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Advanced Manufacturing Office

United States Industrial Motor-Driven Systems Market Assessment: Charting a Roadmap to Energy Savings for Industry

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ABSTRACT
Over 13.5 million electric motors of 1 HP or greater convert electricity into useful work in U. S. industrial process operations. Industry spends over $33 billion (US) annually for electricity dedicated to electric motor-driven systems. Industrial motor system electricity consumption is 24% of all U.S. electricity sold in 1994. Because nearly 70% of all electricity used in industry is consumed by some type of motor-driven system, increases in the energy efficiency of existing motor systems will lead to dramatic nationwide energy savings.

The United States Department of Energy's (DOE) Motor Challenge program is an industry/government partnership designed to help industry capture 9 billion kilowatt-hours per year of electricity savings by the year 2010. These energy savings spurred on by the Motor Challenge program will lead to a potential energy savings of 82 billion kwh/year within industry (65 in manufacturing and 17 in non-manufacturing—mining, agriculture, oil and gas extraction). This amount of energy savings:

- will increase U.S. industry's overall motor system energy efficiency by 12 percent;
- is equivalent to the amount of electricity consumed by the entire country of Venezuela for one year;
- will reduce carbon emissions by 20 MMTCE per year which is equivalent to removing approximately 4 million cars from the road.

The main goal of the Motor Challenge program is to work in partnership with industry to increase the market penetration of energy-efficient motor-driven systems. A key element in the Motor Challenge strategy is to encourage a "systems approach" to how motors, drives and motor-driven equipment are engineered, specified, and maintained by industry. This represents a new way of looking at motor efficiency and the potential for energy and cost savings. The program focuses much of its resources on a few key industrial sectors which are participating in DOE's Industries of the Future (IOF) strategy.(1) The IOF sectors are: Forest Products, Steel, Aluminum, Metal Castings, Chemicals, Glass, Mining, and Agriculture. The Motor Challenge program also targets Water Supply and Wastewater energy savings opportunities - - both industrial and municipal. The Forest Products, Steel and Mining sectors are the leading industries with which Motor Challenge is partnering to develop energy savings strategies, actions, and results. These industry partnership activities are described in this paper.

(1) The DOE Industries of the Future strategy creates partnerships between U.S. industry, government, and supporting laboratories and institutions to accelerate technology research, development, and deployment. Led by the DOE Industrial

Technologies Program within the Department of Energy's Energy Efficiency and Renewable Energy, the Industries of the Future strategy is being implemented in eight energy- and waste-intensive industries: Forest Products, Steel, Aluminum, Metal Castings, Chemicals, Glass, Mining, and Agriculture.

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A market assessment was commissioned by the Motor Challenge program in 1995 to better understand the characteristics of the installed population of motor systems in the manufacturing sector; to understand end user motor system purchase and maintenance practices; and to develop strategic information so that the Program could work with industry to target the best opportunities in key end use sectors. This paper is an overview of the results of the market assessment which lay the groundwork to a Roadmap to Energy Savings.[2]

Introduction—General Characteristics of the U.S. Industrial Motor Systems Energy Consumption

In 1994, U.S. industry consumed 691 billion kilowatt-hours of electricity in process motor-driven systems; 553 billion kwh for the manufacturing sector and 138 billion kwh for non-manufacturing (ie., mining, agriculture, oil and gas extraction, etc.). Motors for industrial heating, ventilation, and air conditioning will add an estimated 68 billion kwh/year in motor system energy use. These motor systems were not studied as part of the market assessment.

Application Energy Distribution

As mentioned, in the US industrial sector, more than 70 percent of all electricity consumption involves motor-driven systems; of this amount of energy, 59 percent goes to some type of fluid movement or compression system, such as pumps, fans, blowers, and compressed air systems with the remaining amount going to other motor system usage (see Table 1).

