributed to this study. We would particularly like to thank the facilities managers and staff who permitted us to conduct inventories of their motor systems and the representatives of industry, government, and academic organizations who volunteered their time to review the study and its reports at various stages of development.

OVERVIEW OF FINDINGS

Magnitude of industrial motor system energy use and potential energy savings.
In 1994, electric motor-driven systems used in industrial processes consumed 679 billion kWh—

* As of Fiscal Year 2000, DOE's Motor Challenge Program has been integrated within a broader initiative of DOE's Office of Industrial Technologies (OIT) that is called BestPractices. OIT's BestPractices introduces industrial plants to emerging technologies and well-proven cost saving opportunities such as motor, steam, compressed air and other plant-wide system opportunities. BestPractices offers resources, tools, and industry contacts/partners to help industrial end users match available and new energy-efficient technologies to their varied plant needs.

23 percent of all electricity sold in the United States. These machines make up by far the largest single category of electricity end use in the American economy. Based on detailed analysis of the motor systems inventory, we estimate that industrial motor energy use could be reduced by 11 to 18 percent if facilities managers undertook *all cost-effective applications of mature proven efficiency technologies and practices.* That is, implementation of all well-established motor system energy efficiency measures and practices that meet reasonable investment criteria will yield annual energy savings of 75 to 122 billion kWh, with a value of $3.6–$5.8 billion at current industrial energy prices.[1] Many kinds of motor system efficiency improvements yield benefits in addition to energy cost reductions. These include improved control over production processes, reduction in waste materials, and improved environmental compliance.



On average, the manufacturing sector could reduce industrial motor energy use by 11% to 18% using mature, proven efficiency technologies and practices. This Greenville Tube production facility reduced its annual energy use by 34% and saved $77,266 annually through improving the efficiency of its tube drawing bench.

Of course, this full potential cannot be captured all at once. That would require expenditures of $11–$17 billion, roughly 10 percent of total new capital expenditures by all manufacturers in 1994. While the opportunities for energy savings and other benefits associated with investments in improved motor systems are enormous, so too are the demands on capital and management resources in industrial organizations. Moreover, we identified many barriers that have prevented industrial facilities managers from capturing more than a small percentage of the potential benefits of motor system efficiency. These are described on page 4.

Categories and relative size of motor system energy savings opportunities.
There are two basic categories of motor system energy efficiency measures:

- **Motor efficiency upgrades,** which improve the energy efficiency of the motor driving a particular machine or group of machines; and,
- **System efficiency measures,** which improve the efficiency of a machine or group of machines as a whole. System efficiency can be improved by reducing the overall load on the motor through improved process or system design, improving the match between component size and load requirements, use of speed control instead of throttling or bypass mechanisms, and better maintenance, to name just a few of the engineering strategies available.

We estimate that motor efficiency upgrades can achieve potential savings of about 19.8 billion kWh per year. Improved methods of rewinding failed motors can contribute an additional 4.8 billion kWh. Energy savings from system efficiency improvements are potentially much larger: 37 to 79 billion kWh per year. Most motor efficiency upgrades can be achieved fairly easily by selecting the most efficient available motor for the application at hand. System efficiency measures, on the other hand, often require a significant amount of effort on the part of industrial end-users and their vendors to identify, design, implement, and maintain.

Progress to date: motor efficiency upgrades.
The Market Assessment Inventory (MAI) found that motors meeting federal efficiency standards that took effect in October 1997 account for 9.1 percent of the motors currently in use in manufacturing facilities. Such motors have been available for two decades. Between 1993 and 1996, they constituted about 18 percent of all motors sold in the 1–200 horsepower range

[1] We applied a guideline of a 3-year simple payback when questioning engineers and market experts regarding the applicability of common motor system efficiency measures. Average industrial energy price: $0.048 per kWh. (EIA 1997)

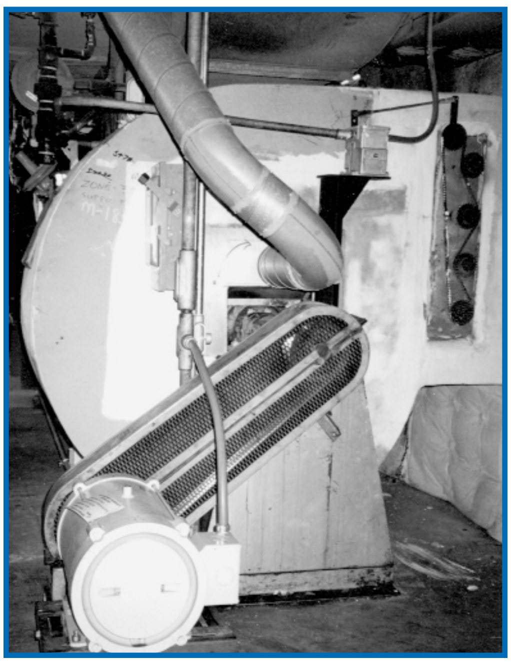
covered by the efficiency standard.[2] In aggregate, efficient motors currently in place are saving industrial facilities 3.3 billion kWh per year, compared to motors of average efficiency sold previous to the promulgation of federal efficiency standards.

Replacement of general purpose AC induction motors currently in use with motors that meet federal efficiency standards will yield energy savings of 13.0 billion kWh per year. Replacement with the most efficient motors currently available will yield an additional 6.8 billion kWh in annual savings. Given patterns of new motor purchase and rewinding of failed motors documented here, it will take 15 to 20 years for current population 1–200 horsepower motors to be 80 percent replaced. The challenge for government and utility efficiency programs is to assist in accelerating the pace of replacement.

Progress to date: system efficiency measures.

The remaining 37 to 79 billion kWh in annual savings will be realized one project or plant at a time through the efforts of facilities managers, engineering and maintenance staff, designers, distributors, and manufacturers. A small number of companies, primarily multinational corporations in industries with high concentrations of motor system energy use, have enacted aggressive programs to identify and capture system improvement opportunities and to monitor and maintain these systems on an ongoing basis. These companies have been amply rewarded for their efforts. The Motor Challenge Program has documented over a dozen major projects that have yielded average system-level energy savings of 33 percent, and some as high as 60 percent. Within the manufacturing sector as a whole, installations of adjustable speed drives now in place yield 3–6 billion kWh in annual savings compared to conventional control mechanisms such as throttle valves and bypass loops. Common improvements to air compressor systems have yielded an estimated 1 billion kWh per year in additional savings.

Using system efficiency measures that included adjustable speed drives and energy-efficient motors on the supply air fan, 3M cut electricity use by 41% in one building and saved over $77,000 per year.



Despite the success of a few companies and the relative maturity of the technologies used to achieve motor systems efficiency, the level of knowledge and adoption of system efficiency measures among facilities managers is very low. Motor systems equipped with adjustable speed drives account for only 4 percent of manufacturing motor system energy, compared to a potential level of application between 18 and 25 percent. We found that only the largest plants had implemented the most common kinds of system improvements in the past 2 years to any great extent, and the pattern of knowledge and implementation, even among the largest companies, was inconsistent. Among all manufacturing facilities, 24 percent reported that they had not taken any of a long list of potential system efficiency measures over the past 2 years.

[2] Standards contained in the Energy Policy Act (EPAct) of 1992 apply to all integral horsepower, general purpose, AC induction motors from 1–200 HP. Such motors constitute 50 to 70 percent of all motors sold in the relevant horsepower classes.

Barriers and solutions.
We and other researchers have found that industrial facilities managers face significant barriers to capturing the financial and operating benefits of motor system energy improvements. Among the most important are the following:

- Low priority of energy efficiency among capital investment and operating objectives. Within manufacturing as a whole, motor system energy costs constitute less than 1 percent of total operating costs. This figure is considerably higher for a small number of energy-intensive industries such as paper and chemicals.
- General lack of awareness among facilities managers, equipment distributors, engineers, and manufacturers' representatives of strategies to achieve motor system efficiency: their costs, management requirements, and benefits.
- Generally low level of staffing for the facilities maintenance function.
- Conflicting incentives for suppliers regarding the promotion of efficient equipment and practices. For example, compressed air distributors have greater incentive to sell additional compressors to customers with increasing load rather than to advise those customers how to control load growth through better maintenance and production planning.

