U.S. Adoption of High-Efficiency Motors and Drives: Lessons Learned

A Historical and Value Chain Perspective

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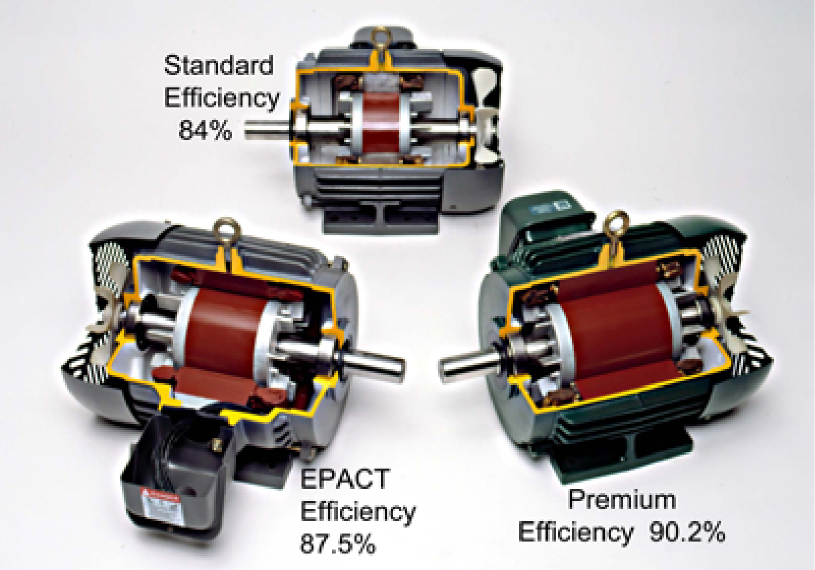

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List of Abbreviations

AAEMM	American Association of Electric Motor Manufacturers
AC	Alternating current
ACEEE	American Council for an Energy-Efficient Economy
AMES	Associated Manufacturers of Electrical Supplies
ASD	Adjustable Speed Drive
CEE	Consortium for Energy Efficiency
CO_2	Carbon Dioxide
DC	Direct current
DOE	U.S. Department of Energy
DSM	Demand Side Management
EISA	Energy Independence and Security Act
EPCA or EPAct	Energy Policy and Conservation Act of 1992
HP	Horsepower
HVAC	Heating, ventilation and air conditioning
HZ	Hertz
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
ITP	Industrial Technologies Program
kWh	Kilowatt hour
NEMA	National Electrical Manufacturers Association
NIST	U.S. National Institute of Standards and Technology

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Executive summary

Motor systems used by manufacturing industries play a large role in national energy profiles. In the United States, industrial motor systems account for about 17% of total electricity use. U.S. adoption of more efficient motors and motor systems could save an estimated 62-104 billion kilowatt hours of electricity annually, at a cost savings of $3-5 billion. This would reduce CO_2 emissions by 15-26 million metric tons per year—equivalent to retiring 4-7 coal-fired power plants or taking 3-5 million passenger vehicles off the road. China's potential is similarly large, with electric motor systems consuming roughly the same amount of electricity as those in the United States—more than 600 billion kWh annually. In fact, opportunities to improve the efficiency of motor systems in China are thought to be greater than those in the United States.

The industry category in which it is most critical to improve motor system efficiency is process manufacturing (food, tobacco, textile, wood, paper, plastic, glass). Compared with product manufacturing (apparel, furniture, electronics), and non-manufacturing industries (mining, oil and gas extraction, water supply), process manufacturing has the highest absolute consumption of electricity, at 419,587 gigawatt hours per year. Motor systems account for fully 71% of this total.

To date, the largest gains in motor efficiency have been achieved through greater use of copper and electrical steel. The main technological difficulty in making additional progress is that the more efficient the motor, the greater the power loss reductions needed in order to make further improvements. For example, if the motor already has an efficiency of 93%, to achieve only an additional 1% of efficiency requires reducing losses by 38%. Efficiency varies by motor size, with larger motors tending toward higher efficiency. The highest-efficiency motors available commercially today have efficiencies of 93-94%, and higher for the largest motors. The most easily realized improvements have already been made, and additional marginal increments in efficiency are extremely hard-won.

Focusing on the entire motor system, not just the motor, offers even greater potential for energy savings. An important tool for increasing motor system efficiency is the adjustable speed drive (ASD), a device that precisely controls motor speed. In the case of a blower, without an ASD to selectively slow the motor, the system is forced to counteract the motor's work after the energy has already been expended, using a baffle or other device to divert air that is already flowing. An ASD, by contrast, responds to the actual need for air flow and adjusts the motor speed accordingly. The use of ASDs can yield substantial benefits: an estimated 10% energy savings for refrigeration applications, 15% for air compressors, and 20% for pumps and fans.

A significant challenge in promoting high-efficiency motors is that motor buyers often misunderstand where the costs of motor ownership lie, and thus do not account for these costs accurately. The greatest cost of motor ownership is that of operating the motor, which represents 97-98% of lifetime costs. Initial purchase price represents only an estimated 2-3%. Although

premium-efficiency motors cost 15-25% more than standard motors, or $8-$40 more per horsepower, they pay for themselves quickly in saved operating costs. The payback period for a high-efficiency motor or a premium-efficiency motor is between 7 months and 4 years, with an average of around 2 years. The exact length of the payback period depends on several factors, including annual hours of use, energy rates, costs of installation and downtime, and the availability of utility rebates.

The United States and Canada have long been the leaders in adopting high- and premium-efficiency electric motors. Both countries have achieved significant improvements through voluntary programs and close collaboration among government agencies, industry groups, non-profit institutions and manufacturing firms. Perhaps more important, both governments continue to lead the way with mandatory standards.

Key findings from the U.S. value chain and adoption story

Our analysis of the U.S. value chain and history of adoption of efficient motors yields the following key findings:

1. Raw materials pose a "pinch point" in the value chain. Motor manufacturers are vulnerable to commodity price fluctuations in copper and steel. The copper market has been marked by extreme price swings since late 2005. Copper is crucial in all motors, but particularly in high-efficiency ones, which require on average 25% more copper. High-quality electrical steel, important for reducing core losses, can be difficult to obtain. It is a specialty made by only selected steel producers concentrated in the United States, Europe and Japan.

2. Several key players have played vital roles in the adoption story. Government agencies such as the U.S. Department of Energy (DOE), non-profit institutions such as the Consortium for Energy Efficiency (CEE) and American Council for an Energy-Efficient Economy (ACEEE), and industry groups such as the National Electrical Manufacturers Association (NEMA) develop standards for products, coordinate testing and help end users make more informed decisions about their motor systems. Groups such as Advanced Energy have provided much of the information that DOE and others use in their programs and have been important in helping motor manufacturers obtain certifications for compliance. Electric utilities have played a significant role; even before regulations, utilities offered their customers rebates and cash incentives for motor efficiency upgrades. System integrators and equipment manufacturers not only design systems, but also make actual motor decisions for their clients. Retailers—not of motors themselves, but of consumer products of all kinds—are considered a *potential* key player. Large retailers with thousands of product manufacturers in their supply chains may be able to incentivize these suppliers to adopt more efficient motor systems in their manufacturing processes as a way to cut costs and become more environmentally sustainable.

3. The major events in the U.S. adoption story were a rise in energy prices and the setting of standards. In response to the energy crisis in the 1970s, motor manufacturers began to define their own proprietary standards, some of which are still used today. Voluntary standards clearly

had a positive effect on adoption rates, although not nearly as much as predicted. Between 1980 and 1985, the penetration rate of high-efficiency motors was below 25%; then, when this standard was made mandatory by the Energy Policy and Conservation Act of 1992 (EPCA, also referred to as EPAct), adoption rates rose steadily, exceeding 60% by the year 2000. Experts expect a similar leap in adoption rates now that the newest standard, NEMA Premium motors, has been made mandatory with a compliance date of December 2010. By 2013, the penetration rate for premium efficiency motors is expected to exceed 70%.

4. Accurate testing of motor efficiency is crucial. The United States and Canada have led other countries in reliable testing. Elsewhere, relevant protocols vary considerably, often allowing lapses that lead to overstating efficiency. The U.S. National Institute of Standards and Technology accredits testing laboratories to ensure that they follow standard test procedures. Through this voluntary NIST program, in 1997, Raleigh-NC-based Advanced Energy became the world's first accredited industrial laboratory for testing the efficiency of motors. Today Advanced Energy is still North America's only accredited motor efficiency test lab that is not associated with a motor manufacturer. As of January 5, 2010, the NIST program had accredited 14 labs globally: 5 in the United States, 3 in China, two each in Mexico and Taiwan, and one each in India and Japan.

5. It is important to ensure that motor repairs are performed correctly in certified motor repair facilities. In the case of older, inefficient motors, replacement with a more efficient model can offer large gains in efficiency. Of a total 35 million integral electric motors (those of one horsepower or greater) currently installed nationwide, each year only 1.4 million are replaced, while about 2-2.5 million are repaired. In many cases, motor repair makes economic sense, as long as it is done to a written specification, under quality controlled conditions, in a certified motor repair facility. To encourage companies to replace failed motors with high- and premium-efficient ones, the DOE and other stakeholders have trained companies to use sophisticated evaluation techniques that clearly account for the energy savings that can be achieved through replacement. Currently under consideration by Congress is a $350-million "crush for credit" motor rebate modeled after the 2009 "cash for clunkers" program for motor vehicles. If enacted, crush-for-credit would provide a $25-per-hp rebate for the purchase of a NEMA Premium motor. The program would also provide a $5-per-hp rebate for the proper disposal of the older, inefficient motor (NEMA, 2010).

6. A focus on the efficiency of the entire motor system, not just the motor, can greatly increase energy savings. A 2004 study commissioned by the European Commission found that, by using available technologies to tap the energy efficiency of motor driven systems, European countries could save up to 202 billion kWh in electricity consumption per year, reducing CO_2 emissions by 100 million tons. The study further estimated that, out of these total electricity savings, energy-efficient motors specifically would account for about 13%, while variable speed drives would account for 25%, and improvements to applications (pumps, fans, compressors, blowers) would account for about 62%. Thus, improvements to applications represent the greatest potential for increasing the energy efficiency of motor systems. However, such opportunities are complex and

involve a large variety of devices—factors that are not easily addressed through adoption of a specific technology such as a motor.

7. Much can be accomplished through education and training for better plant-level decisions. U.S. stakeholders have used training and technical assistance programs to overcome persistent organizational obstacles. For example, education programs can help address misaligned incentives, in which the decision-maker that would buy an efficient motor does not stand to benefit from the motor's savings in energy costs and therefore only considers the efficient motor's higher purchase cost. Facilities can also be encouraged to schedule motor replacements during planned "downtime" to avoid the added costs of having to idle a production line, often a barrier to motor upgrades. Similarly, plant managers can be trained in devising contingency plans for emergency downtimes that result from a motor failure. A contingency plan can avoid the poor motor choices often made in such an emergency, such as using a standard-efficiency model that happens to be warehoused onsite, instead of taking the opportunity to choose replacement with a higher-efficiency model.

Key findings on motor efficiency in China

Our preliminary analysis of the potential for improving motor efficiency in China yields the following key findings:

1. China has vast potential for improving the efficiency of industrial motors and motor systems. In 2006, motor systems accounted for an estimated 61.8% of China's total annual electricity consumption, or 1.43 trillion kWh. If China were to achieve full compliance with premium efficiency standards, the country could cut motor systems' electricity use by about 11%, saving an estimated 150 billion kWh per year.

2. China has favorable positioning and opportunities to improve motor efficiency. These include the country's rapid pace of building completely new facilities. New, "green field" plants may facilitate adoption of best practices without struggling with the change/ no-change decisions that U.S. companies have faced throughout the history of high-efficiency motors adoption. Further potential advantages in China include an aggressive investment policy, the preponderance of state-owned enterprises, and strong political institutions at the provincial level, perhaps allowing for a stricter regulatory framework than has been possible in other countries. In addition, China is well-positioned to test and certify motor efficiency; out of only a handful of accredited labs worldwide, one is in Nanyang, Henan province, and two are in Shanghai.

3. China faces several persistent barriers to improving motor efficiency. On average, motors in China are about 2-5% less efficient than those in developed countries, and motor systems are estimated to be 20-30% less efficient. Major barriers include over-sizing of motors, a market that values low purchase cost over future energy savings, large differences in quality of Chinese-manufactured motors, limited adoption of key technologies such as variable speed drives, lack of information and training, incomplete execution of government energy-efficiency programs, and lack of institutional structure for providing technical assistance and education to motor users.

4. A lack of mandatory standards has hampered efforts to improve motor efficiency. Although the Chinese government has taken many steps to show that motor efficiency is a priority, so far these steps have largely consisted of setting goals and *encouraging* efficient practices and technologies—thus falling short of establishing the type of mandatory standards in place in the United States and Canada. High-efficiency (EPCA level) motors, mandatory in the United States and Canada since 1999, will not be mandatory in China until 2011. The premium-efficiency (NEMA Premium level) standard appears likely to remain strictly voluntary in China for the foreseeable future. Considering that even implementing the new 2011 standard for EPCA level motors will take several years, it seems probable that a mandatory standard for premium-efficiency motors will not occur until at least after 2015.