PRELIMINARY DATA

Table 1 - Manufacturing Motor System Energy Characteristics by Application [3]

Type of Application	Motor System Electricity Consumption (10^9 kwh/year), 1994	% of Total Manufacturing Sector Motor System Energy
Pump Systems	149	27
Compressed Air Systems	100	18
Fan Systems	77	14
Material Movement/Handling	33	6
Other Material Processing	133	24
Industrial Refrigeration	33	6
Other	28	5
Total Manufacturing	553	

(2) This paper presents preliminary data that will be presented in final form in a report to be released by Oak Ridge National Lab in the Fall of 1998.

(3) These data are for the manufacturing sector only; application data for the non-manufacturing sectors is limited, and therefore, conclusions on motor system application energy usage can not be made.

Industry Sector Motor System Energy Distribution
Motor system energy use is highly concentrated by industry sector - - see Table 2. Note that over 60 percent of motor system energy is within the top 6 sectors of which 4 of the 6 are participating the Industries of the Future initiative.

PRELIMINARY DATA

Table 2 - Motor System Energy Characteristics by Industry Sector

Industrial Sector	Motor System Electricity Consumption (10^6 kwh/year), 1994	Industry of the Future (IOF) Sector; Motor Challenge Targeted Sector (MC)	% Total Industrial Motor System Electricity	Cumulative % of Total Motor System Electricity
Chemicals & Allied Products	140,289	IOF	20.2	20.2
Paper & Allied Products	120,078	IOF, MC	17.4	37.6
Water Supply/Wastewater/ Irrigation	54,652	MC	7.9	45.5
Food Processing	51,587		7.5	53.0
Mining	39,625	IOF, MC	5.7	58.7
Steel	35,292	IOF, MC	5.2	63.9
Petroleum & Coal Products	33,750		4.9	68.8
Rubber & Misc. Plastics	32,356		4.7	73.5
Oil & Gas Extraction	29,866		4.3	77.8
Textiles	16,850		2.4	80.2
Transportation Equip.	14,908		2.2	82.4
Agriculture Production	13,452	IOF	1.9	84.3
Aluminum	11,600	IOF	1.7	86.0
Lumber & Wood Products	8,608	IOF	1.2	87.2
Glass	5,784	IOF	0.8	88.0
Metal Casting	5,268	IOF	0.8	88.8
Cement	3,012		0.4	89.2
All Other Sectors	74,286		10.8	100.0
Total	691,263			

* shaded sectors are those that Motor Challenge is initially partnering with most intensively at this time.

Industries of the Future (IOF) sectors account for 53% of total industrial motor system energy consumption. The initial target sectors of Motor Challenge—Paper and Allied Products, Steel, Mining, and Water Supply/Wastewater—account for 36% of total industrial motor system energy consumption.

Concentration of Motor System in Large Plants
Within the Industries of the Future sectors, less than 2,000 "Large Plants" (those with greater than 250 employees) account for almost 35 percent of total industrial motor system energy—see Table 3 (there are over 120,000 plants in the U.S. with greater than 20 employees). This information is leading the DOE Industrial Technologies IOF and Motor Challenge program strategy to target large plants so as to have maximum impact in achieving energy saving results in the near and long term. The larger plants will serve as Showcase examples for other plants in industry to replicate the success stories developed.

PRELIMINARY DATA

Table 3 - Motor System Energy Concentrated in "Large Plants", Industries of the Future Sectors

Industry Sector	Motor System Electricity Consumption in Large Plants (10^6 kwh/year), 1994	# of Large Plants	Average Motor System Electricity Consumption per Large Plant (10^6 kwh/year)	% Total Industrial Motor System Energy for Large Plants in Sector
Chemical & Allied Products	95,487	846	112.9	13.8
Paper & Allied Products	85,906	255	336.9	12.4
Mining	17,735	185	95.9	2.6
Steel	24,680	197	125.3	3.6
Agriculture	NA	NA	NA	NA
Aluminum	8,111	100	81.1	1.2
Glass	5,768	188	30.7	0.8
Metal Casting	3,684	200	18.4	0.5
Total Industries of the Future "Large Plants"	241,171	1,971	122.4	34.9
Total Industry	691,263			

Moving Towards a Systems-Oriented Solutions
Evidence the Market is Changing
In the early to mid 1990s, the majority of public and private-sector efforts to improve motor system energy efficiency focused on the motor, rather than other individual motor-driven system components or, more importantly, on the system as a whole. There is evidence in the past 2 to 4 years, however, that change is occurring in the market, as influenced by both private and public sector activities to focus more on system-based solutions. Examples of these activities, include:

- People are much more focused on motor systems than just on the motor alone. Although hard to measure, people and private sector companies, in general, are more focused on motor system opportunities as part of their

promotion of energy efficiency products and services to customers, or for end users, to achieve overall productivity gains in their manufacturing plants.