Partnership solutions.
In order to capture the economic and environmental benefits of improved motor system efficiency, all participants in the motor systems markets—end-users, manufacturers, distributors, and designers—must develop new ways of doing business. Realizing the benefits of motor systems upgrades may be a relatively simple matter of adopting specifications for motor purchases and rewinds. To capture system efficiencies, facilities managers and their vendors, and consulting engineers will need to assess operations on a periodic basis to identify the major savings opportunities available in virtually every factory, then work together to design and implement the projects.

Facilities managers, their vendors, and consulting engineers will need to work together to identify and capture major savings opportunities.

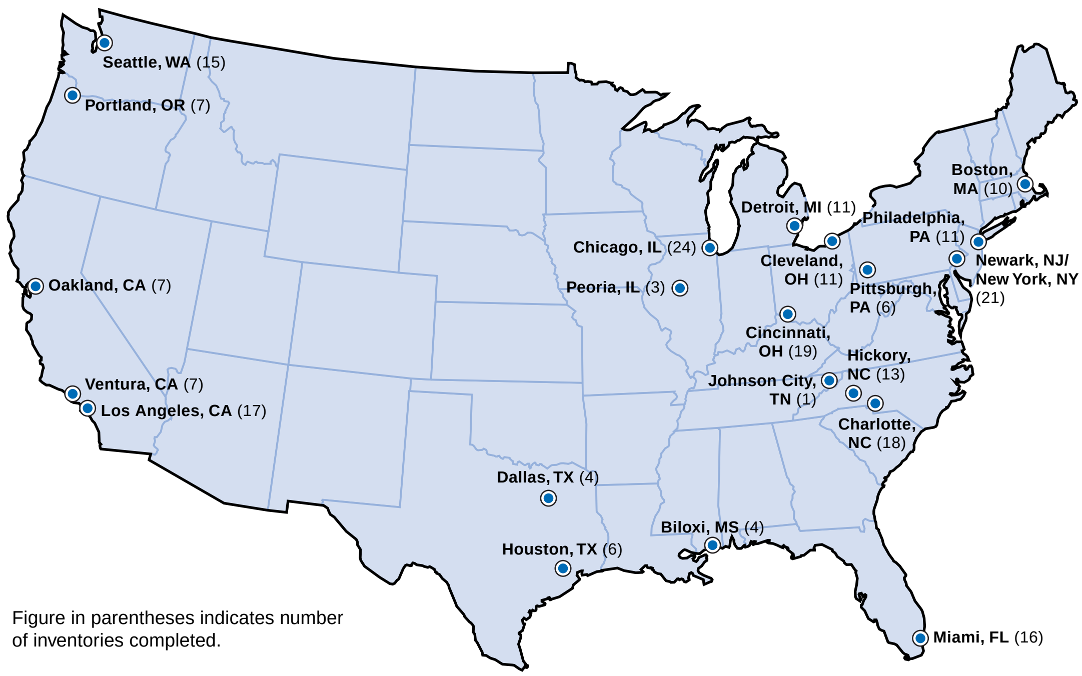
No one group of market actors can accomplish this transformation working alone; the barriers of conflicting interests and resource constraints are simply too high. Rather, end-users and suppliers must identify where their business interests in motor systems efficiency coincide and develop ways to work together to realize those interests. The Motor Challenge Program is designed to assist market actors in accomplishing these objectives. Among the program's many achievements to date is the development of the MotorMaster+ motor selection software, which couples an electronic equipment catalog to a sophisticated economic analysis program to help customers select the most cost-effective motor for their needs. Not only has this software program been of direct benefit to end-users, but it has been distributed by motor vendors as a promotional tool for their energy-efficient lines. The Motor Challenge Program, guided by the results of this Market Assessment and the advice of industry experts, continues to develop new initiatives to transform the market for industrial electric motor systems.

RESEARCH ACTIVITIES

THE MARKET ASSESSMENT INVENTORY

The principal research activity of this project was the Market Assessment Inventory (MAI). During calendar 1997, the assessment team conducted on-site studies of 265 industrial facilities on behalf of the DOE; 254 of these constituted a carefully designed probability-based sample of the entire manufacturing sector. An additional 11 non-manufacturing facilities were inventoried to provide case studies of motor system energy use in such industries as mining, agriculture, and water supply. The inventory was carried out in 20 metropolitan areas nationwide with additional sites in non-metropolitan areas. Figure E-1 shows the locations in which site studies were completed.

Figure E-1: Locations of MAI Activity



The MAI consisted of two parts: the Motor Systems Inventory and the Practices Inventory.

The Motor Systems Inventory.

For the Motor Systems Inventory, trained field engineers, accompanied by a representative of the plant, collected detailed information about every motor-driven system they could observe that was used in a production process. In very large plants, motor systems were sampled to contain the amount of time spent on site with the respondents' personnel. At each plant, the field engineer also worked with plant personnel to take instantaneous load measurements on a sample of motors. These measurements were used to estimate average part loads—a key element in estimates of energy use and potential savings. Through this process, we compiled detailed information on 29,295 motor systems—both the motor itself and the piece of equipment it drove. In addition, we compiled instantaneous load measurements on nearly 2,000 motor systems.

The Practices Inventory.

Achievement of significant increases in motor system efficiency depend to a large extent on the adoption of good design, purchase, and management practices. Equipment on the typical factory floor is constantly updated, reconfigured, and readjusted. Under normal patterns of use, motors wear out and need to be rebuilt or replaced every 7 to 10 years. Motor systems require continual monitoring and maintenance to run at their design efficiencies. Each decision and action in the daily stream of motor system design, purchase, and maintenance carries with it consequences for energy efficiency and consumption. The Practices Inventory gathered information on the prevalence of actions identified by industry experts as "good practice" in the sample facilities. The Practices Inventory also collected critical information needed to model the change in the motor systems population over time.

Accuracy of inventory results.
The results of any statistically based study such as the MAI are subject to error. Researchers generally identify two basic kinds of errors: sampling error and non-sampling error. In a properly structured study, sampling error can be quantified. We have done so for the most important quantities estimated—motor system energy for the population and key subgroups—using established statistical methods. Non-sampling errors arise due to difficulties in making accurate observations of the population of interest. The effects of these errors cannot be quantified on the basis of the observations themselves. However, they can be described qualitatively. Readers will best be able to understand and apply the results presented below if they understand the sources and sizes of these errors.

- **Sampling error.** Most of the description of the motor system population and energy savings opportunities contained in this report proceeds from estimates of motor system energy used by various groups of motor systems in the population. The assessment team estimated 90-percent confidence intervals for their estimates of total motor system energy in all manufacturing, total motor system energy in each two-digit manufacturing SIC group, and each major application (pumps, fans, air compressors, and other process systems).[3] The 90-percent confidence interval for total manufacturing motor system energy was ± 18 percent. The confidence intervals for total motor system energy in the individual two-digit SIC groups ranged from ± 4 percent (SIC 32: Stone, Clay, and Glass) to ± 81 percent (SIC 33: Primary Metals). The relatively large confidence intervals for Primary Metals and Chemical Products (± 46 percent) reflect the underlying diversity of the facilities found in those industries.
- **Non-sampling error.** The MAI posed many challenges to accurate observation of conditions in sample facilities. These are discussed throughout the report in the context of the specific observations they affected. The assessment team developed and implemented numerous data quality control procedures including: a complete manual review of completed inventories by a trained engineer; automated data quality checks on the raw data once entered; and a final round of "reality checking" on the partially processed data. Anomalous observations were referred back to the data collector or to our contacts at the participating sites for clarification and correction. Despite these precautions, we frequently needed to call on the judgment of site personnel or our field engineers to provide information that could not be directly observed or independently verified. These instances are noted throughout the report.

OTHER RESEARCH

This study supplemented the primary research of the MAI with extensive review of secondary sources and reanalysis of primary data sets including results of industrial facilities audits undertaken by utilities, motor system engineering studies carried out for various utility DSM programs, and the DOE Industrial Assessment Center Program database containing results of over 10,000 energy audits of small manufacturing facilities. The results of this research are reported in the *Interim Report* (XENERGY 1997) of this project. We draw upon these materials throughout this report to place the inventory findings in context.