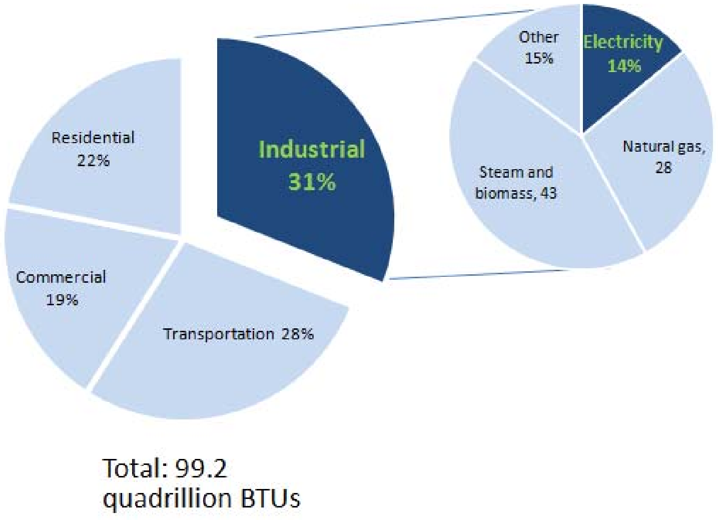
5. While several Chinese motor manufacturers produce high- and premium-efficiency motors for export, they largely focus on low-cost, standard-efficiency motors for the domestic market. A 2006 market study by the International Copper Association in Beijing found that, within Chinese motor production, the share of high- and premium-efficiency small and medium motors was less than 10%. The study further noted that of this 10%, about 70% was exported. The current low demand for high- and premium-efficiency motors in the Chinese market implies that, in the near future, domestic motor manufacturers are not likely to focus on premium-efficiency motors other than for the export market. Presumably, domestic production of high-efficiency (EPCA level) motors for the Chinese market can be expected to increase substantially in response to the 2011 compliance date for the new mandatory standard.

Introduction

Motor systems used by manufacturing industries account for a large share of industrial countries' energy use, often up to one-third or more of the national total. High- and premium-efficiency motors are widely available and have great potential for reducing energy use, but in many countries they have not yet been widely adopted, with the notable exception of the United States and Canada. In this study we will examine the U.S. value chain for these more efficient motors. We will also summarize the U.S. adoption story and the lessons learned, including the market drivers of adoption; barriers and how they were overcome; and priorities for encouraging more widespread future adoption. We will include international comparisons, specifically highlighting China, a large and fast-growing industrial user of electric motors and motor systems. Our analysis will provide a preliminary look at how lessons from the U.S. experience could potentially be transferred to the China context.

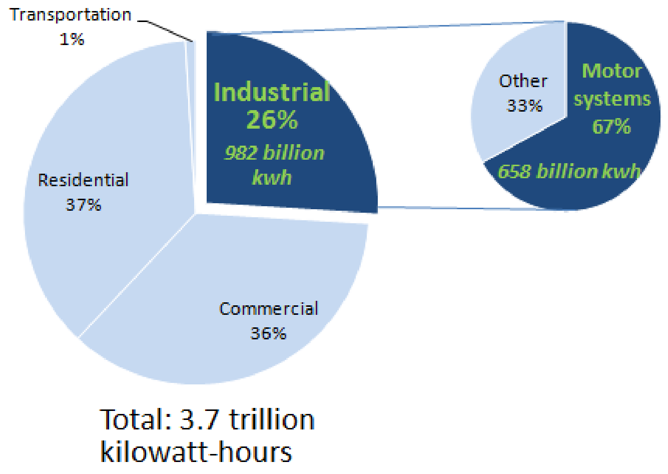
In the United States, the industrial/manufacturing sector accounts for about 31% of total energy consumption (see Figure 1). Within industrial energy use, electricity is the third largest source, accounting for 14% of the total energy consumed. However, viewed as a share of all U.S. electricity use, the industrial sector accounts for about 26% of the total, or 982 billion kilowatt hours per year. An estimated two-thirds of this electricity, or 658 billion kilowatt hours per year, is consumed by motor-driven equipment (see Figure 2). In other words, motor systems in industry/manufacturing account for about 17% of total electricity consumed in the United States.

Figure 1. U.S. total energy consumption, by sector, 2008



Source: CGGC, adapted from U.S. DOE, Annual Energy Review 2008

Figure 2. U.S. electricity use, by sector, 2008



Source: CGGC, adapted from U.S. DOE, 2009. Retail Sales

The adoption of more efficient motors and motor systems in the United States could save an estimated 62-104 billion kilowatt hours of electricity annually, at a cost savings of $3-5 billion (Consortium for Energy Efficiency, 2009). As shown in Table 1, the resulting reduction in CO_2 would be 15-26 million metric tons per year—equivalent to the annual emissions from 4-7 coal-fired power plants, or from 3-5 million passenger vehicles.

Table 1. Estimated potential yearly reductions in cost, energy and Co_2 from high-efficiency motor systems

Cost Saved	Energy Saved	CO_2 Reduced	CO_2 Equivalent	CO_2 Equivalent
$3-5 billion	62-104 billion kilowatt hours	15-26 million metric tons	Annual emissions from 4-7 coal fired power plants	Annual emissions from 3-5 million passenger vehicles

Source: (Consortium for Energy Efficiency, 2009); CO_2 equivalents from (U.S. EPA, 2009)

China's potential for saving energy through more efficient motors and motor systems is similarly large. Electric motor systems consume roughly the same amount of electricity as those in the United States—more than 600 billion kWh annually—but in China this represents more than 50% of national electricity use. Electric motors as well as pumps and fans in China are approximately 2-5% less efficient on average than those in the United States and Canada, and motor-driven equipment is often applied with little attention to system efficiency. A team of U.S./China researchers have concluded that China's opportunities to improve the efficiency of motor systems are greater than those in the United States (McKane, Guijin et al., 2008).

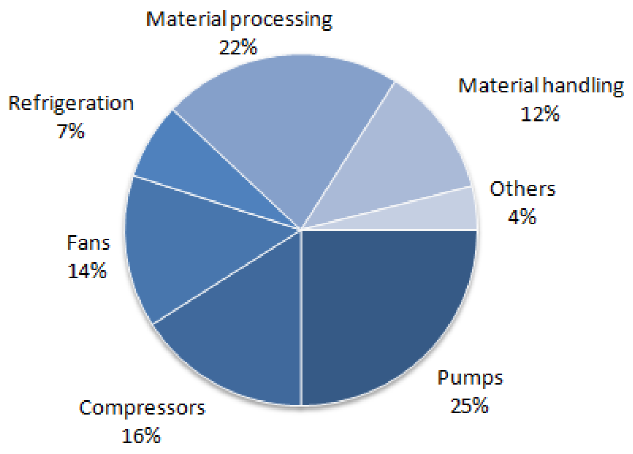
Electric motors are used in a broad variety of applications, as shown in Figure 3. Many studies have identified pumps, fans, and compressors (systems with centrifugal loads) as the most common motor applications; they are used in every industry and account for 49- 61% of total energy associated with motors used in manufacturing (U.S. DOE, 2002). The most common specific contexts for these applications are the following:

- Pumps (25% of motor system energy in manufacturing): for circulating water or other process fluids
- Compressors (16%): for heating, ventilation and air conditioning (HVAC) and for pneumatic power tools
- Fans (14%): for ventilation and exhaust systems
- Refrigeration systems (7%): for food primarily, also for paper and metals processes

Additional contexts for motor applications include the following broad umbrella categories:

- Material processing (22%): including mills, grinders, lathes
- Material handling (12%): including belts, conveyors, elevators, cranes
- Other applications (4%): including process heating such as ovens and kilns

Figure 3. Motor applications and % of motor system energy used in manufacturing



Source: CGGC, based on (U.S. DOE, 2002). Note: data do not include motors associated solely with plant heating and ventilating equipment.

Motor systems' electricity consumption is different for each major manufacturing category, as shown in Table 2. The lowest share of electricity use by motor systems is in product manufacturing (apparel, furniture, electronics), at 40% of total consumption. The highest share of electricity use is in the non-manufacturing category (mining, oil and gas extraction, water supply, sewage, irrigation), where motor systems account for 82% of total electricity. However, the industry category in which it is most critical to improve motor system efficiency is process manufacturing (food, tobacco, textile, wood, paper, plastic, glass). This is because process manufacturing has the highest absolute consumption of electricity—at 419,587 gigawatt hours per year—with motor systems accounting for fully 71% of this total.

Table 2. Motor system share of total electricity consumption, U.S. manufacturing types

Type of industry	Products	Total electricity consumption (GWh/year)	Motor system share of electricity consumption
Discrete manufacturing	Apparel and products made from fabrics, furniture and fixtures, primary metal industries, fabricated metal products, industrial and commercial machinery and computer equipment, electronic and other electrical equipment and components, transportation equipment, measuring, analyzing and controlling instruments; photographic, medical, miscellaneous manufacturing industries	121,616	40%
Non-Manufacturing	Mining, oil and gas extraction, water supply, sewage and irrigation	137,902	82%
Process manufacturing	Food, tobacco, textile, lumber and wood products, paper, printing, chemicals, petroleum refining, rubber and plastics products, leather products stone, clay, glass, and concrete products	419,587	71%

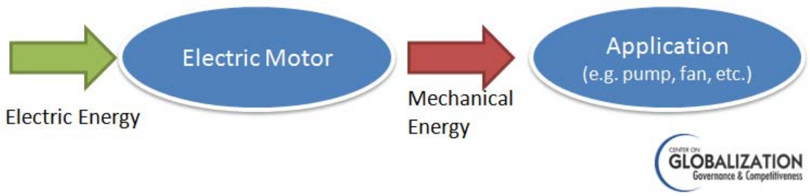
Source: CGGC, based on (U.S. DOE, 2002)

Technology description

Types of electric motors

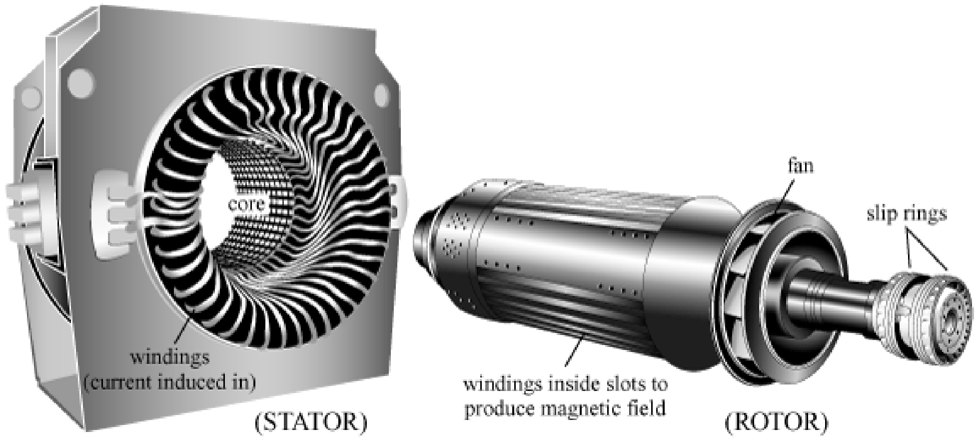
Electric motors convert electric energy to mechanical energy and create the rotational force necessary to run equipment such as a pump, fan, blower, or compressor (see Figure 4). An electric motor consists of two major parts, the rotor and stator (see Figure 5). When electric current is flowing though an electric motor, rotors and stators each create magnetic fields that rotate the motor shaft, or the rotating unit that is attached to the application that is being driven (pump, fan, or other). Motor efficiency refers to the ratio of mechanical energy output to electricity input.

Figure 4. Input and output of electric motors



Source: (Mabuchi Motor, 2009).

Figure 5. Two major parts of electric motor: stator and rotor

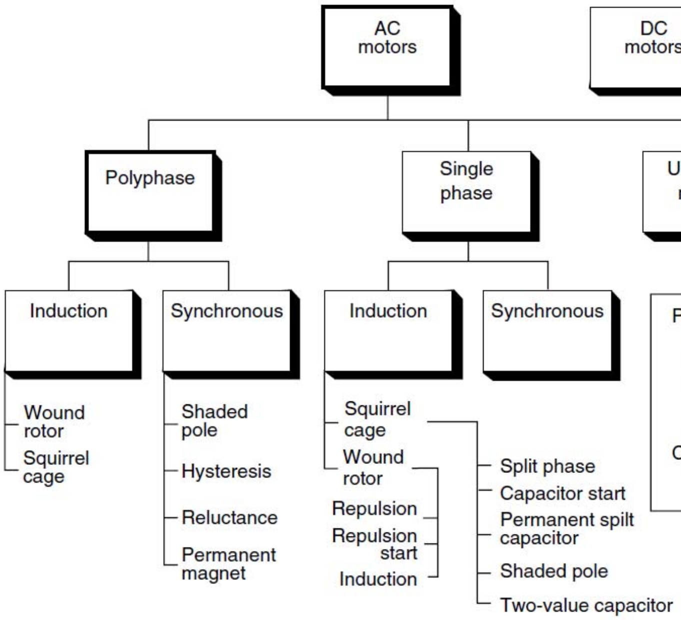


Source: (Physics World, 2009)

Electric motors come in many different configurations. The type of motor most appropriate for a given manufacturing application varies widely, based on several factors summarized in Figure 6. The most basic of these factors is the type of electric power input: direct current (DC) or alternating current (AC). In the past, the more common type was the DC motor, offering superior speed and control of rotating power. However, DC motors are more expensive, less reliable and less suitable than AC motors for extended periods of use. DC motors are currently used for train and automotive traction applications because of their strong power at start up. They are also suitable for ball mills,[1] rotary kilns and winders used for the paper and steel industry, where they are valued for their high rotating power (Francis, 2009; Kreith & Goswami, 2007; Woodbank Communications Ltd, 2005).

In today's industrial manufacturing applications, AC motors are far more common, offering lower price, robustness, and a wide range of power output. Within AC motors, three-phase induction motors are the most widely used. At the final level of configuration shown in Figure 6, AC motors comprise various options for induction versus synchronous forms, each representing a different technique for creating a magnetic field in the rotor and stator. AC motors offer great potential for energy savings and cost efficiency, especially when coupled with speed control devices (Kreith & Goswami, 2007; Woodbank Communications Ltd, 2009). This report focuses on AC motors for use in manufacturing.