- Training curriculum has been developed by the Energy Center of Wisconsin, the Hydraulic Institute, and Motor Challenge that educates industry on fluid system optimization principles—pump and fan systems training.
- Motor Challenge tools, such as MotorMaster+ and other technical information are being used by thousands of people as provided directly by Motor Challenge, or by the 170 Motor Challenge Allied Partners that disseminate Motor Challenge information with the support of the Program (Allied Partners are non end users, such as original equipment manufacturers, distributors, utilities, State energy agencies, engineering firms, etc.). Likewise, MotorMaster+ software has been greatly upgraded to help the user to analyze system effects when installing a new motor (e.g., putting an energy efficient motor on a centrifugal load).
- The Compressed Air Challenge has been developed recently as a result of Motor Challenge efforts to unite participants in the compressed air system market. The Compressed Air Challenge is looking at all varieties of opportunities to improve compressed air system efficiency, and are developing information and training curriculum to support plant operation staff to target these opportunities.
- The Electric Power Research Institute (EPRI) has developed the software program called ASDMaster. ASDMaster helps a person designing and purchasing an electronic AC adjustable speed drive to choose and specify the best ASD for their application. System effects are analyzed with the program.
- Motor Challenge Showcase Demonstrations are proving that system energy savings opportunities are tremendous and average around 30 percent (see section later in this paper).
- Companies such as 3M, Dupont, Johnson & Johnson are promoting system-based solutions within their companies.

The Systems Approach

A "systems approach" seeks to increase the efficiency of electric motor systems by shifting the focus from individual components and functions to total system performance (see Figure 1). When applying the systems approach process system design and manufacturing best practices seek to optimize performance in the entire process system, and then on selecting components and control strategies which best match the new, reduced process load. The steps involved in accomplishing a system optimization would involve: characterizing the process load requirements; minimizing distribution losses; matching the driven equipment to load requirements; controlling the process load in the most optimal manner considering all cycles of the process load; and properly matching the motor and drive to each other as well as the load.