3 The 90-percent confidence interval is the range around the sample estimate that has a 90-percent probability of containing the actual population value of the parameter in question—in this case, total motor system energy.

SUMMARY OF KEY FINDINGS

FINDINGS

Improvements in industrial motor system efficiency offer huge opportunities to invest in the enhanced efficiency and profitability of American industry. The key findings from this study concerning the nature and scope of those opportunities are as follows:

- **Industrial motor systems represent the largest single electrical end use in the American economy. In 1994, industrial electric motor systems used in production consumed over 679 billion kWh, or roughly 23 percent of all electricity sold in the United States.** Motors used in industrial space heating, cooling, and ventilation systems used an additional 68 billion kWh, bringing total industrial motor system energy consumption to 747 billion kWh, or 25 percent of all electricity sales. This is roughly equal to *total electric sales to the commercial sector in 1994 (795 billion kWh).*

- **Potential industrial motor system energy savings using mature, proven, cost-effective technologies range from 11 percent to 18 percent of current annual usage or 62 to 104 billion kWh per year, in the manufacturing sector alone. Potential savings in the non-manufacturing industries are estimated at an additional 14 billion kWh.** This is roughly equivalent to potential energy savings in such major commercial end uses as indoor lighting. (XENERGY 1993) By way of comparison, all utility-sponsored demand-side management programs produced annual energy savings of 62 billion kWh in 1996. (EIA,b) The potential motor system energy savings for all industries translate into reductions in energy costs up to $5.8 billion, which directly increases the bottom line of industrial facilities. Realization of these savings would reduce carbon equivalent emissions by up to 29.5 million metric tons per year.

Improving the performance of this coal slurry pumping system has saved Peabody Holding Company 87,184 kWh per year. In U.S. industry, improvements to fluid systems represent over 60% of the overall industrial motor system energy savings potential.

- **Improvements to the major fluid systems—pumps, fans, and air compressors—represent up to 62 percent of potential savings.** This estimate does not include savings associated with improving the efficiency of the motors driving these systems. The technical aspects of optimizing pump, fan, and air compressor systems are well understood (if not widely implemented).

- **For specific facilities and systems, potential savings far exceed the industry average.** Motor Challenge has documented major cost-effective projects that have reduced energy consumption at the motor system level by an average of 33 percent, and by as much as 59 percent.

- **Motor system energy use and energy savings are highly concentrated by industry and size of plant.** Roughly 3,500 manufacturing facilities (1.5 percent of the total) account for nearly half of all motor system energy use and potential savings in the manufacturing sector.

- **For industries that use significant amounts of motor system energy, the financial impact of motor system energy costs and potential savings are substantial.** Most of the process industries with high levels of motor energy use operate on thin margins—on average 16 percent of operating revenues.[4] Any reductions in operating costs can substantially enhance profitability.

[4] Operating margin here corresponds to the quantity "Income from Operations" as defined in the *Quarterly Financial Report for Manufacturing, Mining, and Trade Corporations.* That is, Net Sales, Receipts, and Operating Revenues less Depreciation and all Operating Costs.

- **The magnitude and patterns of motor system energy use and potential savings vary greatly among industries.** Programs to assist industrial facilities in realizing motor energy savings must take these differences into account.
- **Except in the largest facilities, the level of knowledge and implementation of systematic approaches to motor system energy efficiency is low.** Although the engineering and industrial management community, with the support of Motor Challenge, has elaborated a set of best practices for motor systems design, purchase, and management, few companies are aware of these practices and fewer still have adopted them.
- **Overcoming the barriers to adoption of efficient motor systems purchase and management practices will be difficult.** These barriers include: conflicting priorities for capital investment, long capital replacement cycles, understaffing and under-training of plant maintenance and management functions, and conflicting motivations among equipment suppliers.

IMPLICATIONS FOR PROGRAM DESIGN

The findings of the Market Assessment provide a number of clear messages for the design of the Motor Challenge Program. These are as follows:

- Focus program resources on those industries and facilities in which the highest levels of energy savings are available. These are: Chemicals, Primary Metals (Steel & Aluminum), Paper and Allied Products, Water Supply and Wastewater, and Mining.
- Focus program resources on equipping manufacturers, designers, distributors, and purchasers of pump, fan, and compressor systems to specify and maintain optimized systems.
- Provide extensive and varied educational opportunities and tools for end-users to learn about and apply knowledge on efficient motors, motor system components, and motor system management.

Over the past 2 years, the Motor Challenge Program has implemented various components that take into account the market intelligence provided by this project. These initiatives include the following:

- **Partnerships with end-user industry organizations.** Motor Challenge is currently developing joint programs with the Technical Association of the Pulp and Paper Industry, the Association of Iron and Steel Engineers, the American Water Works Association, the Water Environment Federation, and the National Mining Association to reach plant engineers and managers in these industries.
- **Partnerships with supplier organizations.** Motor Challenge is pursuing a number of joint programs and initiatives with the industry associations that represent manufacturers and distributors of pump, fan, and compressed air systems. These programs include training for end-users, development of information products and design decision tools, and efficiency test protocols.
- **Educational resources.** Motor Challenge offers a broad range of educational products targeted to end-users. These include the MotorMaster+ computerized motor management tool, a technical information hotline, Showcase Demonstration case studies, and a host of other useful publications.

Tools like MotorMaster+ 3.0 can help industry capture energy savings opportunities and related cost and productivity benefits.

The Motor Challenge Program will continue to refine these offerings to help industry realize the motor energy savings opportunities and related economic benefits identified by the Market Assessment Study.

KEY FINDINGS: SELECTED DETAILS

Industrial motor systems represent the largest single electrical end use in the American economy.

- In 1994, motors systems used for production processes only (not including facility heating and ventilating) consumed 679 billion kWh, or 23 percent of all electricity sold in the United States that year (2,931 billion kWh). If the energy associated with industrial HVAC systems is added, this total comes to 747 billion kWh, or 25 percent of all electric sales.
- Process motor system energy accounts for 63 percent of all electricity used in industry.

Table E-1 shows the distribution of motor system energy use by major industry groups.

Table E-1: Motor System Energy Use by Major Industry Group

Industry Categories	Net Electric Demand* (million kWh)	Motor System Energy (million kWh)	Motor System Energy as % of Total Electricity
Manufacturing	**917,834**	**541,203**	**59%**
Process Industries (SICs 20,21,22,24,26,27,28,29,30,31,32)	590,956	419,587	71%
Metal Production (SIC 33)	152,740	46,093	30%
Non-metals Fabrication (SICs 23,25,36,38,39)	106,107	50,031	47%
Metals Fabrication (SICs 34,35,37)	68,031	25,492	37%
Non-Manufacturing	**167,563**	**137,902**	**82%**
Agricultural Production (SICs 01, 02)	32,970	13,452	41%
Mining (SICs 10, 12,14)	44,027	39,932	90%
Oil and Gas Extraction (SIC 13)	33,038	29,866	90%
Water Supply, Sewage, Irrigation (SICs 494, 4952,4971)	57,528	54,652	95%
Total All Industrial	***1,085,397***	***679,105***	***62.6%***

* 'Net Demand for Electricity' is the sum of purchases, transfers in, and total on-site electricity generation, minus sales and transfers off site. See MECS 1994 Table 12A-B.

Estimates of potential motor system energy savings in the manufacturing sector using mature, proven, cost-effective technologies range from 62 to 104 billion kWh per year, or 11 to 18 percent of current motor system energy use.