Figure 6. Motor configurations



Source: (Kreith & Goswami, 2007)

Technical measures to improve motor efficiency

High- and premium-efficiency AC motors achieve greater efficiency by reducing the loss of heat and magnetic field as electricity goes through the motor. In modern premium-efficient models,

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[1] According to Wikipedia, a ball mill is a "type of grinder used to grind materials into extremely fine powder for use in mineral dressing processes, paints, pyrotechnics, and ceramics."

losses account for only 3-6% of the energy that flows through the motor. As shown in Table 3, losses can be divided into five major types: stator power losses, rotor power losses, magnetic core losses, friction and windage losses, and stray load losses (Emadi & Andreas, 2005). Of these, stator power losses represent the largest category (37% of total energy loss), yet there are few opportunities to reduce these losses without also decreasing the power available to create the magnetic field. Similarly, stray load losses (16% of total energy loss) can theoretically be addressed by redesigning several features of the stator winding, but each design change may in fact increase losses in other areas. Rotor power losses, magnetic core losses and friction and windage losses can be reduced by using higher quality materials and optimizing the design for larger magnetic fields and greater electricity flow (Kreith & Goswami, 2007).

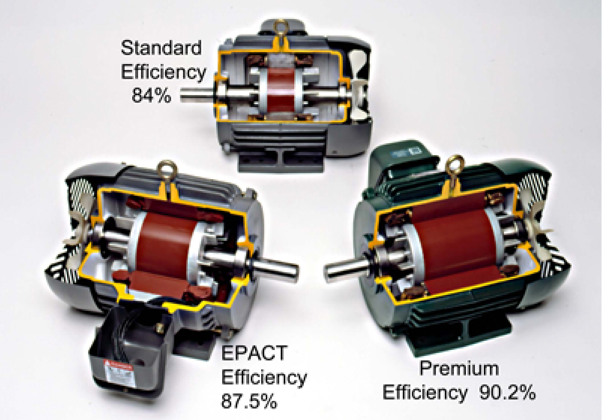
Table 3. Measures to reduce energy loss in electric motors, by type of loss

Type of loss	% of total energy loss	Technical difficulty of reducing loss	Measures to reduce loss
Stator power losses	37	Prohibitive	Theoretically, there is little possibility to reduce the loss of stator power without also decreasing the power available to create the magnetic field.
Rotor power losses	18	Moderate	• Increase conductor material (e.g. magnet wiring in the stator winding, or aluminum in the rotor) • Increase in flux across the air gap • Use permanent magnets to eliminate rotor power losses • Use semiconductor power switch systems to eliminate rotor power losses
Magnetic core losses	20	Moderate	• Increase the length of the magnet structure • Use thinner laminations in the magnetic structure • Use silicon-grade electrical steel
Friction and windage losses	9	Moderate	• Reducing these heat-producing losses can also save energy by requiring less use of the ventilation system
Stray load losses	16	Prohibitive	These losses can be addressed through re-design of the stator winding, but major reductions are difficult because each design change may actually increase losses in other areas.

Source: CGGC, based on (Emadi & Andreas, 2005).

To date, the largest gains in motor efficiency have been achieved through greater use of copper and electrical steel (shown in red); the higher the use of these materials, the higher the efficiency, as shown in Figure 7. The main loss reductions possible via these measures have already been tapped in the highest-efficiency motors now commercially available, and further loss reductions are much more difficult and costly to achieve.

Figure 7. Improving efficiency of a 10-hp electric motor via greater use of copper and electrical steel



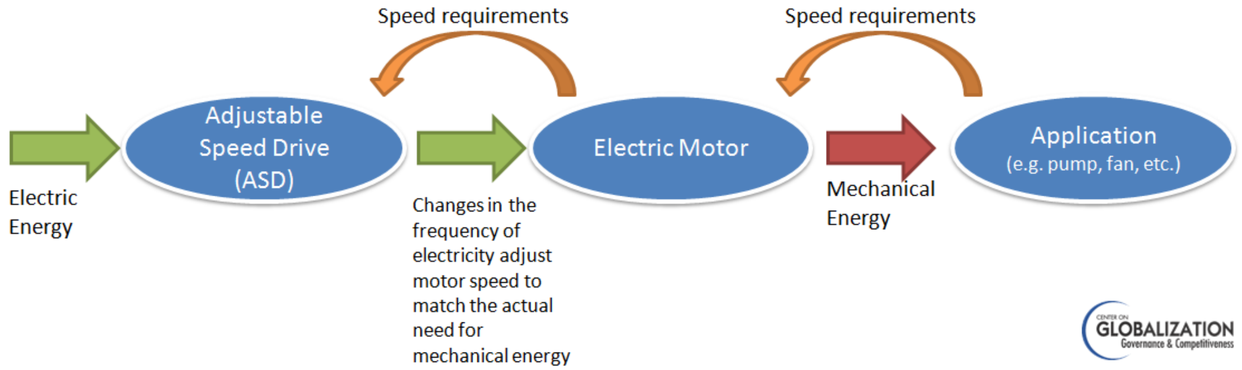
Source:(Copper Development Association Inc., 2009)

Adjustable speed drives (ASDs)

An electric adjustable speed drive (ASD) is a motor controlling device that can be electrically connected to a motor to provide precise motor speed control. Without an ASD's ability to selectively slow the motor, an application is forced to counteract the motor's work after the energy has already been expended. For example, in order to decrease air flow, a blower without an ASD requires a baffle or other device to divert air that is already flowing. An ASD, by contrast, responds to the actual need for air flow, adjusting the motor speed accordingly by changing the frequency of the electricity entering the motor (see Figure 8).

ASDs are particularly useful in systems with centrifugal loads such as pumps, fans, blowers, air compressors, and chillers. Because the amount of air flow corresponds closely to the motor speed—and in many cases the air flow is required to change continuously—the use of ASDs can yield substantial energy savings: an estimated 10% savings for refrigeration applications, 15% for air compressors, and 20% for pumps and fans (Kreith & Goswami, 2007). Some sources would put these estimates of energy savings even higher (Butler, 2010).

Figure 8. Entire motor system with adjustable speed drive (ASD)



Source: CGGC

Given the large role of these centrifugal-load systems in U.S. industrial energy use (accounting for 49% to 61% of total energy consumed by electric motors used for manufacturing activities), ASDs have significant potential to provide energy savings well beyond those possible with high-efficiency motors alone. However, the penetration rate of AC motors with ASDs appears to be low. A key barrier is technological risk. Implementing an ASD on a system that was designed to operate as fixed speed can raise issues for plant engineers who face possible production interruptions due to technical problems (Boteler, 2010).

According to a 2002 report by the U.S. Department of Energy, motor systems with ASDs represented only 8.8% of total applications in the United States (see Table 4). The penetration rate of ASDs for compressed air and pump applications was notably low, at 1.7% and 3.2% respectively (U.S. DOE, 2002). For comparison, during the same period, the penetration rate of motors meeting the EPAct efficiency standard was roughly 50-60% (Boteler, 2009). More recent adoption rate figures are not available, but sales of ASD systems reached a total of $4.5 billion in 2002 (Blaabjerg & Thoegersen, 2004). Market penetration of ASDs for all motor sizes is still thought to be low, although the rate for larger motors may be higher, estimated at nearly 20% (Spear, no date).

Table 4. U.S. adoption rate of motor systems with adjustable speed drives (ASDs), by application

	Motor Systems with ASDs	
Application	**Number**	**% of Total**
Pump	77,510	3.2%
Fan	101,204	7.3%
Compressed Air	11,044	1.7%
Other	907,570	11.4%
All Applications	***1,097,328***	***8.8%***

Source: (U.S. DOE, 2002)

Motor system efficiency

A focus on the efficiency of the entire motor system, not just the motor, can greatly increase energy savings. A 2004 study commissioned by the European Commission found that, by using available technologies to tap the energy efficiency of motor driven systems, European countries could save up to 202 billion kWh in electricity consumption per year, reducing CO_2 emissions by 100 million tons. This represents a €10 billion savings per year in operating costs for industry. The study further estimated that, out of these total electricity savings, energy-efficient motors specifically would account for about 13%, while variable speed drives would account for 25%, and improvements to applications (pumps, fans, compressors, blowers) would account for about 62% (Keulenaer et al., 2004). Thus, improvements to applications represent far greater potential for increasing energy efficiency than improvements to the motor alone.

However, improvements to applications are complex. They involve a large variety of devices and factors that are not easily addressed through adoption of specific technologies such as a more efficient motor. Table 5 illustrates this situation in the case of an air compressor, showing several design and optimization measures that can save energy. These measures include using sophisticated control systems (annual energy savings of 12%), recovering waste heat (savings of 20%), and optimizing certain end-use devices (savings of 40%). Because of the case-by-case nature of these energy-saving measures, the task of promoting their adoption is far less straightforward than promoting the use of high-efficiency motors. This study is therefore limited to addressing lessons learned in motors and drives—in other words, the portion of the motor system that, to date, has been the focus of specific efforts by governments, industry, and non-governmental organizations to provide a regulatory and institutional framework for improving motor efficiency.

Table 5. Energy saving measures and potential energy savings: air compressor example

Energy saving measure	Potential annual energy savings, %
High-efficiency motors	2
Electric adjustable speed drives (ASDSs)	15
Upgrades to compressor	7
Use of sophisticated control systems	12
Recovery of waste heat for use in other functions	20
Improved cooling, drying and filtering	5
Improvement of overall system design	9
Reduction of frictional pressure losses	3
Optimization of the compressor or replacement of compressed air with electrical or hydraulic systems	40
Reduction of air leaks	20
More frequent filter replacement	2

Source: (Kreith & Goswami, 2007)

Basic challenges in improving motor efficiency

Technological challenges

The major technological difficulty in improving motor efficiency is that the more efficient the motor, the greater the loss reductions needed in order to make further improvements. This challenging relationship is illustrated in Table 6. In order for a motor with 73% efficiency to improve by 1%, power losses must be reduced by only 8%. However, if the motor already has an efficiency of 93%, to achieve only an additional 1% of efficiency requires reducing power losses by 38%. Efficiency varies by motor size, with larger motors tending toward higher efficiency. The highest-efficiency motors available commercially today have efficiencies of 93-94%, and higher for the largest motors. The most easily realized improvements have already been made, and additional marginal increments are extremely hard won.

Table 6. Reductions in power loss losses necessary to meet motor efficiency targets (%)

Original efficiency	Increased efficiency target	Reduction in power losses necessary to achieve target
73	74	8
83	84	11
89	90	16
90.5	91.5	19
91.5	92.5	28
93.0	94	38

Source: (Emadi & Andreas, 2005)

In the U.S. experience to date, an important challenge has been the choice that end users face between buying a new, efficient motor and repairing an old one. Although replacing a failed motor with a new, more efficient model offers large gains in efficiency, many companies instead opt to repair. To encourage companies to replace rather than repair failed motors, stake holders including the Department of Energy, ACEEE, and NEMA have undertaken to train companies to use sophisticated evaluation techniques that clearly account for the energy savings that can be achieved through replacement. NEMA and ACEEE are also proposing new programs to promote early retirement of older, less efficient motors. One such proposal, now under consideration by Congress, is a $350-million “crush for credit” motor rebate modeled after the 2009 “cash for clunkers” program for motor vehicles. If enacted, crush-for-credit would provide a $25-per-hp rebate for the purchase of a NEMA premium motor. The program would also provide a $5-per-hp rebate for the proper disposal of the older, inefficient motor (NEMA, 2010).

Of a total 35 million integral electric motors currently installed nationwide, each year only 1.4 million are replaced, while about 2-2.5 million are repaired. Of the replacements, about 370,000 units—or 27% of the market—are NEMA Premium motors (Boteler, 2008). In many cases, motor repair does make economic sense, as long as it is done to a written specification, under quality controlled conditions, in a certified motor repair facility. Since far more motors are repaired each year than replaced, it is important to ensure that repairs are done correctly. In recognition of this reality, some utilities are beginning to offer programs that certify repair shops and offer incentives for customers to use them (Butler, 2010).

Some studies have indicated that motor repair degrades efficiency, while other research disproves this claim. According to motor testing experts, the key to successful repair without compromising efficiency is ensuring that the repair is done correctly. Although there is ample evidence that motors can be restored to their original efficiency, it is unclear how many motor repair facilities have the correct mix of capabilities (Butler, 2010). In any case, it is clear that no amount of repair will improve the efficiency of a motor beyond its original nameplate rating (Copper Development Association Inc., 2009). To help motor owners compare the true costs of repair versus replacement, and to accurately account for the various factors that determine payback periods, the DOE offers a software program called MotorMaster+, which helps inform decisions on buying a new motor, rewinding a failed one, or replacing a working one (U.S. DOE, no date).

A final important technical challenge is testing motor efficiency. Accurate testing is a critical and complex task, requiring an exact accounting of losses. The United States and Canada have led other countries in reliable testing. Elsewhere, relevant protocols vary considerably, often allowing lapses that lead to overstating efficiency. The U.S. National Institute of Standards and Technology accredits testing laboratories to ensure that they follow standard test procedures. Through this voluntary NIST program, in 1997, Raleigh-NC-based Advanced Energy became the world's first accredited industrial laboratory for testing the efficiency of motors. Today Advanced Energy is still North America's only accredited independent motor efficiency test lab ("independent" meaning not associated with a motor manufacturer). As of January 5, 2010, the NIST program had accredited 14 labs globally: 5 in the United States, 3 in China, two each in Mexico and Taiwan, and one each in India and Japan (National Institute of Standards and Technology, 2010). [2]

Much has happened even in the past 6-12 months to unify motor testing procedures across the world. One international standard, IEC 60034-30, approaches testing by adding up losses, while the IEEE standard (used widely in the United States) approaches testing by precisely measuring electricity input versus power output. Although these two standards are used worldwide, until recently, they did not line up with each other and thus yielded different results, with IEEE yielding more conservative results for energy efficiency. Now the two methods have been reconciled so that either approach will yield the same results. This enables laboratories to continue using the approach they are best equipped for, and still achieve standard results (Eckhart, 2010).