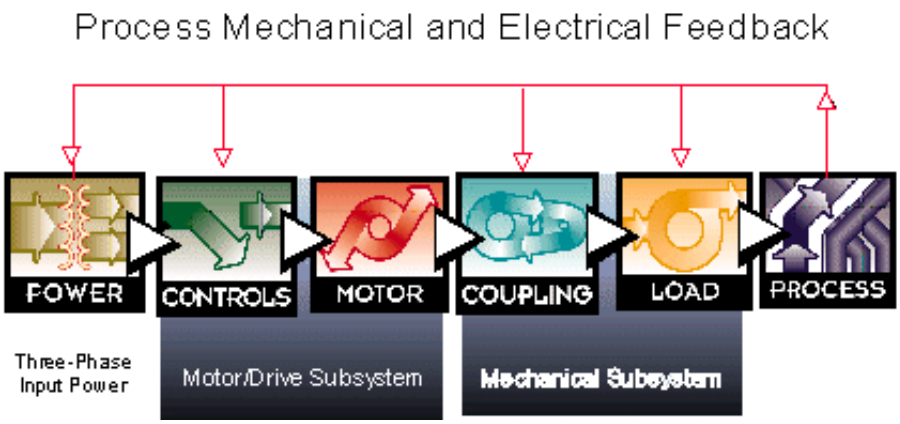

Figure 1: Motor System Diagram

Motor Challenge is Demonstrating the System Approach Pays

Motor Challenge *Showcase Demonstration* case studies provide examples of how companies have undertaken improvements in their electric motor systems and have benefitted from verified energy savings and related improvements in waste reduction and productivity. DOE has sought Motor Challenge industry partners who are willing to participate as Showcase Demonstrations. In exchange for technical assistance and the opportunity to try out new technologies, Showcase participants must be willing to undertake detailed monitoring and analysis that will help all other industry partners understand how to make their operations run better. To date, 13 Showcases have been completed and have saved in aggregate $2.2 million US at an average payback of approximately 1.5 years (see Table 4). Even more impressive is the average system efficiency improvement of 33% for all 13 projects. These Showcase examples prove that there are large opportunities available to industry with efficient motor systems. Additionally, the case studies generated from these projects are in large demand by trade magazines for publication; by Motor Challenge Allied Partners (suppliers, utilities, distributors, engineering firms, etc.); and by industry end users.

Motor and Motor System Energy Savings

The market assessment estimated energy savings that are economic (less than 3 year payback). Only savings in the industrial sector were estimated. The results below do not include improvements to commercial building motor system applications. There were three savings analysis areas:

New energy efficient motor purchases—Energy savings from the purchase of new energy efficient motors, driven by both the new Energy Policy Act (EPACT) motor regulation and purchases of energy efficient motors for applications that are not covered by EPACT.

Improved motor management practices—Energy savings from better management of currently installed motors with improved repair practices, more properly matching motor size to the driven load, and the adoption of motor management best practices.

Improved motor system optimization—Energy savings from overall system optimization from better matching fluid handling devices (e.g., pumps) to the load, and implementing more optimal control strategies and technologies (adjustable speed drives) to accommodate fluctuating loads.

Table 4 - Motor Challenge Showcase Demonstration Results

Showcase Demo **Company Site**	**Type of Plant**	**Energy Savings** **kWh/Year**	**System Savings, %**	**Annual Cost Savings, $US**	**Payback on Investment, Years**
General Dynamics	Metal Fabrication, Metal Plating	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
Strohs Brewing	Beer brewing	473,000	52	$19,000	0.1
City of Milford	Municipal sewage pumping	36,096	17	$2,960	5.4
Louisiana-Pacific	Strand board	2,431,800	50	$85,100	1.0

City of Trumbull	Municipal sewage pumping	31,875	44	$2,614	4.6
Nisshinbo California	Textiles	1,600,000	59	$100,954	1.3
Greenville Tubing	Stainless steel tube fabrication	148,847	34	$77,266	0.5
Alumax	Primary aluminum production	3,350,000	12	$103,736	0.0
OXY-USA	Oil field pumping	54,312	12	$5,362	0.5
City of Long Beach	Municipal waste incineration	3,661,200	34	$329,508	0.8
Bethlehem Steel	Fan system on basic oxygen furnace	15,500,000	50	$542,600	2.1
Total/Average		38,663,734	33	$2,166,330	1.5

Energy Savings from New Energy Efficient Motor Purchases

As of October, 1997, the Energy Policy Act of 1992 motor regulation (EPACT) requires that general purpose, polyphase, single speed, squirrel-cage induction motors manufactured for sale in the US and rated from 1-200 HP meet minimum efficiency standards. In addition to these standards, EPACT also requires standardized testing procedures and labeling. [EPACT does not require users of motors to replace currently installed standard efficient motors with energy efficient models, but rather only requires the purchase of some categories of new motors to be energy efficient]. Table 5 shows the projected energy savings from motors covered by EPACT(1 to 200HP); the incremental energy savings when EPACT motors are upgraded to higher efficiencies suggested by the Consortium for Energy Efficiency (CEE) levels (above EPACT levels); and the energy savings for upgrading motors not covered by EPACT that are above 200HP. These energy savings do not include the savings available from energy efficient motor upgrades in commercial building facility applications.