Savings estimation methods.
We estimated potential energy savings for motor efficiency upgrades and correction of motor oversizing by applying standard engineering formulae to observations of each motor system inventoried to which the measure would apply. Determining whether system efficiency measures apply to a particular motor system requires more data, time, and professional judgment than could be brought to bear in the course of the inventory. We, therefore, developed and implemented the following three-step process for estimating potential energy savings from the inventory data:

1. **Estimate total energy usage by major application.** We used the results of the inventory to estimate energy use by major application category: pumps, fans, air compressors, and other process systems.
2. **Compile expert opinion and case studies on measure applicability and savings fractions.** We solicited the opinions of industry experts—primarily consulting engineers, manufacturers' technical staff, and industry association representatives—regarding the percentage of systems to which various measures in the major application categories could be cost-effectively applied. We also solicited their opinions on the average savings these measures could achieve, in terms

of percentage of initial system energy use. We gathered similar information from case studies and other documents. Using this information, we formulated high, low, and midrange estimates of potential savings for each principal measure type within the major motor system application categories.

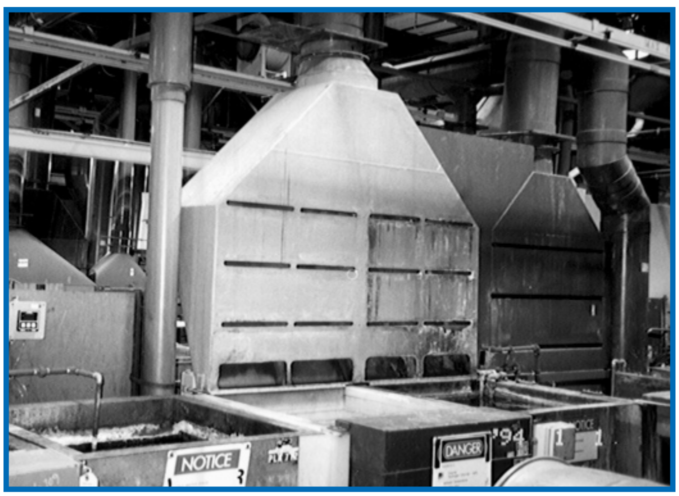
3. **Calculate high, low, and midrange savings estimates.** The savings estimates were calculated by applying the following formula:

$$\textit{Applicability}_{\textit{(High,Midrange,Low)}} \times \textit{Average Savings Fraction} \times \textit{System Energy.}$$

Because the motor systems grouped under "Other Process Systems" are so diverse, we did not feel it would be appropriate to apply to them the savings estimation process described above. Rather, we applied the method for speed control measures alone. Thus, the potential savings for this category is likely to be somewhat underestimated.

Throughout this analysis, we used a 3-year simple payback as the economic threshold for estimating applicability factors. These savings estimates can be understood as the economic potential for motor system efficiency improvements in existing industrial facilities.

Distribution of potential savings by type of measure.
Table E-2 shows how potential savings are distributed among different kinds of measures and end uses in manufacturing only. Potential efficiency improvements in non-manufacturing facilities add another 14 billion kWh in annual savings. The savings in the major groups of measures are additive. The term "CEE Efficiency Levels" refers to a set of motor efficiency standards proposed by the Consortium for Energy Efficiency, which are somewhat higher than the standards recently promulgated by the federal government. Nearly two-thirds of all potential savings derive from system improvements, such as the substitution of adjustable speed drives for throttling valves or bypass loops in pumping systems or fixing leaks in compressed air systems. Improvements to the major industrial fluid systems—pumps, fans, and air compressors—present between 45 and 62 percent of the total savings opportunities, taking into account low and high estimates.



General Dynamics Armament Systems' (formerly Lockheed Martin Armament Systems') ASD retrofit has resulted in annual savings of more than $68,000, with a 1.5 year payback.

Economic and environmental impacts of potential motor system energy savings in manufacturing.
Potential motor system energy savings carry significant impacts for the national economy and environment.

- Potential savings would reduce greenhouse gas emissions by 15.3 to 26.0 million metric tons of carbon per year.
- These savings are equivalent to removing 3.2 to 5.4 million cars from the road.

- The monetary value of these savings (after accounting for the price effects of self-generation) is $3.0 to $5.0 billion per year.
- In addition to energy savings, these improvements will yield a number of other economic benefits, including increased control over manufacturing processes and higher levels of quality control.

Table E-2: Summary of Motor Energy Savings Opportunities by Measure in Manufacturing Facilities

Measure	Potential Energy Savings GWh/Year			Midrange Savings as Percent of	
	Low**	Midrange**	High**	Total Motor System GWh	System-Specific GWh
Motor Efficiency Upgrades*					
Upgrade all integral AC motors to EPAct Levels***		13,043		2.3%	
Upgrade all integral AC motors to CEE Levels***		6,756		1.2%	
Improve Rewind Practices		4,778		0.8%	
Total Motor Efficiency Upgrades		24,577		4.3%	
Systems Level Efficiency Measures					
Correct motor oversizing	6,786	6,786	6,786	1.2%	
Pump Systems: System Efficiency Improvements	8,975	13,698	19,106	2.4%	9.6%
Pump Systems: Speed Controls	6,421	14,982	19,263	2.6%	10.5%
Pump Systems: Total	15,396	28,681	38,369	5.0%	20.1%
Fan Systems: System Efficiency Improvements	1,378	2,755	3,897	0.5%	3.5%
Fan Systems: Speed Controls	787	1,575	2,362	0.3%	2.0%
Fan Systems: Total	2,165	4,330	6,259	0.8%	5.5%
Compressed Air Systems: System Eff. Improvements	8,559	13,248	16,343	2.3%	14.6%
Compressed Air Systems: Speed Controls	1,366	2,276	3,642	0.4%	2.5%
Compressed Air Systems: Total	9,924	15,524	19,985	2.7%	17.1%
Specialized Systems: Total	2,630	5,259	7,889	0.9%	2.0%
Total System Improvements	36,901	60,579	79,288	10.5%	
Total Potential Savings	***61,478***	***85,157***	***103,865***	***14.8%***	

* Potential savings for Motor Efficiency Upgrades calculated directly by applying engineering formulas to Inventory data.
** High, Medium, and Low savings estimates for system efficiency improvements reflect the range of expert opinion on potential savings.
***Includes savings from upgrades of motors over 200 HP not covered by EPAct standards.

For specific facilities and systems, potential savings far exceed the industry average. Motor Challenge has documented major cost-effective projects that have reduced energy consumption by an average of 33 percent, and by as much as 59 percent at the system level.

Table E-3 summarizes the results of 13 motor systems efficiency projects supported and documented by Motor Challenge as part of its Showcase Demonstration component. Most of these projects involved assessment of and adjustments to fluid systems such as pumps, fans, and compressors, often accompanied by the addition of adjustable speed drives (ASDs) for speed control.

- These projects achieved energy savings of 38.6 million kWh per year at an average payback of 1.5 years.
- The high system-level savings are not atypical of these kinds of projects. There are many case studies of similar kinds of projects in the literature, and savings of this magnitude are reported by industry experts.

Table E-3: Summary of Motor Challenge Showcase Demonstration Projects

Company	Type of Plant	Energy Savings kWh/Year	Savings as % of Initial Sys. Energy	Annual Cost Savings	Payback on Investment (Years)
General Dynamics	Metal fabrication	451,778	38%	$68,000	1.5
3M Company	Laboratory facility	10,821,000	6%	$823,000	1.9
Peabody Coal	Coal processing	103,826	20%	$6,230	2.5
Stroh Brewery	Beer brewing	473,000	52%	$19,000	0.1
City of Milford	Municipal sewage	36,096	17%	$2,960	5.4
Louisiana-Pacific	Strand board	2,431,800	50%	$85,100	1.0
City of Trumbull	Sewage pumping	31,875	44%	$2,614	4.6
Nisshinbo California	Textiles	1,600,000	59%	$100,954	1.3
Greenville Tube	Stainless steel tubing	148,847	34%	$77,266	0.5
Alcoa	Primary aluminum	3,350,000	12%	$103,736	0.0
OXY-USA	Oil field pumping	54,312	12%	$5,362	0.5
City of Long Beach	Waste incineration	3,661,200	34%	$329,508	0.8
Bethlehem Steel	Basic oxygen furnace steel mill	15,500,000	50%	$542,600	2.1
Total/Average		***38,663,734***	***33%***	***$2,166,330***	***1.5***

Motor Challenge Showcase Demonstration site, Nisshinbo California, Inc., improved their ventilation system energy efficiency by 59%, cutting costs by over $100,000 per year.