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[2] Advanced Energy has assisted the two labs in Taiwan and is now helping the South Korean government build one that should be accredited in the summer of 2010 (Butler, 2010).

Economic challenges

A significant economic challenge in promoting high- and premium-efficiency motors is that motor buyers often misunderstand where the costs of motor ownership lie, and thus do not account for these costs accurately. The greatest cost of motor ownership is that of operating the motor, which represents 97-98% of lifetime costs. Initial purchase price represents only an estimated 2-3% (Butler, 2010). Although premium-efficiency motors cost 15-25% more than standard motors, or $8-$40 more per horsepower, they quickly pay for themselves in saved operating costs. According to various sources, the payback period for an EPAct or NEMA Premium motor is between 7 months and 4 years, with an average around 2 years. The exact length of the payback period depends on several factors, however, including annual hours of use, energy rates, costs of installation and downtime, and the availability of utility rebates (U.S. DOE, no date). The effects of selected factors on the payback period are summarized in Table 7.

Although cost factors are very important—including not only costs of purchase and operation, but also installation and maintenance—these costs are also weighed against additional factors such as reliability, secondary benefits such as less wear on equipment or less operating noise, and secondary problems such as disruptions in frequency and reductions in useable mechanical power (Kreith & Goswami, 2007). Thus, operational cost savings are far from the only factor that determines whether a company will choose a high-efficiency motor.

Table 7. Selected factors that determine length of payback period for purchase of EPAct and NEMA Premium motors

Factor	Description
Hours per year of motor use	More hours of motor use translate into a shorter payback period. Above 8,000 hours per year, the payback is likely to be less than 3 years.
Energy price	Electricity rates paid by industrial facilities vary widely in different areas of the country. The higher the rate, the shorter the payback. In high-rate regions such as the Northeast and California, payback periods are typically 2 years.
Type of new motor (NEMA vs EPAct)	A NEMA Premium motor costs more than an EPAct one but allows higher cost savings. At a use rate of 8,000 hours per year, usually the NEMA allows a faster payback, in some cases less than one year.
Size of motor	The larger the motor, the longer the payback. The achievable cost savings for a larger motor are not precisely proportional to the higher purchase cost.

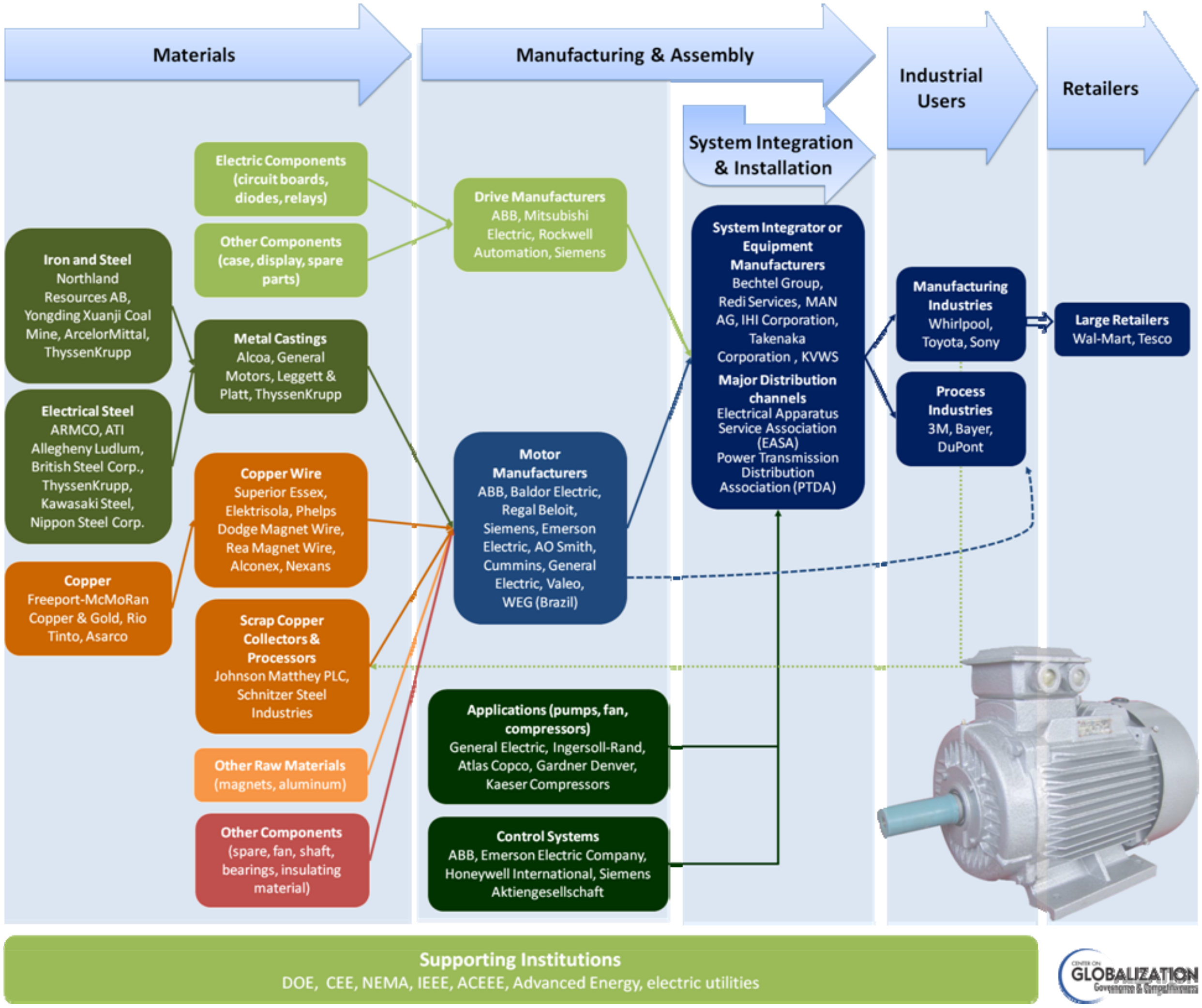
Sources: (Butler, 2010; Copper Development Association Inc., 2009; U.S. DOE, no date).

High-efficiency electric motors value chain

Overview of value chain

This section will describe the overall structure of the value chain, which consists of five main stages: Materials & components, manufacturing & assembly, system integration & installation, industrial users, and retailers (see Figure 9). Also important is a sixth category, supporting institutions, which includes government and private organizations that have a significant impact on various stages of the chain.

Figure 9. Electric motor value chain



Source: CGGC

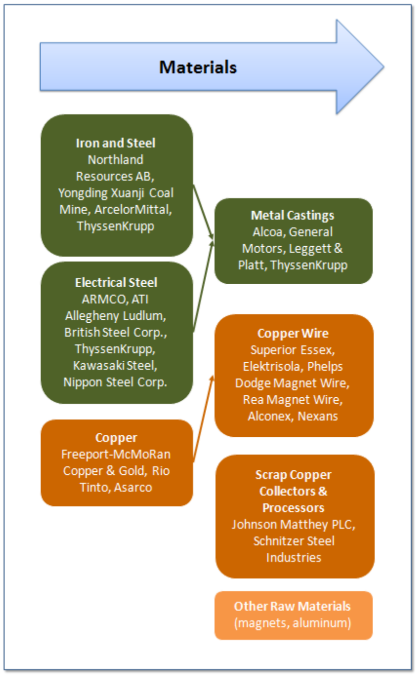
Electric motors are complex products assembled from a number of raw materials and subcomponents. Moving from left to right across the value chain, manufacturers perform sub-assembly, final assembly and testing of the stator, rotor, shaft and cooling fan. Especially for larger motors (100+ hp), many of the assembly phases such as insulation or wiring require significant manual work and a high degree of accuracy and skill. After testing, the motor manufacturer may sell the product directly to the final user (usually the case for motor replacements) or to a system integrator or equipment manufacturer (often a contractor building a plant for a customer). In either case, the manufacturer or system integrator puts together the following final elements:

- **drive system** - a plastic box or metal cabinet containing electrical components such as circuits and relays, along with a user interface (display and buttons) and the plugs for the control system. The drive is fundamental, since it governs the starting phase and protects the motor from electric shocks. Today the drive system’s function is increasingly performed by variable speed systems (see Technology Description section).
- **control system** - a network made of central computers, computer-run devices, sensors, human interfaces and software to control the industrial process.
- **application -** the equipment that is run by the motor; in manufacturing, the primary applications are pumps, fans, compressors and blowers.

This value chain analysis will discuss geography, pinch points, key players, market structure, and critical issues in the provision of high-efficiency electric motors. A detailed discussion is provided for each of the four motor manufacturing stages—Materials, Manufacturing & Assembly, System Integration & Installation—as well as for Supporting Institutions. The stage labeled Industrial Users will be described in the context of both System Integration and Supporting Institutions, since these are the points of contact through which industrial users are most influenced in their motor decisions. The Retailer stage represents large companies that may have thousands of motor-using manufacturers in their supply chains, but are currently not involved in their motor decisions. It is possible that such large firms could choose to embrace motor efficiency as a criterion in supplier development as a way to reduce energy use throughout their supply chains. Thus, for the purposes of this report, retailers are included only as a *potential* player in the future adoption of high-efficiency motors.

Materials & components

The two main raw materials important to the manufacture of high- and premium-efficiency motors are electrical steel and copper. Copper is used mainly in the form of wire, incorporated into the windings. Other, more costly materials such as aluminum or permanent magnets are employed for specific purposes not relevant to the AC motors addressed in this report (e.g., electric vehicles). Relevant motor components include spare parts such as nuts, bolts, and screws, bearings, and insulating material.



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Electrical steel

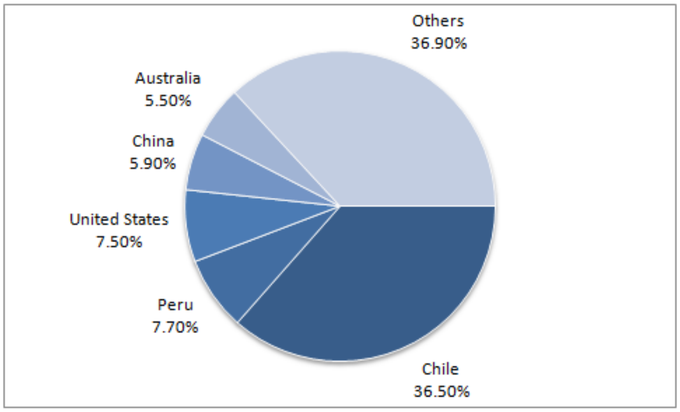
Electrical steel plays an important role in motor efficiency, helping to reduce core losses. Chemically it is an iron alloy that may have from zero to 6.5% silicon and sometimes an addition of manganese and aluminum.

It can be difficult to obtain high-quality electrical steel. Producers of electrical steel are relatively few, and they are concentrated in the United States, Europe and Japan. Relevant firms include ARMCO, ATI Allegheny Ludlum, British Steel Corporation, ThyssenKrupp, Kawasaki Steel, and Nippon Steel.

Copper and copper wire

The global copper market shows a high degree of concentration. The five leading export countries account for about 60% of the world total of 14 million tons per year. Chile clearly dominates, with 36.5% of the total market (see Figure 10). Next are Peru (7.7%), the United States (7.5%), China (5.9%), and Australia (5.5%). All other countries combined account for the remaining 36.9% (Freedonia, 2009).

Figure 10. World copper mine production, 2007



Source: (Freedonia, 2008)

Since late 2005, the copper market has experienced extreme price volatility. In the 17 months between January 2005 and May 2006, the price of a ton of copper tripled, from $3,000 to nearly $9,000 (see Figure 11). By early 2007, the price had dropped to around $5,000, only to return to $9,000 one year later, and fall back below $3,000 by the end of that year. At the time of this writing (February, 2010), the price per ton of copper was $6,660 (Metalprices.com).

Figure 11. Copper prices on London Metal Exchange, 2004-2009

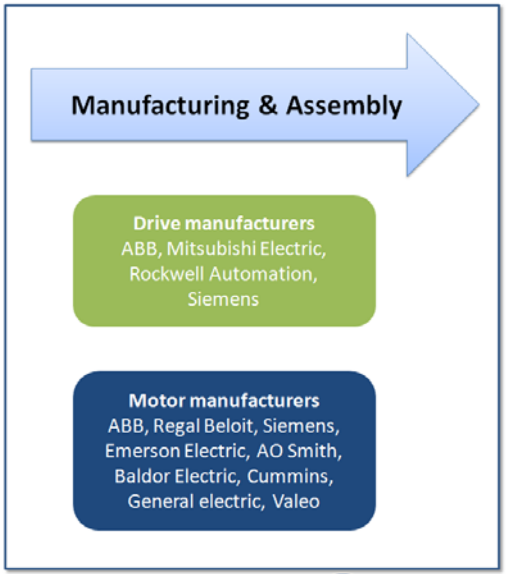
Source: CGGC

China, a large producer and consumer of copper, exerts an increasingly strong influence on the market. India is another fast-growing consumer. Overall increases in the price of copper over the past five years have stimulated the development of new technologies, along with efforts to fully exploit new and existing reserves. In the United States, the world's third largest producer, several large, integrated companies dominate the competitive landscape, extracting and processing copper and other metals. The Earth's total endowment of copper is vast, yet only a fraction is economically viable with current extraction technologies. Over the past 50 years, copper extraction has increased at an average rate of 4% per year. Even under generous assumptions regarding advances in technology and rates of consumption, several forecasts estimate future availability at only 25 to 60 years (L. R. Brown, 2006). Copper recycling is a viable option for extending copper supplies, since recycled copper is nearly indistinguishable from primary copper (INMET, 2009). Today recycled copper represents 41% of total copper in use globally (European Copper Institute, 2007).