PRELIMINARY DATA

Table 5 - Savings from New Energy Efficient Motor Purchases for the U.S. Manufacturing Sector

	Energy Savings (10^6 kwh/year)	**% Total Manufacturing Motor System Energy Savings**
Savings from upgrading motors covered by EPACT to EPACT level efficiencies	7,286	11.1
Savings from upgrading motors covered by EPACT beyond EPACT efficiencies to CEE level efficiencies	4,303	6.5
Savings from upgrading motors not covered by EPACT (greater than 200 HP) to maximum efficiency levels currently available	4,579	7.0
Total Savings	16,168	24.6

Improved Motor Management Practices
Table 6 shows the energy savings from improved motor management practices and systems within the manufacturing plant.

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Table 6 - Savings from Improved Motor Management Practices for the U.S. Manufacturing Sector

	Energy Savings (10^6 kwh/year)	**% Total Manufacturing Motor System Energy Savings**
Savings from improved motor repair and rewind practices	1,001	1.5
Savings from improved sizing and design of motors and drives to each other and the applied driven load	5,000	7.6
Total Savings	6,001	9.1

Improved Motor System Optimization
Table 7 shows the savings from optimizing motor systems using a systems approach.

PRELIMINARY DATA

Table 7 - Savings from Improved Motor System Optimization for the U.S. Manufacturing Sector

Motor System Energy Saving Area	**Energy Savings (10^6 kwh/year)**	**% Total Manufacturing Motor System Energy Savings**
Savings from improved pump system optimization	10,838	16.5
Savings from improved pump system control (including ASDs)	10,838	16.5
Savings from improved fan system optimization	3,245	4.9
Savings from improved fan system control (including ASDs)	1,857	2.8
Savings from improved compressed air system optimization	7,644	11.8
Savings from improved compressed air system control (including ASDs)	1,911	2.9
Savings from optimization and better control of non-fluid systems (e.g., material handling, movement and processing devices)	7,207	11.0
Total Savings	43,540	66.3

As Figure 2 shows two-thirds of the manufacturing motor system savings are system related, demonstrating that management decisions and technical actions

that support a systems approach at the corporate and plant level will be the key to achieving large scale energy efficiency improvement in manufacturing motor systems.

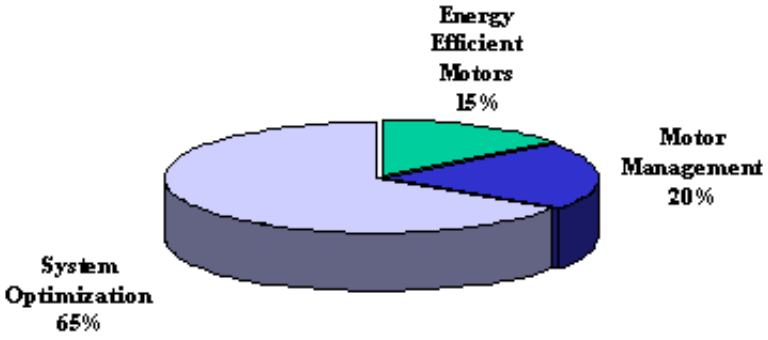

Figure 2 - Breakout of Manufacturing Motor System Savings

Targeting the Opportunities

As mentioned, Motor Challenge is targeting the industry sectors of Forest Products (especially pulp and paper), Steel, Mining, and Water Supply/Wastewater. Figure 3 and 4 show the potential energy savings within the pulp and paper and steel industries, respectively. Medium to large-sized pump systems are the prime opportunity in pulp and paper, whereas large fan and compressed air systems are the target within the steel industry.

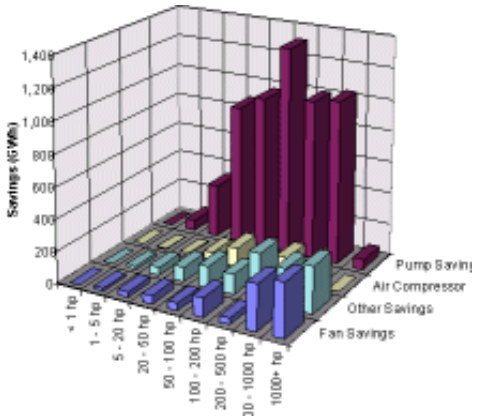

Figure 3 - Pulp and paper industry motor system savings (Million kwh/year)