Motor system energy use and energy savings are highly concentrated by industry and size of plant.

- As Table E-4 shows, the top 10 motor system energy consuming four-digit SIC groups account for nearly half of all manufacturing motor system energy use and half of all potential motor system energy savings. These groups include only 3,583 facilities, or 1.5 percent of all manufacturing plants.
- The largest 780 plants in the above groups account for over one-third of all manufacturing motor energy use. These plants are owned by roughly 500 separate companies.

Table E-4: Concentration of Motor Energy Use in Manufacturing

SIC Code	Industry Categories	Motor System Use (million kWh)	Percent of Total Manufacturing Motor System kWh	Motor System Savings (million kWh)	Number of Establishments
2621	Paper Mills	55,777	10.3%	5,711	310
2911	Petroleum Refining	40,805	7.5%	6,138	247
2819	Industrial Inorganic Chemicals, nec.*	37,232	6.9%	4,361	568
2631	Paperboard Mills	27,007	5.0%	2,765	219
3312	Blast Furnaces and Steel Mills	25,323	4.7%	2,742	284
2869	Industrial Organic Chemicals, nec.*	28,721	5.3%	3,364	631
2813	Industrial Gases	21,733	4.0%	2,545	623
2821	Plastics Materials and Resins	13,667	2.5%	1,601	456
3241	Cement, Hydraulic	9,147	1.7%	1,081	190
2611	Pulp Mills	6,402	1.2%	656	55
	Total of Top 10	265,814	49.1%	30,964	3,583
	Total: All Manufacturing	***541,203***		***62,350***	***246,950***

Sources: MECS 1994, Census of Manufactures 1992.
*nec. denotes "not elsewhere classified".

For industries that use significant amounts of motor system energy, the financial impact of motor system energy costs and potential savings are substantial.

Table E-5 displays motor system energy use and potential savings per establishment in the 10 four-digit SIC groups with the highest annual motor energy consumption. In all these industries, the annual cost of motor system energy in a typical plant exceeds $1 million; in steel mills it is $6 million. Potential savings at the typical plant are also very large, ranging from $90,000 per year in the Industrial Organic Chemicals sector to nearly $1 million per year in Petroleum Refining.

The right-hand column of Table E-5 shows potential energy savings as a percentage of operating margin. These figures suggest the potential impact of motor energy savings on the bottom line. The process industries listed in Table E-5 operate on very thin margins, that is: the difference between revenues from sales and variable costs including labor, materials, and selling costs. In 1996, operating margins for the 10 groups listed below ranged from 10 to 24 percent, and clustered around 16 percent. Thus, even relatively small increases in operating margin can have a significant impact on profitability.

A typical integrated steel mill spends about $6 million annually on motor system energy. One company—LTV Steel—is reducing its costs by improving this contact water system through the use of technologies such as ASDs and high efficiency pumps.

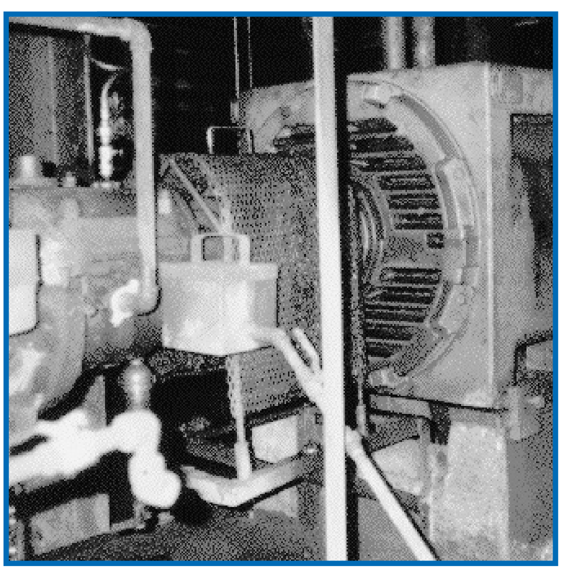


Table E-5: Financial Impact of Motor Energy Consumption and Savings: Selected Industries

Industry Groups	Motor System Costs/Estab.	Motor Energy Costs/Total Operating Costs	Savings per Estab. per Yr.	Savings as % of Operating Margin
Paper Mills	$4.6 mm	6.5%	$659,000	5.0%
Petroleum Refining	$5.6 mm	1.4%	$946,000	1.0%
Industrial Inorganic Chemicals, nec.	$1.6 mm	10.4%	$283,000	6.0%
Paperboard Mills	$3.0 mm	6.4%	$492,000	5.0%
Blast Furnaces and Steel Mills	$6.0 mm	2.1%	$358,000	2.0%
Industrial Organic Chemicals, nec.	$1.3 mm	1.0%	$91,000	1.0%
Industrial Gases	$1.1 mm	21.7%	$116,000	13.0%
Plastics Materials and Resins	$1.5 mm	1.5%	$121,000	1.0%
Cement, Hydraulic	$2.2 mm	9.6%	$219,000	4.0%
Pulp Mills	$1.7 mm	6.7%	$483,000	5.0%

Sources: MECS 1994, Bureau of Economic Analysis 1997, Census of Manufactures 1993.

The magnitude and patterns of motor system energy use and potential savings vary greatly among industries.

In developing motor systems efficiency strategies for individual plants or industries, it will be important to take these differences into account and to target sectors and measures with particularly high savings potential.

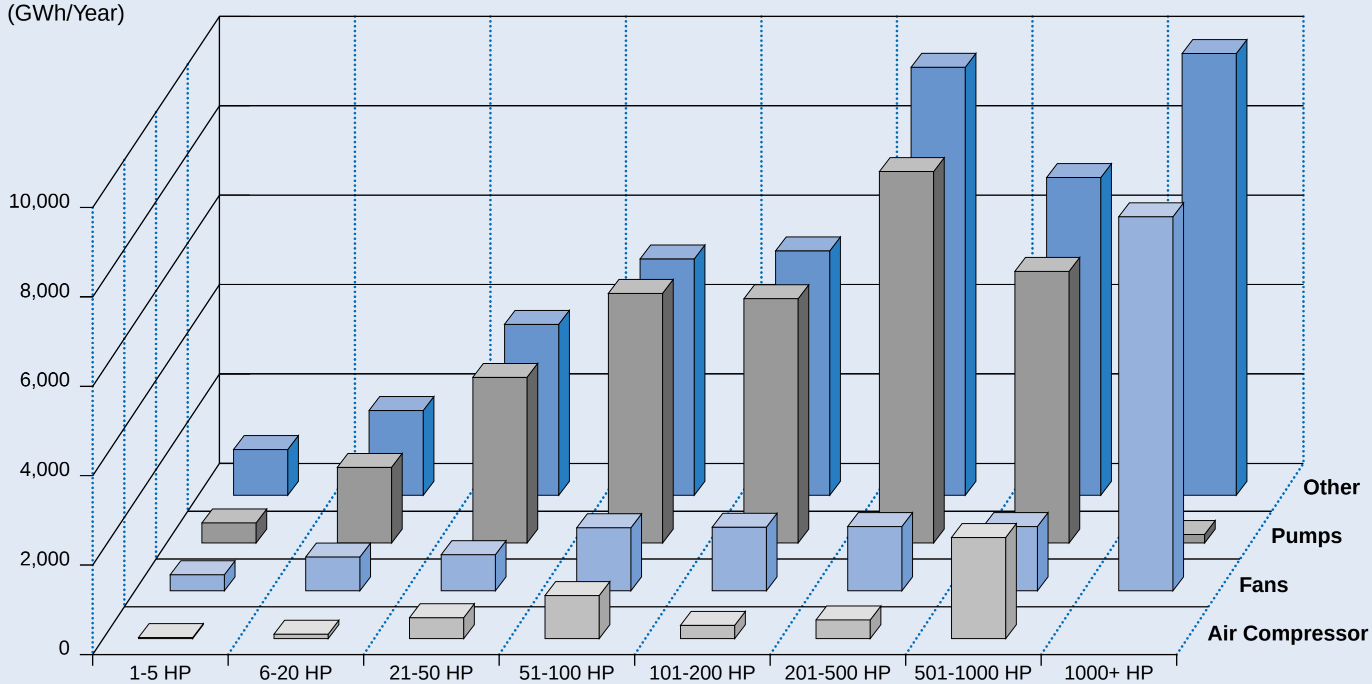
Patterns of motor energy use.
Each major industry group has a unique distribution of total motor system energy by application and motor size. Figure E-2 shows these distributions for the Paper and Allied Products (SIC 26) and Primary Metals (SIC 33) industries. Much of the motor system energy in the paper industry is concentrated in mid- and large-sized pumps, as well as in pulping equipment and paper machines which are driven, in part, by very large horsepower motors. In the metals industries, a great deal of motor system energy is concentrated in large fans which serve major combustion processes. Other concentrations of motor energy are in large air compressors and materials processing machines.