Copper magnet wire firms include Superior Essex, Elektrisola, Phelps Dodge Magnet Wire, Rea Magnet Wire, Alconex, and Nexans. Since copper is a crucial material in all motors, it represents a potential pinch point in the value chain, particularly for high-efficiency motors, which require on average 25% more copper. Companies have the option of salvaging copper from motors that are no longer in use. This can be labor intensive, but given the increasing reliance on copper and the volatility of copper prices, recycling may become a more attractive option (Black, 2009; Copper.org, 1998).

Manufacturing and assembly

Drive manufacturers



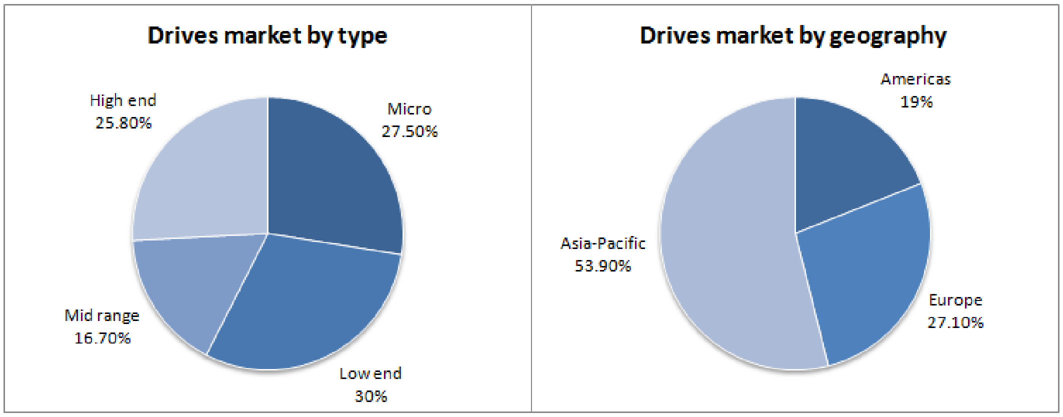
A drive is a system that controls the motor by modifying the input current in terms of voltage and frequency. Since AC electric motors are commonly used in industrial applications, this analysis focuses on drives specifically designed for AC motors. Lead manufacturers include ABB, Mitsubishi Electric, Rockwell Automation, and Siemens.

Most manufacturers of AC drives are electric and electronic component manufacturers. These players are numerous, but dominated by the above-mentioned lead firms. Characteristics of the market include the following (Datamonitor, 2009b):

- Equal bargaining power between component suppliers and manufacturers
- Exploitation of global market opportunities by large multinational companies
- High standardization and low product differentiation

In 2008 the global market for drives reached a value of $9.8 billion, after an average annual growth rate of 7.5% in the period 2004-2008. Figure 12 depicts the world drive market by type and by geography. By type, the market is segmented according to power range: micro drives (up to 4 kw), low end (5 - 40 kw), mid range (41 - 200 kw) and high end (201+ kw). Low-end drives have the largest market share (30%), and mid-range drives have the lowest share (16.7%). The Asia-Pacific region dominates the market with a 53.9% share, followed by Europe (27.1%) and the Americas (19%).

Figure 12. World drives market by type and geography



Source: (Datamonitor, 2009b)

Motor manufacturers

Market analyses often consider electric motors together with generators. The two products perform very different functions—generators convert mechanical energy into electricity, while motors convert electrical energy into mechanical power—however, they share many of the same suppliers, production phases, main players, and competitive landscape. The U.S. market for motors and generators is valued at $15 billion. According to our estimates, the total market for new integral electric motors in the United States is slightly less than $1 billion. Of this, the NEMA Premium share is around 25%, or roughly $250 million (Boteler, 2009; Freedonia, 2009; U.S. Census Bureau, 2004). Major firms include Baldor, ABB, Regal Beloit, Siemens, Emerson Electric, and WEG (Brazil).

The market for motors and generators has the following characteristics (Freedonia, 2009):

- Large number of manufacturers, ranging from small niche producers to OEMs and large multinationals that often perform assembly and installation
- High competition due to a mature market and lack of a large replacement aftermarket (products have a long average life compared to other industrial equipment)
- Medium-high standardization of products
- Increasing presence of foreign-based, lower-cost suppliers. Competition is somewhat lower in the integral motors segment, comprising a few multinational companies along with numerous small, private niche firms.

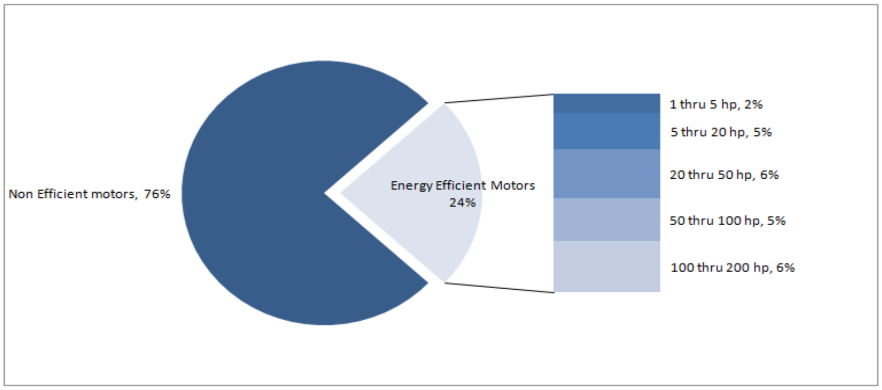
Although the market for electric motors and generators is considered mature, it is undergoing the following changes (Freedonia, 2009):

- The commoditization of electronic components allows motor manufacturers to make in-house drive systems and sell a complete package of motor and drive

- NEMA Premium and similar standards push companies to make high-efficiency motors
- Rising energy prices stimulate the adoption of new, high-cost materials such as permanent magnets, formerly used only for specialized applications.

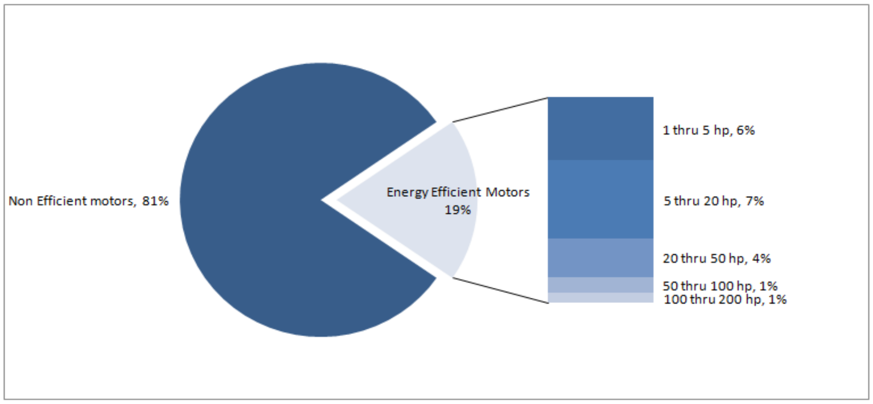
In 2003, U.S. shipments of efficient motors, including interplant transfers,[3] accounted for 24% of total motors value (see Figure 13) and 19% of total quantity (see Figure 14). In value, shipments were fairly balanced among the different horsepower categories, except for the 1-5 hp category, which had a smaller share. In quantity, shipments tended to decrease with horsepower, since demand is on average higher for smaller motors. Large motors involve high transportation costs because of their dimensions, weight and need for special handling, making it more convenient to perform assembly near the customer, or at least at a distance manageable by truck.

Figure 13. 2003 U.S. shipments of electric motors by value



Source: CGGC, based on (U.S. Census Bureau, 2004)

Figure 14. 2003 U.S. shipments of electric motors by quantity



Source: CGGC, based on (U.S. Census Bureau, 2004)

High- and premium-efficiency electric motors tend to have a higher unit value than standard-efficiency motors, on average an increase of about 30%. The relationship between different power ranges and motor unit price is shown in Figure 15. Motor unit price more than doubles

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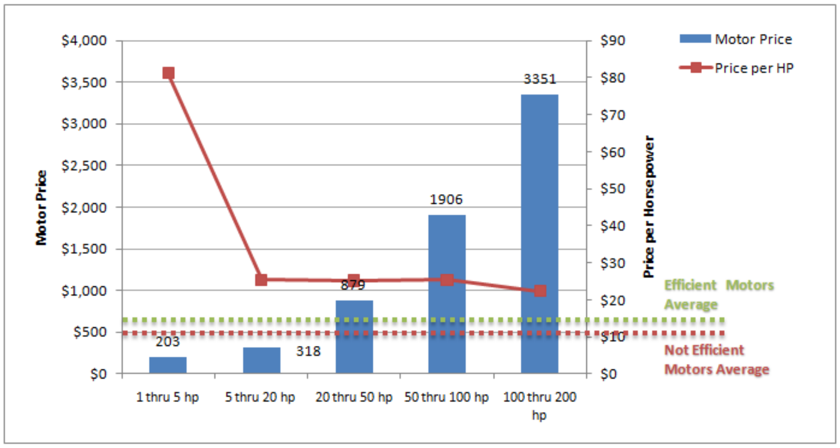
[3] This figure refers to integral polyphase induction motors, excluding synchronous.

with the first step up in horsepower category, such that a 20-50 hp motor costs $879, and a 50-100 hp motor costs $1,906. A 100-200 hp motor costs $3,351. More specifically, a look at price per horsepower shows a strong price decrease moving from 1-5 hp motors ($80 per hp) to 5-20 hp motors ($25 per hp), followed by a stabilization in the higher horsepower categories. This means that despite higher sales volumes for smaller motors, they do imply some fixed costs (for instance, manual work phases or the need for particular tools or equipment). Larger motors do not appear to represent any scale advantage or disadvantage.

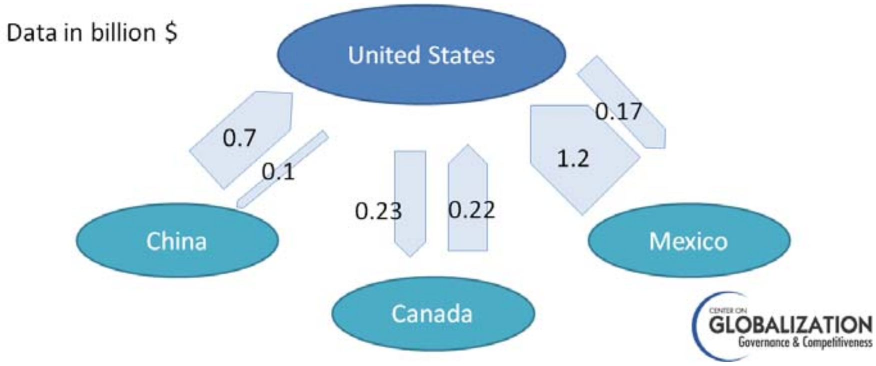
Figure 15. 2003 Motors unit value (blue bar) and price per horsepower (red line)



Source: CGGC, based on (U.S. Census Bureau, 2004)

As for international trade in electric motors, the United States' primary trading partners are Mexico, China and Canada (see Figure 16). On average, the trade flow values are relatively low—mostly less than $1 billion annually—and predominantly involve smaller motors. The United States is a net exporter only to Canada, selling just slightly more motors to that country than it buys. U.S. motor exports to Mexico and China are significantly lower than imports from either country.

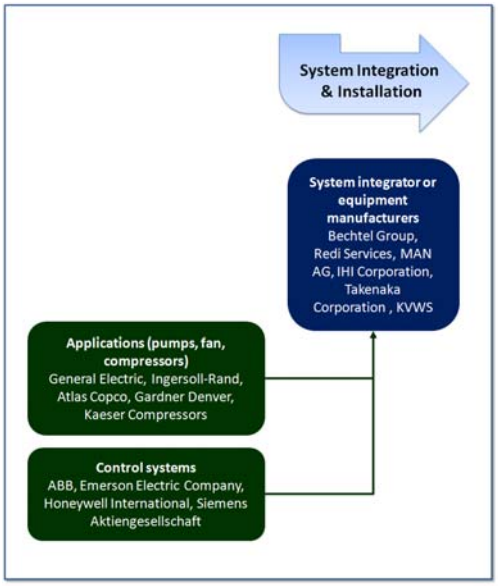
Figure 16. 2008 U.S.-centered import/export flows of electric motors



Source: CGGC, based on Comtrade Data

System integrators and equipment manufacturers

System integrators couple the motor and drive with the application. They also interface the motor/drive system with the client's control system. Integrator firms include not only equipment manufacturers, but also construction and engineering companies that specialize in industrial buildings. Both categories are considered mature and fragmented, with many firms of varying sizes and degrees of influence. Lead firms include Bechtel Group, Redi Services, MAN AG, and IHI Corporation.