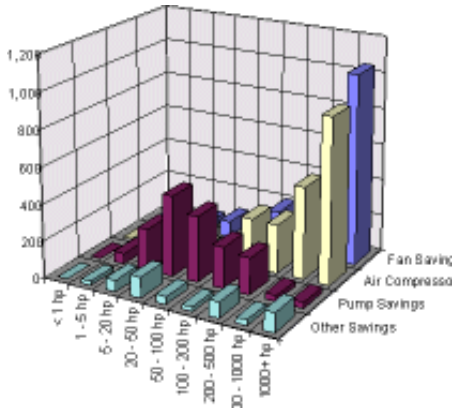

Figure 4 - Steel industry motor savings (Million kwh/year)

Key Motor Challenge Industry Partnerships

Motor Challenge relies on working within the established industry channels to develop strategies that will most effectively influence the industrial end users at a variety of decision-making levels. The following are summaries of key Motor Challenge industry partnerships:

Pulp and Paper: TAPPI is the technical professional society of the pulp and paper

industry. As a Motor Challenge Allied Partner TAPPI lends credibility to Motor Challenge's standing with pulp and paper company's technical staff. Even more importantly, TAPPI provides a great deal of leverage for the Motor Challenge. TAPPI is the world's largest technical association for individuals and companies in the paper, packaging, converting and related industries, with more than 33,000 members in over 70 countries (most members are in the U.S.). Motor Challenge products are being distributed by TAPPI to members, and joint training sessions on motor management, adjustable speed drives, and pump system optimization have already been conducted or are being planned.

Steel: DOE-ITP and Motor Challenge have begun to work with the Association of Iron and Steel Engineers (AISE). Efforts will begin to develop a partnership similar to the TAPPI/Motor Challenge partnership to deliver technical information and training through the AISE organization. Likewise, the American Iron and Steel Institute (AISI) has a long-standing partnership with ITP in the area of advanced steel making technology development.

Mining: Recently, the National Mining Association (NMA) became the eighth industry sector to partner with ITP in the Industries of the Future initiative. NMA will become a Motor Challenge Allied Partner. A strategy will be developed with NMA to deploy energy efficient motor system technology and information to the U.S. mining industry.

Water Supply/Wastewater: Working with a variety of organizations, including the American Water Works Association (AWWA), Motor Challenge has targeted this motor system energy intensive industry. Over the past two years, a training workshop series focusing both on motor management and pump system optimization principles has been deployed in a variety of States in the U.S (e.g., California and New York). All training sessions have been very highly attended and have been well received. AWWA regional chapters are now being targeted as a mechanism to get broader replication of the education curriculum developed and deployed.

Conclusions: Putting the Whole Strategy Together and Moving Forward
Showing the overall value of motor system efficiency to the key industries, along with developing the overall outreach strategy in unison with these sectors will be the key achieving results. Motor Challenge is currently developing a plan that will both complement the IOF R&D portfolio being developed and that meets the needs of any individual industry or company. A multi-step approach is being developed by Motor Challenge with industry with the following elements:

- instituting a cooperative training and communications program with an industry that helps plant people become more proficient in the use of new tools and best practices; articles will be developed to reach a broad audience; industry groups will be networked to develop mutual interests (e.g., link the pulp and paper industry (TAPPI) to the pump industry (Hydraulic Institute)).
- develop more industry specific showcase demonstrations; work with groups such as TAPPI to develop benchmarking information so that plant operators can determine the best opportunities in their respective pulp and paper mills.
- develop and provide easy access to pertinent information specific to an industry.
- undertaking marketing campaigns with original equipment manufacturers, suppliers, distributors, and end users to increase attention to the opportunities—at all levels from plant operations staff to CEOs.
- provide recognition to the people that are getting results with awards; develop articles and communications about these people through various media to promote their successes.

Most importantly, Motor Challenge will develop its strategy so as to add value to the Industries of the Future portfolio of emerging technology, technical information and tools so assist U.S. industry to be more energy efficient and competitive with reduced emissions and waste released to the environment.