In Primary Metals, the largest savings are in large fan and air compressor systems. At Alcoa's Mount Holly aluminum production facility, the company managed to save more than $100,000 simply by shutting off one fan in each dust collection system.

Patterns of potential savings.
Figure E-3 shows that potential savings opportunities cluster in the application/horsepower groups with the greatest amounts of energy. Most of the savings in the paper industry are concentrated in improvements to pump systems. In Primary Metals, the largest savings can be found in large fan and air compressor systems. Savings in pump systems are also substantial in the lower horsepower ranges. The concentration of many of the savings opportunities in systems driven by large motors suggests that their implementation will require considerable planning and capital outlay.

Figure E-2: Motor System Energy Usage by Application and Motor Horsepower

Paper and Allied Products (SIC 26)
(GWh/Year)



Primary Metals (SIC 33)
(GWh/Year)

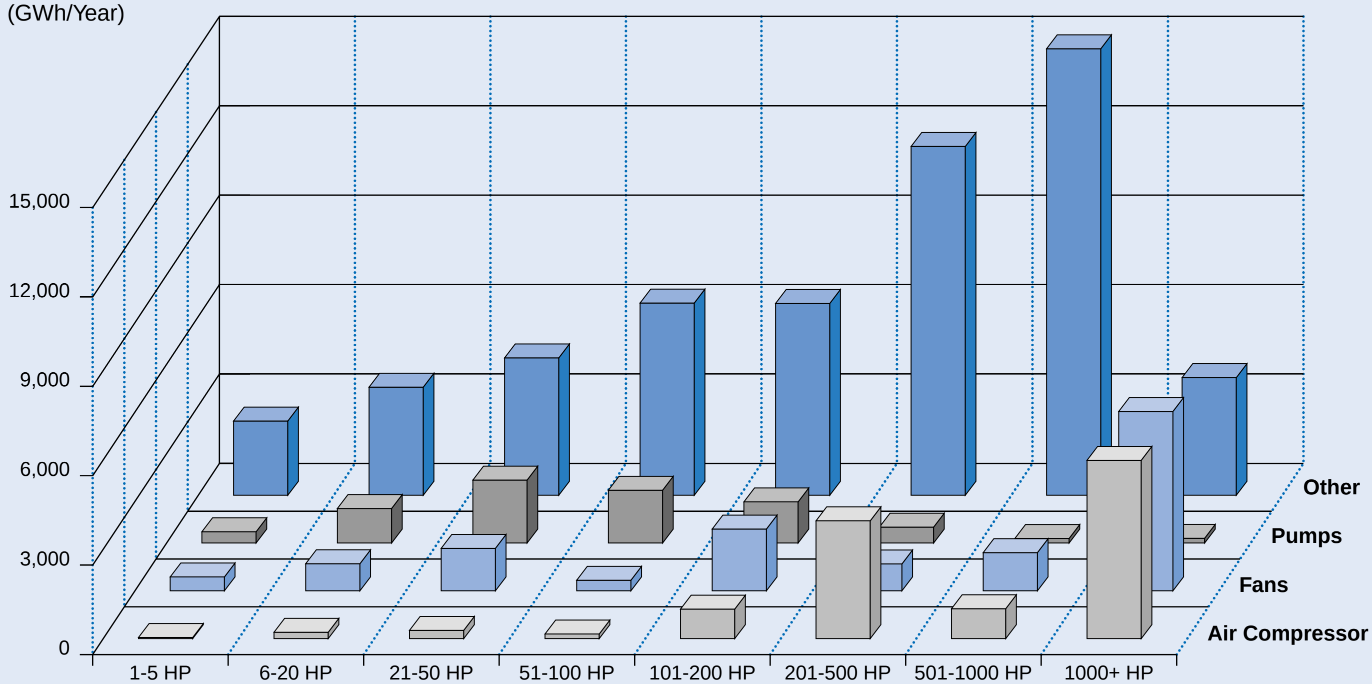
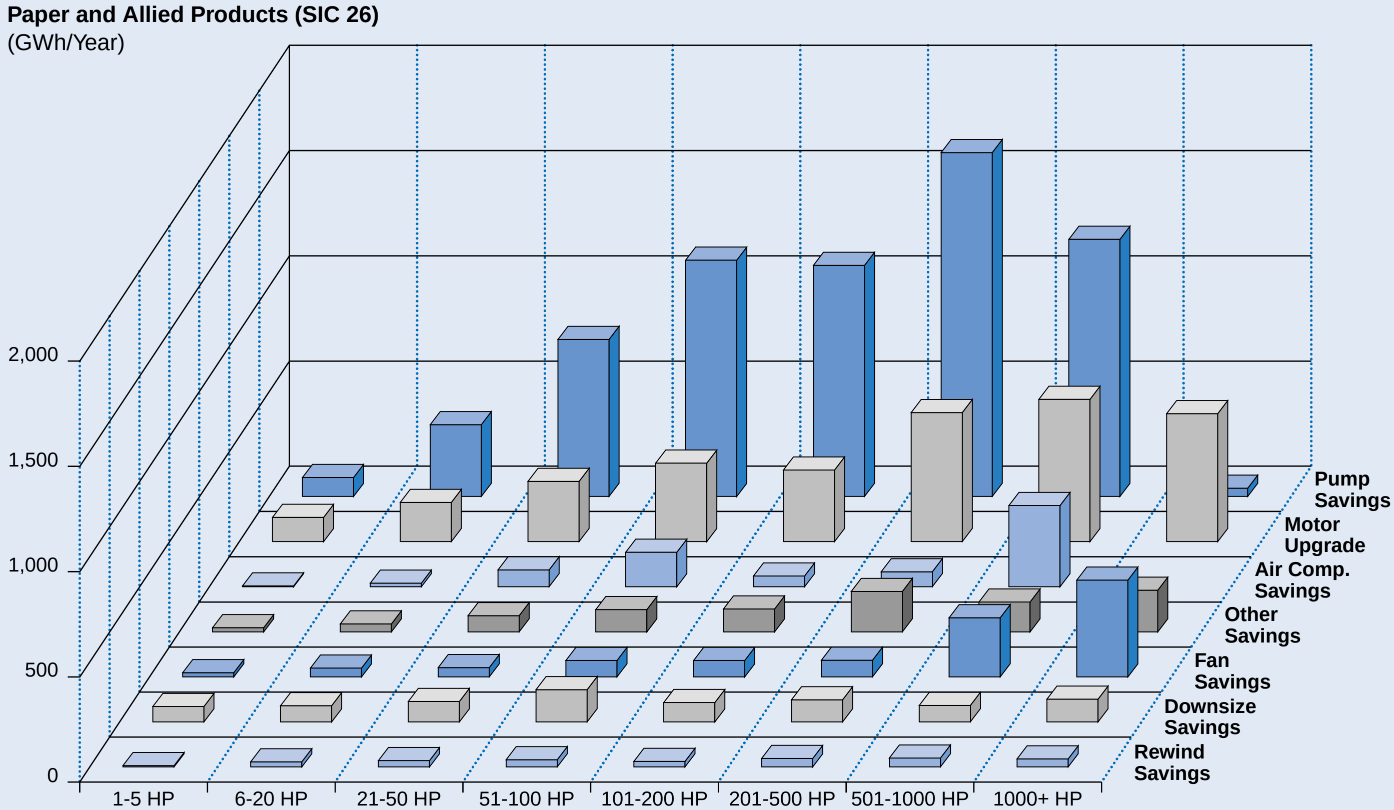
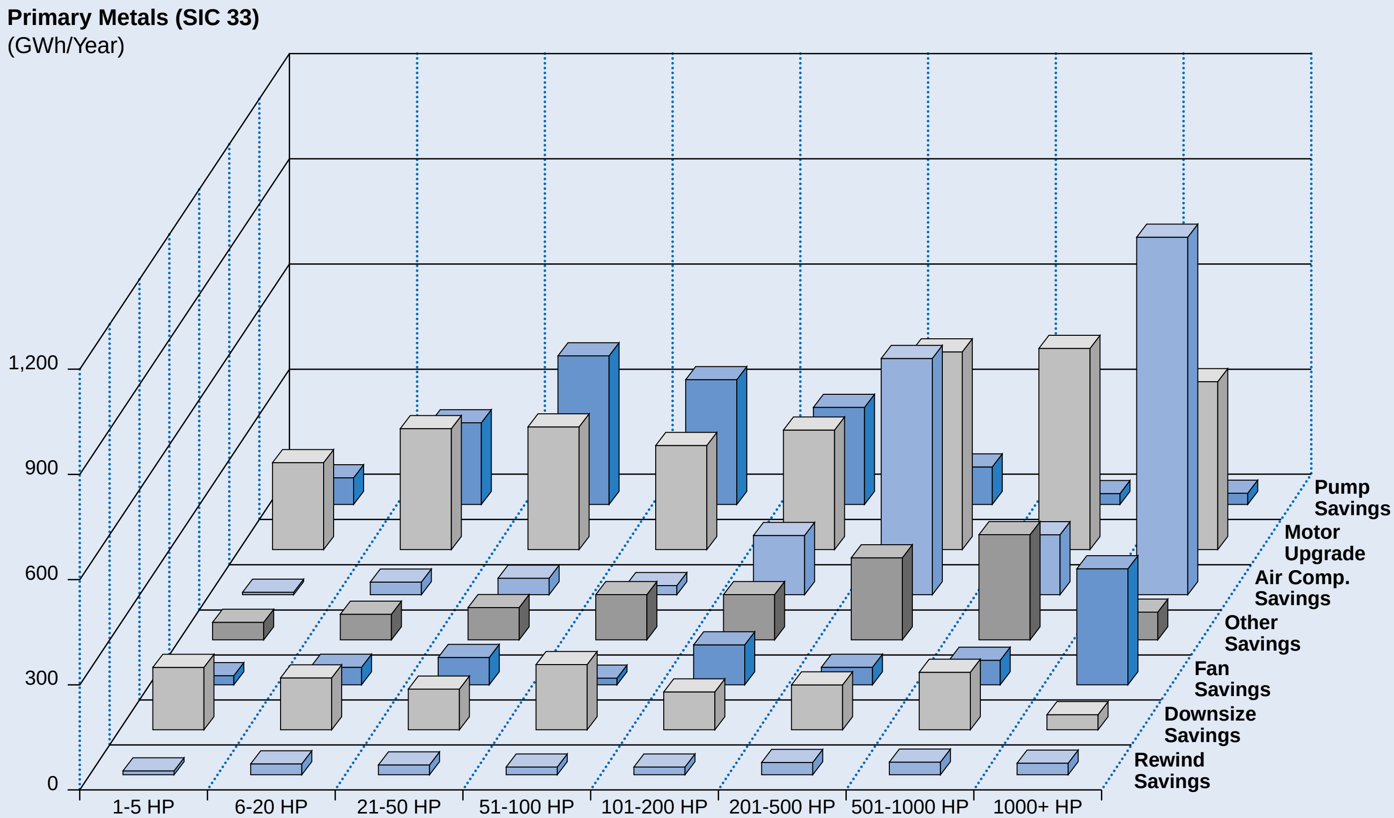