The industry shows the following characteristics (Datamonitor, 2009c):

- Competition due to low differentiation, high fixed costs, and high R&D costs
- Price volatility of raw materials

In the category of construction and engineering firms, the industry is characterized by the following (Datamonitor, 2009a):

- Competitive tendering to win contracts
- Presence of norms and regulations
- Numerous sub-contractors
- Temporary project structures

Supporting institutions

Several types of supporting institutions and examples of their influence on the electric motors value chain are depicted in Table 8. The main government agency is the U.S. Department of Energy (DOE), which sets regulations and promotes industrial energy efficiency through its Industrial Technologies Program (ITP). Non-governmental organizations include the Consortium for Energy Efficiency (CEE), Institute of Electrical and Electronic Engineers (IEEE), National Electrical Manufacturers Association (NEMA), American Council for an Energy-Efficient Economy (ACEEE), and International Electrotechnical Commission (IEC). Groups such as Advanced Energy have provided much of the information that DOE and others use in their programs and have played an important role in helping motor manufacturers obtain certifications for compliance (Butler, 2010). Energy Service Companies (ESCOs) have a potentially important role to play in enhancing motor system efficiency, although to date, their penetration in industrial motor system markets has not been fully developed (International Energy Agency, 2006). Electric utilities have played an especially important role, offering rebates and incentives and implementing motor management programs.

Table 8. Description of the main supporting institutions influencing the U.S. electric motors value chain

Category	Examples	Influence on the electric motors value chain
Governmental agencies	Department of Energy (DOE), Industrial Technologies Program (ITP)	Set regulations, promote programs and initiatives for more efficient energy use
Organizations	National Electrical Manufacturers Association (NEMA), Consortium for Energy Efficiency (CEE), American Council for an Energy-Efficient Economy (ACEEE), Institute of Electrical and Electronic Engineers (IEEE), International Electrotechnical Commission (IEC), Advanced Energy	Develop standards and coordinate testing procedures for motor efficiency Promote motor efficiency to motor manufacturers and users Work with utilities, R&D organizations and state energy offices Advise DOE on motor efficiency regulations, provide information on motor management (e.g., Advanced Energy's widely distributed HorsePower Bulletin)
Energy service companies (ESCOs)	Honeywell, Carrier, Johnson Controls, NORESCO	Provide industrial clients with energy solutions including high-efficiency motor systems
Utilities	More than 60 currently active utility programs nationwide are listed by the CEE*	Rebates, incentives, co-sponsorship of programs for motor efficiency enhancement (ex. Motor Decisions Matter Campaign)

Source: CGGC. For a list of utility programs, see http://www.cee1.org/ind/mot-sys/mtr-ms-main.php3

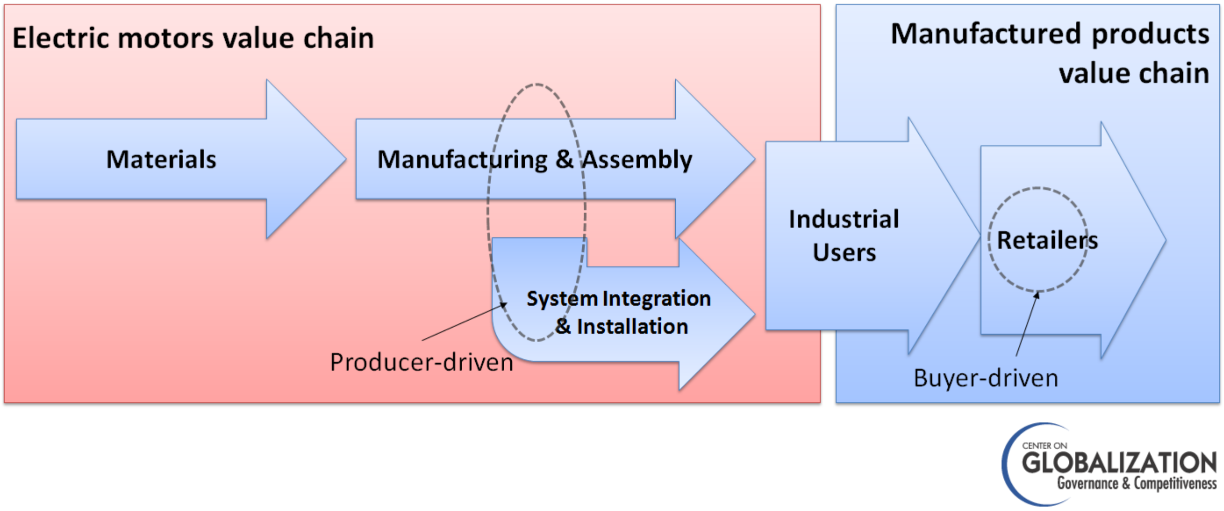
Global value chain analysis

In the literature on commodity chains, two main types have been identified to describe the position of lead firms:

- Producer-driven: when the lead firms are manufacturers
- Buyer-driven: when the lead firms are retailers and marketers (global brands)

In the electric motors value chain, two separate chains converge at the point of the industrial user (see Figure 17). Industrial users buy electric motors from the *electric motors* value chain and employ them in their production processes, which in turn form part of the *manufactured products* value chain. For example, a drinking glass producer will purchase electric motor systems to run machines to make drinking glasses—thus connecting the electric motors chain with the suppliers of raw materials and other players involved in the drinking glass manufacturing value chain. As shown in Figure 17, the electric motors value chain is producer-driven, while the manufactured products value chain is buyer-driven.

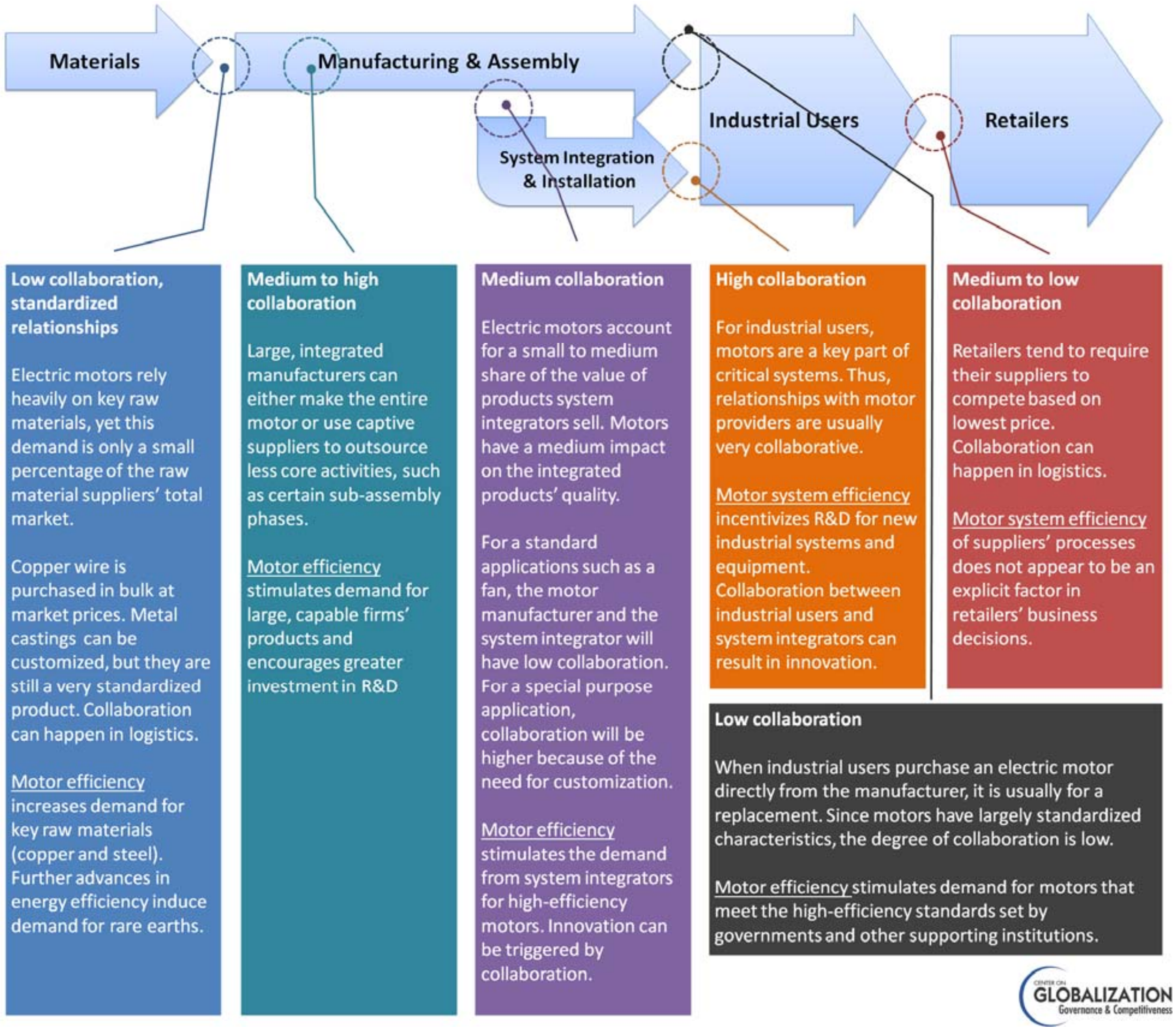
Figure 17. Role of lead firms in electric motors value chain and in manufactured products value chain



Source: CGGC

Along the value chain, different types of relationships can be established by players according to power asymmetry and the degree of explicit coordination. These relationships push companies to a higher or lower degree of inter-firm collaboration. The ways in which collaboration relates to motor efficiency are described in Figure 18. The lowest degree of collaboration lies in the relationship between materials suppliers and manufacturers. A medium degree of collaboration marks relationships in most of the value chain, while the highest collaboration occurs between system integrators and industrial users. This appears to be the crucial point where many motor decisions are influenced. A focus on motor efficiency can either *stimulate* relationships (for instance, by increasing demand), or *be stimulated* by them (for instance, when collaboration among players leads to innovation). Important relationships between key players in the U.S. adoption of high-efficiency motors and motor systems will be described in greater detail in the following section, “History of Adoption in the United States.”

Figure 18. Governance structures and relationships between key players in the electric motor value chain



Low collaboration, standardized relationships

Electric motors rely heavily on key raw materials, yet this demand is only a small percentage of the raw material suppliers' total market.

Copper wire is purchased in bulk at market prices. Metal castings can be customized, but they are still a very standardized product. Collaboration can happen in logistics.

Motor efficiency increases demand for key raw materials (copper and steel). Further advances in energy efficiency induce demand for rare earths.

Medium to high collaboration

Large, integrated manufacturers can either make the entire motor or use captive suppliers to outsource less core activities, such as certain sub-assembly phases.

Motor efficiency stimulates demand for large, capable firms' products and encourages greater investment in R&D

Medium collaboration

Electric motors account for a small to medium share of the value of products system integrators sell. Motors have a medium impact on the integrated products' quality.

For a standard applications such as a fan, the motor manufacturer and the system integrator will have low collaboration. For a special purpose application, collaboration will be higher because of the need for customization.

Motor efficiency stimulates the demand from system integrators for high-efficiency motors. Innovation can be triggered by collaboration.

High collaboration

For industrial users, motors are a key part of critical systems. Thus, relationships with motor providers are usually very collaborative.

Motor system efficiency incentivizes R&D for new industrial systems and equipment. Collaboration between industrial users and system integrators can result in innovation.

Medium to low collaboration

Retailers tend to require their suppliers to compete based on lowest price. Collaboration can happen in logistics.

Motor system efficiency of suppliers' processes does not appear to be an explicit factor in retailers' business decisions.

Low collaboration

When industrial users purchase an electric motor directly from the manufacturer, it is usually for a replacement. Since motors have largely standardized characteristics, the degree of collaboration is low.

Motor efficiency stimulates demand for motors that meet the high-efficiency standards set by governments and other supporting institutions.

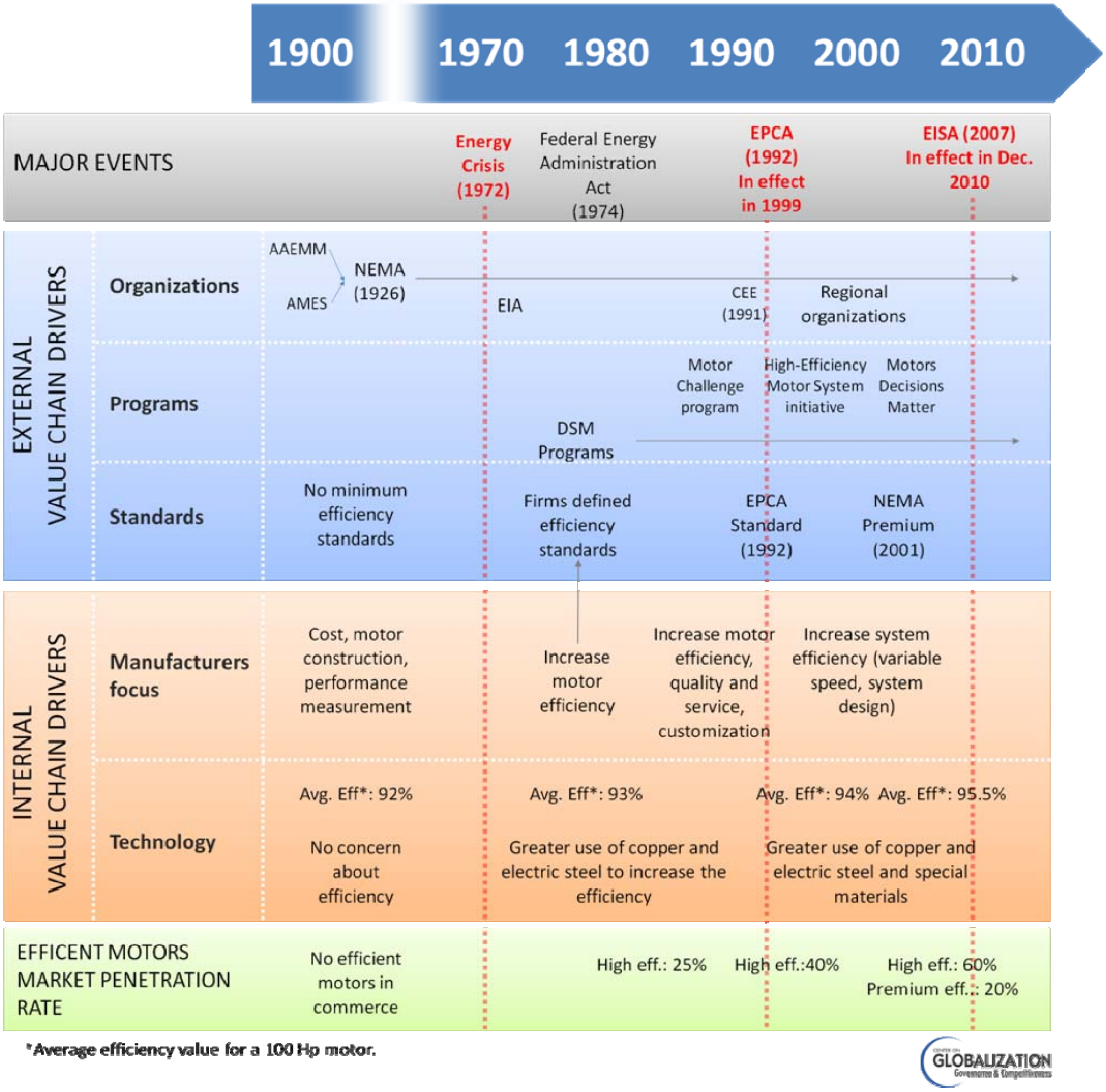
Source: CGGC

History of adoption in the United States

Timeline

The evolution of electric motors in the United States over the past 100 years can be viewed in terms of 1) major historical or regulatory events, and 2) five drivers that are either internal or external to the value chain. These major events and adoption drivers are summarized in Figure 19, along with their corresponding impact on the rate of market penetration. In the following discussion we will describe each event and adoption driver in detail. We will also trace the penetration rate for high- and premium-efficiency motors, along with projections through 2013.