Figure E-3: Distribution of Potential Energy Savings by Application and Motor Size





Patterns of potential savings across industries.
Table E-6 shows potential motor system energy savings by application for each two-digit SIC group. The numbers printed in blue indicate measure groups with particularly high concentrations of potential savings. These 22 SIC/measure groups (out of 126) account for 69 percent of all potential savings.

Table E-6: Potential Systems-Level Motor Energy Savings by Manufacturing SIC and Application

SIC	Industry Category	Estimated Savings (GWh/Year) Fan System	Pump System	Compressed Air Systems	Other Proc. Systems	Motor Upgrade	Motor Downsizing	Replace vs. Rewind	All Systems	As % of Total Energy
20	Food and Kindred Products	157	1,250	494	517	1,376	585	295	4,674	12.4%
21	Tobacco Products									
22	Textile Mill Products	170	593	408	166	743	305	121	2,506	15.0%
23	Apparel & Other Textile Products	1	0	68	15	47	22	8	162	13.9%
24	Lumber and Wood Products	153	243	324	341	432	336	184	2,013	8.8%
25	Furniture and Fixtures	87	5	78	33	173	68	26	471	12.7%
26	Paper and Allied Products	1,082	6,293	773	881	3,197	845	870	13,942	14.0%
27	Printing and Publishing	52	17	74	90	305	153	39	731	12.3%
28	Chemicals and Allied Products	942	7,556	6,813	994	4,219	1,409	1,255	23,188	16.1%
29	Petroleum and Coal Products	271	6,159	1,352	169	1,736	459	453	10,599	20.4%
30	Rubber and Misc. Plastics Products	113	1,851	813	411	1,498	435	303	5,424	14.8%
31	Leather and Leather Products	27	0	0	0	22	6	3	58	11.8%
32	Stone, Clay, and Glass Products	31	18	96	20	117	45	14	343	15.4%
33	Primary Metal Industries	738	1,537	2,150	1,085	3,199	983	749	10,441	11.9%
34	Fabricated Metal Products	34	181	303	80	298	195	46	1,137	15.6%
35	Industrial Machinery and Equipment	28	195	200	94	368	208	44	1,138	15.4%
36	Electronic and Other Electric Equipment	18	1,554	513	43	609	222	93	3,053	23.1%
37	Transportation Equipment	353	1,109	941	242	1,195	340	235	4,415	14.9%
38	Instruments and Related Products	71	119	123	78	263	169	39	862	13.3%
39	Misc. Manufacturing Industries									
	All Industry Groups	***4,330***	***28,681***	***15,524***	***5,259***	***19,799***	***6,786***	***4,778***	***85,157***	***14.8%***

Saturation of the most common motor system efficiency technologies—energy-efficient motors and adjustable speed drives—is relatively low.

- **Energy-efficient motors.** The inventory found that motors meeting EPAct standards accounted for 9.1 percent of all motors currently in use, with the highest concentration (25.5 percent) in the 101–200 horsepower range. EPAct compliant motors use 18.7 percent of total motor system energy in manufacturing.

- **Adjustable speed drives.** The inventory found that 9 percent of all observed motor systems, accounting for 4 percent of all motor system energy were equipped with adjustable speed drives. Over 90 percent of the ASD-equipped motor systems were of 20 horsepower or less. In this size range, it is more likely that the ASD was installed primarily to increase control over the production process rather than to save energy. Based on the application of engineering screening criteria for the application of ASDs, we estimate that motors representing 18 to 25 percent of total manufacturing motor system energy could be cost-effectively equipped with ASDs.

Over 40 percent of motors are operating at less than 40 percent part load. Substantial energy savings can be gained by better matching the size of the motor to the load.

Based on instantaneous load measurements of nearly 2,000 motors operating under reportedly normal conditions, we found that 44 percent were operating at part loads below their efficient operating range. We calculated energy savings associated with resizing these motors to better match load at 1.2 percent of total motor system energy. For pump, fan, and other fluid systems, low part loads may indicate that the entire system is operating at far below its optimal efficiency.

Except in the largest facilities, the level of knowledge and implementation of systematic approaches to motor system energy efficiency is low.

ELEMENTS OF BEST PRACTICE

Over the past 5 years, industrial engineers and plant managers have begun to evolve and articulate a systematic approach to achieving energy efficiency in motor systems. The development of this "systems approach" has been supported by Motor Challenge, as well as by dozens of efforts led by electric utilities, trade and professional organizations, and government agencies in the U.S. and Canada. The systems approach, as it now stands, consists of three elements:

- System performance optimization;
- Selection of efficient components; and
- Operation and maintenance.

Table E-7 provides examples of each of these elements in the context of pumping systems, along with the range of savings associated with each kind of efficiency measure. Similar tables for other kinds of fluid systems are found in Section 2 of this report.

Table E-7: Energy Saving Opportunities in Pump Systems

Equipment Group/Efficiency Measure	Range of Savings (Percent of System Energy)
Process System Design	
Reduce Overall System Requirements	
•Equalize flow over production cycle using holding tanks.	10%–20%: depends on variation in flow.
•Eliminate bypass loops and other unnecessary flows.	10%–20%: depends on initial system design.
•Increase piping diameter to reduce friction.	5%–20%: depends on initial system design.
•Reduce "safety margins" in design system capacity.	5%–10%
•Reduce system effects due to piping bends.	
Match Pump Size to Load	
•Install parallel systems for highly variable loads.	10%-30%: depends on initial system design.
Reduce or Control Pump Speed	
•Reduce speed for fixed loads: trim impeller, lower gear ratios.	5%–40%: depends on initial system design.
•Replace throttling valves with speed controls to meet variable loads.	5%–50%: depends on initial system design.
Component Purchase	
•Replace typical pump with most efficient model.	1%–2%
•Replace belt drives with direct coupling.	About 1%
•Replace typical motor with most efficient model.	1%–3%
Operation and Maintenance	
•Replace worn impellers, especially in caustic or semi-solid applications.	1%–5%

FINDINGS ON CURRENT MOTOR SYSTEMS DESIGN, PURCHASE, AND MAINTENANCE PRACTICES

The following paragraphs summarize key findings on customers' awareness and implementation of the elements of best practice discussed above. Percentages reflect weighting of Practices Inventory results to the population.

- **Most motor purchase decisions are made at the plant level.** Even among multi-site organizations, 91 percent reported that all motor purchase decisions were made at the plant level.
- **Awareness of the availability of energy-efficient motors and understanding of their performance advantages is low.** Only 19 percent of respondents reported being aware of "premium efficiency" motors, the common marketing designation for motors that met EPAct standards prior to their promulgation in October 1997.

Only 4 percent of customers reported that they understood the efficiency ratings associated with the premium or high-efficiency designations; 38 percent reported being somewhat aware of these relationships. These results likely reflect the inconsistency of product designations that existed prior to the promulgation of the EPAct standards, as well as generally low levels of product knowledge.

Motor purchase decisions are typically made at the plant level.

- **Only 22 percent of customers surveyed reported that they had purchased any efficient motors in the past year.** Among all customers surveyed, the average reported percentage of efficient motors purchased in the past year was 12 percent. According to the Bureau of the Census *Current Industrial Reports,* efficient motors constituted 15 percent of all 1–200 horsepower units shipped domestically in 1996. Thus, we believe that customer reporting on this topic was fairly accurate.
- **Customers most often use the size of the failed motor being replaced as a key factor in selecting the size of the new motor. Twenty-nine percent use the size of the failed motor as the *only* factor in the sizing decision. This practice can lead to persistent oversizing of motors, which leads to inefficient operations.**
- **Only 11 percent of customers interviewed reported having written specifications for motor purchases; only two-thirds of these customers included efficiency in their specifications.** Consistent with other findings, larger plants tended to use written specifications more often than smaller ones.
- **Reducing capital costs is the most important consideration driving customers' decision whether to rewind or replace failed motors.** Only 12 percent of customers reported that they considered the lower energy operating costs of new motors in the rewind versus replace decisions. Very few customers report providing specifications to rewind contractors. If improperly done, rewinding reduces the efficiency of motors from 1 to 2 percent.

Except among the very largest facilities, the frequency with which system-level improvements are undertaken is very low. Customers were asked whether they had implemented a list of specific system-level improvements for pump, fan, and compressed air systems over the past 2 years. Except for fixing leaks in compressed air systems, none of the measures were mentioned by more than 8 percent of the respondents. Larger facilities reported making such improvements more frequently.

See Table E-8 for a summary of these results.

Table E-8: Reported System Measures Undertaken During the 2 Years Prior to the Inventory

	Size Categories[5]					
	Large	Med/Large	Medium	Sm/Med	Small	*Total*
Fan Systems						
Retrofitted with ASDs	20%	7%	1%	0%	1%	***1%***
Retrofitted with inlet guide vanes	9%	1%	0%	0%	3%	***2%***
Checked components with large pressure drops	3%	1%	10%	0%	3%	***3%***
No fan systems in facility	0%	29%	24%	18%	43%	***38%***
No improvements	67%	49%	45%	80%	33%	***40%***
Pump Systems						
Substituted speed controls for throttling	22%	8%	11%	1%	0%	***1%***
Used parallel pumps to respond to variations in load	14%	4%	2%	0%	3%	***2%***
Reduced pump size to fit load	0%	5%	7%	11%	3%	***4%***
Increased pipe diameter to reduce friction	5%	6%	6%	11%	1%	***3%***
No pump systems in facility	13%	28%	24%	17%	40%	***35%***
No improvements	45%	57%	42%	52%	34%	***38%***
Compressed Air Systems						
Replaced 1-stage rotary screw units with more efficient models	7%	16%	29%	2%	4%	***6%***
Used parallel compressors to respond to variations in load	23%	12%	10%	13%	7%	***8%***
Reconfigured piping and filters to reduce pressure drops	14%	24%	5%	13%	1%	***5%***
Added multi-unit controls to reduce part load consumption	23%	10%	6%	0%	4%	***4%***
Reduced size of compressors to better match load	10%	6%	1%	2%	1%	***1%***
Fixed leaks	42%	40%	34%	36%	15%	***20%***
No compressed air systems in facility	0%	3%	0%	1%	10%	***8%***
No improvements	39%	44%	37%	62%	52%	***52%***
No Reported Improvements	30%	27%	14%	45%	21%	***24%***

[5] The size categories are based on sample stratification cut points. All establishments in each two-digit SIC group were initially allocated to Large, Medium, and Small size strata, with roughly one-third of all establishments in the SIC group in each size stratum. The cut points between Large, Medium, and Small varied by SIC group. In some regions, we needed to combine adjacent groups to provide a sufficiently large sample frame. Thus, Large and Medium/Large are not mutually exclusive size designations. Likewise for Small and Medium/Small.

ORGANIZATION OF THE REPORT

The remainder of this report is organized as follows:

- **Section 1: The U.S. Industrial Motor Systems Inventory.** This section presents the results of the Inventory, focusing on the distribution of manufacturing motor systems and energy by industry, horsepower, application, efficiency, hours of use, and part load. This section also contains case studies of motor system energy use in non-manufacturing industries.
- **Section 2: Motor System Energy Savings Opportunities.** This section presents detailed estimates of motor system energy savings by type of measure, industry, application, and horsepower size. We also provide extensive documentation of the methods used to develop these estimates.
- **Section 3: Motor Systems Purchase and Maintenance Practices.** This section presents the results of the Practices Inventory in detail, along with related information from the literature.
- **Appendix A: Profiles of Key Industrial Sectors** contains short profiles of five key motor system energy-using sectors covering industry structure and conditions, general energy use patterns, and technical energy savings opportunities specific to the industry. Appendix A also includes summaries of inventories performed at non-manufacturing industrial sites.
- **Appendix B: Standard Tables** contains detailed tables of motor inventory and savings information for each two-digit manufacturing SIC group.
- **Appendix C: Methodology** contains detailed technical descriptions of the sampling approach and variance calculations. It also contains copies of data collection forms.
- **Appendix D: Stock Adjustment Model** contains a description of the model used to forecast the size and overall efficiency of the manufacturing motor inventory. It also contains the inputs, assumptions, and results of the forecast through the year 2002.

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