Figure 19. Timeline of U.S. adoption of energy-efficient electric motors



MAJOR EVENTS			Energy Crisis (1972) Federal Energy Administration Act (1974)	EPCA (1992) In effect in 1999 EISA (2007) In effect in Dec. 2010
EXTERNAL VALUE CHAIN DRIVERS	Organizations	AAEMM, AMES → NEMA (1926)	EIA CEE (1991)	Regional organizations
	Programs		DSM Programs Motor Challenge program	High-Efficiency Motor System initiative Motors Decisions Matter
	Standards	No minimum efficiency standards	Firms defined efficiency standards	EPCA Standard (1992) NEMA Premium (2001)
INTERNAL VALUE CHAIN DRIVERS	Manufacturers focus	Cost, motor construction, performance measurement	Increase motor efficiency Increase motor efficiency, quality and service, customization	Increase system efficiency (variable speed, system design)
	Technology	Avg. Eff*: 92% No concern about efficiency	Avg. Eff*: 93% Greater use of copper and electric steel to increase the efficiency	Avg. Eff*: 94% Avg. Eff*: 95.5% Greater use of copper and electric steel and special materials
EFFICENT MOTORS MARKET PENETRATION RATE		No efficient motors in commerce	High eff.: 25%	High eff.:40% High eff.: 60% Premium eff.: 20%

*Average efficiency value for a 100 Hp motor.

Source: CGGC

Major events

The following three events serve as milestones in the evolution of the U.S. high-efficiency motor industry:

1972: The energy crisis. Until the oil shocks of the 1970s, low energy prices made the efficient use of energy a relatively low priority. Motor manufacturers mainly focused their efforts on lowering motor price while maintaining the same level of performance—for instance, using less copper or creating lightweight designs—sometimes to the detriment of efficiency. Similarly, public organizations and private associations such as NEMA had no particular concern with efficiency (Andreas, 1992). The energy crisis prompted a new focus on energy efficiency, and Congress passed the Federal Energy Administration Act of 1977. Motor manufacturers began to build new, more efficient motors and to define proprietary standards (Andreas, 1992).

1992: Energy Policy and Conservation Act (EPCA). For the first time, federal legislation set a standard for minimum levels of motor efficiency, based on the existing standards of NEMA and rules set by the DOE. These new regulations applied to motors manufactured or imported after October 1997 (Nailen, 2008).

2007: Energy Independence and Security Act (EISA). This legislation sets a wide range of federal energy management goals and requirements. Included is an upgrade of U.S. minimum motor efficiency levels to match the NEMA Premium Efficiency standard that was developed by industry in 2001. The federally required NEMA Premium standard will go into effect in December 2010.

External value chain drivers

Organizations. Electric manufacturers associations have existed in the United States since the early 20th century, seeking to standardize and optimize motor characteristics and improve manufacturing processes. In 1926, NEMA was founded through the merger of two earlier groups, the American Association of Electric Motor Manufacturers (A.A.E.M.M.), and the Associated Manufacturers of Electrical Supplies (A.M.E.S.). NEMA's stated purpose was to define standards, improve motor manufacturing procedures, lobby for relevant legislative change, and develop a culture and business climate oriented to electric products (S. A. Brown, 2001). CEE, a nonprofit body of organizations and public agencies in the United States and Canada, was the first to promote motor efficiency standards for its members (utilities), who sought to incentivize even higher levels of efficiency once EPCA motors became the minimum standard. NEMA later aligned the NEMA Premium with CEE's standards. Currently, CEE is evaluating higher efficiencies than NEMA Premium, since their member utilities again need motors to rebate after December 2010, when the motors they have been rebating will become the minimum standard under EISA (Butler, 2010).

Programs. Several motor efficiency programs have arisen from collaborations between the U.S. government, electric utilities, and other organizations. A summary of key programs that have helped to drive adoption of high-efficiency motors appears in Table 9.[4] Beginning in 1977, a number of Demand Side Management (DSM) programs were instituted by government, utilities and industrial users, including on-site analyses, loans, partial rebates, and direct installation of equipment. For many years, electric utilities have played a significant role in helping markets move to implement more efficient motors and drives. Even before regulations, utilities offered their customers rebates and cash incentives for motor efficiency upgrades. The DOE partnered with industry in its Motor Challenge Program, with the goal of helping firms use a systems approach to designing, buying, installing, and managing motors, drives, and motor-driven equipment. The Consortium for Energy Efficiency promotes premium energy-efficient motors (the NEMA standard). CEE also highlights the importance of improving the efficiency of the entire motor system. Two important CEE campaigns that focused on motor system efficiency are the High-Efficiency Motor System Initiative and the Motor Decisions Matter campaign.

Table 9. Summary of key motor efficiency programs, United States

Organization	Type	Program	Launch Year	Scope	Tools
Government, Utilities, Industrial users	Public and private	Demand Side Management programs	1977	Programs inform industrial users and promote adoption of higher-efficiency motors	External expert assistance, on-site analyses, loans, partial rebates, concentrated marketing efforts, direct installation of equipment, technical assistance
U.S. DOE / Industry partners	Industry/ government partnership	Motor Challenge Program	1993	Promotes energy-efficient motors	Motor Systems Efficiency Tool Development and Dissemination (e.g. MotorMaster+ software) Partnership programs between different kinds of organizations
CEE	Joint United States and Canada organization	Premium-Efficiency Motors Initiative	1996	Promotes premium energy- efficient motors	Definition of standard (NEMA Premium) Advance program design Consumer education about the energy and non-energy benefits of premium-efficiency motors
		High-Efficiency Motor System initiative	1999	Promotes energy-efficient motor systems	Adjustable Speed Drives Sector-Specific Strategies Motor Decisions Matter Campaign
		Motor Decisions Matter	2001	Promotes greater awareness of the benefits of motor systems efficiency	Customized "business" message aimed at senior plant and corporate management Specific business cases developed through a network of partners

Source: CGGC, based on (Consortium for Energy Efficiency, 2009; Donald, 1997; Scheihing, 2009; XENERGY, 2000)

Standards. From 1900 until the 1970s, there were no minimum efficiency standards for electric motors. As of the 1970s, firms began to define their own proprietary standards (described below, under "Internal value chain drivers"). The first U.S. government-mandated standard for efficient motors was "EPCA," taking its name from the Energy Policy and Conservation Act of 1992. The

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[4] A detailed summary of utility programs can be found as an Excel spreadsheet on the CEE website, at http://www.cee1.org/ind/mot-sys/mtr-ms-main.php3

second government-mandated standard was passed as part of the Energy Independence and Security Act of 2007. This EISA standard essentially adopts the “NEMA Premium” standard already defined by industry back in 2001, to go into effect in December 2010. Interestingly, while the NEMA Premium industry standard covers motors all the way up to 500 horsepower, EISA only includes motors of 1-200 horsepower. EISA also regulates new models that were not covered under EPCA (Butler, 2010; NEMA, 2008).

Internal value chain drivers

Manufacturers’ focus. In the beginning, motor manufacturers paid attention chiefly to cost, motor construction, and function—thus focusing mainly on reducing costs while maintaining the same level of performance. Motor efficiency was only relevant in that the motor had to have a certain minimum efficiency to avoid overheating. As a result, the actual efficiency of motors varied greatly. For motors of the same horsepower, average efficiency could vary over a range of 3-4%.

From the 1970s on, lead manufacturers promoted their own standards, some of which are still used today (Andreas, 1992). Table 10 provides a list of these companies and the standards they developed. Most were considered the leading players at that time, and many still exist or have been acquired by competitors. For example, General Electric, an industry leader, was an early adopter of its own Energy Saver standard, comparable to today’s NEMA Premium.

Table 10. Leading companies and proprietary standards in the 1970s

Company	Standard	Standard still existing?	Comparable to	Company still in business?
Litton (Magnetek after 1984)	E-Plus, E + III	No	-	Yes, but no longer makes motors
General Electric	Energy Saver	Yes	NEMA Premium	Yes
Reliance Electric Co. (Rockwell Automation, and now Baldor Group)	XE Energy Efficient	No (lasted until the acquisition by Baldor)	-	Yes, but has been acquired
Baldor Electric Co.	Super-E	Yes	IE3, NEMA Premium	Yes
Louis Allis	Spartan High Efficiency	No (moved to NEMA)		Yes
U.S. Electric Motors (now Emerson)	Corro-Duty Premium Efficiency	Yes	NEMA Premium	Yes, but has been acquired
Emerson Electric	Premium Efficiency	No		Yes
Toshiba/Huston Intl.	Premium Efficiency	Yes	NEMA Premium	Yes

Source: Based on (Andreas, 1992) and updated by CGGC.

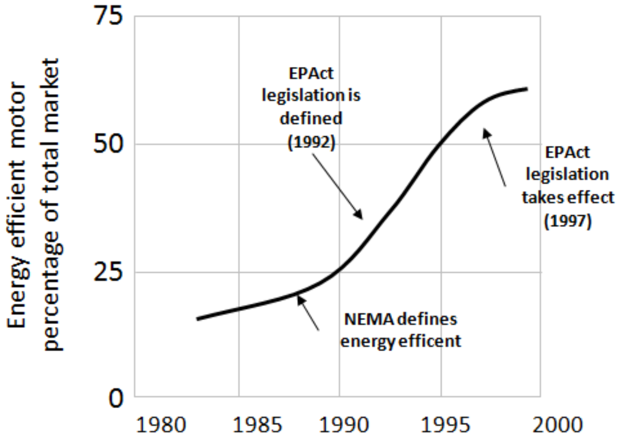
Technology advances. In the 1980s, international competition began to intensify, and many motors were imported from abroad, including those for new facilities as well as old facilities that were replacing motors procured in the 1970s. Some U.S.-based companies responded by establishing off-shore manufacturing facilities to lower costs. Some firms also invested in R&D for process and product improvements (Funding Universe, 2009).

By the end of the 1980s, efficiency losses had been reduced about 25% compared to the level in the 1960s. This means that a 40-hp motor with 90% efficiency improved to an efficiency of 92.5% (Andreas, 1992), a level comparable to the EPAct standard defined later, in 1992.

Market penetration rate

High-efficiency motors were on the market well before U.S. regulations made them mandatory with the EPAct standard. However, the purchase price was 15-25% higher than the price for standard motors. The penetration rate grew quite slowly as long as purchase was voluntary, as shown in Figure 20. Between 1980 and 1985, the penetration rate was below 25%, far below expectations (Nailen, 2008). Then, when similar standards were made mandatory by the Energy Policy Act of 1992 (EPAct), adoption rates rose steadily, exceeding 60% by the year 2000.

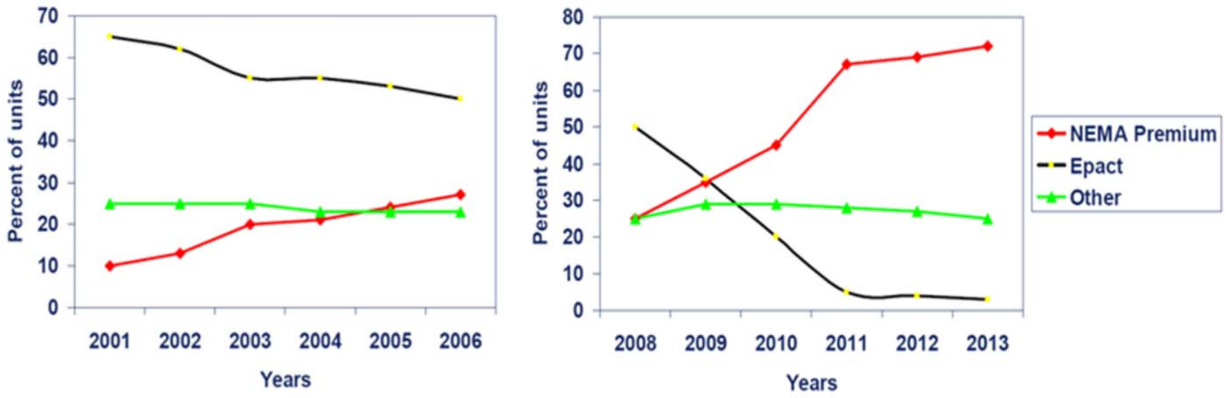
Figure 20. U.S. market penetration of EPAct efficiency motors



Source: CGGC adapted from (Nailen, 2008).

The penetration rate for NEMA Premium motors shows a similar pattern. Beginning in 2001, when the voluntary standard was defined, penetration grew relatively slowly, reaching only 25% by 2006 (Figure 21). However, since the EISA was passed in 2007, much stronger growth is predicted in anticipation of the premium standard that will be mandatory as of December 2010. By 2013, the penetration rate for premium-efficiency motors is expected to exceed 70%.

Figure 21. Market penetration of EPAct and NEMA Premium motors, past and forecast

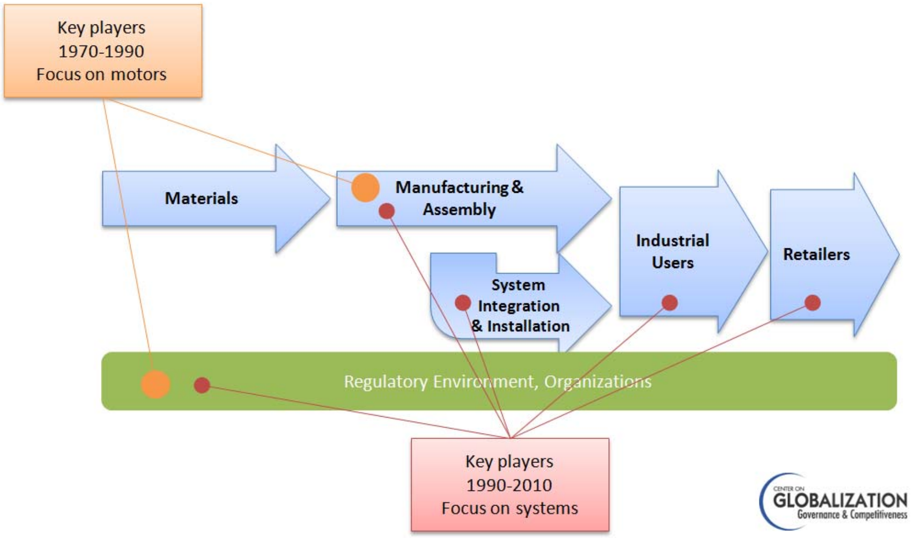


Source: (Boteler, 2009)

Key players

Between 1970 and 1990, the key players triggering the adoption of high-efficiency motors were the manufacturing and assembly companies that improved the efficiency of motors according to their own evolving standards. This was accomplished with extensive support from industry organizations such as NEMA and government Demand Side Management[5] programs that emphasized on-site analysis and technical assistance.

Figure 22. Key U.S. players in the adoption of high efficiency electric motors over time.



Source: CGGC

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[5] Demand Side Management, a term coined during the energy crises of the 1970s, refers to a general approach to addressing energy needs by focusing not just on the supply side, but also on the end user.

Since 1990 the focus has moved from addressing only the motor, to addressing the energy efficiency of the entire motor system including motor, drive and application. The impact that this shift in focus has had on key players in the adoption story is shown in Figure 22. Because of the importance of motor system efficiency, System Integrators are crucial, along with equipment manufacturers that design the application devices in motor systems. Motor manufacturers remain key players, since they continue to do R&D on technological improvements to motors and systems. Electric utilities provide important incentives and education. Government and other supporting institutions play a critical role by setting new and higher standards and helping end users make more informed decisions about their motor systems. Finally, retailers are considered a potential key player. Large retailers with thousands of goods manufacturers in their supply chains may be able to incentivize these suppliers to adopt more efficient motor systems as a way to cut costs and make their manufacturing processes more environmentally sustainable.

Barriers to adoption

In the United States, further adoption of high-efficiency motor systems could reduce industrial motor systems' electricity use by 11-18%, or 62-104 billion kWh per year. This represents an annual cost savings of $3-5 billion. In addition, redesigning motor systems could yield other potential benefits such as improvements in the control of production processes (for instance, through variable speed drives) and less waste of maintenance effort and materials (Consortium for Energy Efficiency, 2009).

Before these savings can be fully realized, however, several barriers to adoption must be addressed. Table 11 summarizes the following types of barriers:

Organizational. These barriers include organizational factors such as misaligned incentives, in which the part of the organization that would buy a high- or premium-efficiency motor does not stand to benefit from the motor's savings in energy costs, and so only considers the purchase cost, which is higher than that for a less efficient motor (Almeida et al., 2008). An additional organizational challenge is that many facilities lack contingency plans in the event of a breakdown or motor failure. Many manufacturers will simply keep a motor in use until it fails. Thus, an estimated 70% of replacement motors are emergency replacements and only about 30% are planned replacements (Payne, 2009). Unplanned interruptions, particularly those that threaten product quality, cause manufacturers to focus solely on getting production running again, thus potentially opting for any motor easily available, including low-performers that may have been warehoused onsite. Motor education and training campaigns such as CEE's Motor Decisions Matter have emphasized the importance of having a contingency plan that includes a carefully-chosen motor that can be acquired on short notice and integrated smoothly into production.

Economic. An economic barrier results from "downtime" costs when a production line must be idled in order to replace the current motor with a more efficient one (McCoy et al., 1990). This economic opportunity cost may cause a company to postpone or avoid a decision to replace a motor (Eckhart, 2009). In 2005, Advanced Energy learned that downtime costs are a serious barrier when, as part of a large research project, the firm tried to give away 100 free, brand-new NEMA Premium motors to industrial customers, intending to study the customers' old motors in the lab. It was surprisingly difficult to give away the new motors, even though some were 150-hp motors worth more than $10,000 (Advanced Energy, 2006; Butler, 2010).

Technical. Industrial users are aware of the risk that a new motor will not integrate well with existing control systems; in fact, a more efficient motor will tend to run faster than a less efficient one, so it can actually cause energy use to increase if not integrated well with careful attention to matching the motor speed to the optimal process speed for pumps, fans, etc (Butler, 2010).

Path dependency. Inertia constitutes a barrier in that end users are often unwilling to switch to a new technology despite the promise of better performance.

Value chain. An additional barrier in the value chain is that system integrators and equipment manufacturers may have incentives to sell end users a cheaper motor system that is less efficient than available alternatives (Almeida et al., 2008).

Table 11. Barriers to adoption of high-efficiency electric motors and motor systems

Barriers	Description
Organizational	Buyers are procurement cost-oriented, budget-constrained Misaligned incentives arise between purchasing budgets and operation budgets Plants focus on short-term savings rather than life cycle cost assessment Facilities lack contingency plans; managers are undertrained in maintenance and management functions Energy may be considered an overhead cost that no one is responsible for Plant-level decision-makers lack knowledge of systematic approaches to motor system efficiency
Economic	The increase in efficiency achievable with a new, efficient motor may not appear cost-effective, especially when downtime costs are incurred
Technical	Challenges arise when a new motor is integrated into an existing control system
Path dependency	End users exhibit inertia, lack of willingness to change to new technologies Managers anticipate potential problems integrating the new motor with the legacy control system
Value chain	System integrators and equipment manufacturers may have conflicting motivations, offering final users cheaper motor systems that are less efficient

Source: CGGC, based on (Almeida et al., 2008; Bernatt & Bernatt, 2008; McCoy et al., 1990; Sorrell, 2004)

International comparison

The United States and Canada have long been the leaders in adopting high-efficiency electric motors. Both countries have achieved significant improvements through voluntary programs and close collaboration among government agencies, industry groups, non-profit institutions and manufacturing firms (Boteler, 2009; McKane, Cockrill et al., 2008). Perhaps more important, both governments continue to lead the way with mandatory standards.

A comparison of selected countries' motor efficiency standards appears in Table 12. As presented here, standards are divided into 4 classes: low, high, premium, and super premium. As of December 2010, the United States and Canada will accept only premium-efficiency motors. The only other country or region that has set a similar standard is Europe, but it will not be in effect there until 2015—and for smaller motors, in the range of 0.75 - 7.5 kW, not until 2017. For comparison, the United States/Canada standard has included small motors since the EPAct standard, in 1997. Europe's EPAct-level standard, IE2, is considered equivalent to the premium standard if the motor is coupled with a variable speed drive. Interestingly, Europe is already considering a "super premium" standard—to exceed the current premium level—but, given the region's 2015-2017 date for premium motors, this super premium standard presumably will not apply soon.

Table 12. Motor efficiency standards in selected countries

	Standard and *Compliance date*			
Country/ Region	**Super Premium**	**Premium**	**High**	**Low**
Europe	IE4 *(draft)*	IE3 *2015 (2017)**	IE2	IE1
U.S./Canada (Mexico and Brazil)		NEMA Premium *Dec. 2010*	EPAct *1997*	
China		Grade 1 *Voluntary*	Grade 2 *2011*	Grade 3
Israel			IEC 60034-2 (Europe IEC based) *2006*	
Australia and New Zealand			AS NZS *2006* Method A (U.S. NEMA-based) Method B (Europe IEC-based)	
South Korea			KS C (Europe IEC-based) *2008 (fractional motors in 2010)*	

*** After 2015 IE2 motors will be accepted only if coupled with a variable speed drive. For smaller motors (0.75 – 7.5 kW range) the compliance date is 2017.**

Source: CGGC, based on (Leroy Somer, 2009)

Mexico and Brazil have developed their own regulations rather than directly adopting U.S. standards, yet they are completely aligned to the United States and Canada in terms of requirements and timing. China has set its own equivalent of the premium standard, called "Grade 1," but the compliance date, 2008 is not considered mandatory. Several other countries lag significantly behind in standards. As of 2006, Israel, Australia and New Zeland have based their regulations on International Electrotechnical Commission (IEC) standards, but these are in line with the EPAct, not the premium, standard; they also lack any enforcement mechanism. South Korea is in a similar situation, only a bit delayed, since it adopted its EPAct-level standards only in 2008.

Although a global standard for efficient motors would yield obvious benefits, it is still far from a reality. Several challenges arise when attempts are made to unify standards:

- Different types of motors (e.g. AC/DC, Synchronous/Asynchronous, number of poles, type of material, horsepower range, speed range)
- Different input currents (60 Hz versus 50 Hz)
- Different types of testing methods (e.g. IEEE and IEC)

To address and accommodate these differences, in 2002, the IEC and IEEE (Institute of Electrical and Electronic Engineers) agreed to work together to define global technical standards. Other international initiatives such as SEEEM 2006 (Standards for Energy Efficiency of Electric Motor Systems) have been launched to promote integration and harmonization among standards.

Potential for high-efficiency motor adoption in China

Since the 1980s, the Chinese government has sought to reduce energy consumption in the industrial sector, managing to reduce its energy intensity (the ratio of energy consumption to total GDP) by 80% from 1991 to 2003. This commitment was recently confirmed through the Eleventh Five-Year Plan, with the objective of further reducing energy intensity by 20% (UK-China Market Transformation Programme, 2008). Energy use by motors and motor systems is an area with strong potential for improvement. In 2006, motor systems accounted for an estimated 61.8% of China's total annual electricity consumption, or 1.43 trillion kWh. If China were to achieve full compliance with premium efficiency standards, the country could cut motor systems' electricity use by about 11%, saving an estimated 150 billion kWh per year (Sheng & Kai, 2009). China has ample reason to pursue high-efficiency motors and motor systems, standing to benefit from the lessons learned in the United States. Indeed, several U.S. institutions are involved in the effort. For example, ACEEE is closely associated with standard setting in China (Elliott, 2009). NEMA has been sharing the U.S. motor efficiency experience with Chinese counterparts and has conducted seminars in China (Eckhart, 2009).

Efforts to promote motor efficiency in China

The Chinese government has undertaken several major efforts to improve motor efficiency. One effort regards labeling; as of September 2008, all voltage motors up to 315 kW manufactured or imported into China must have an efficiency label confirming they meet a defined standard of Grade 1, 2 or 3, with Grade 1 equating to the NEMA Premium standard. These labeling standards and the related testing procedures follow those of the IEC, so they are in line with Europe. China's motor efficiency efforts include the following (Nadel et al., 2001; UK-China Market Transformation Programme, 2008; Wang, 2006):

- Certification and labeling
- International collaborations (e.g. with United States, Europe, World Bank, United Nations, other Asia-Pacific countries)
- Financing (administration of fiscal reward funds for energy-saving technology upgrades)
- Opening of four motor system energy conservation service agencies specialized in capacity building, equipment procurement, technical training, plant assessment and case studies
- Development of regional ESCOs

China has some favorable positioning and opportunities to improve motor efficiency. These include the country's rapid pace of building completely new facilities. New "green field" plants may facilitate adoption of best practices without struggling with the change/no-change decisions that U.S. companies have faced throughout the history of high-efficiency motors adoption. Further potential advantages in China include an aggressive investment policy, the preponderance of state-owned enterprises, and strong political institutions at the provincial level, perhaps allowing for a stricter regulatory framework than has been possible in other countries (Eckhart, 2009). In addition, China is well-positioned to test and certify motor efficiency; out of only a handful of accredited labs worldwide, one is in Nanyang, Henan province, and two are in Shanghai (National Institute of Standards and Technology, 2009).

Barriers to motor efficiency

Despite China's potential for green-field development and its notable strides in labeling standards and testing capability, the country's status quo in motor efficiency is quite far behind that of developed countries, especially the United States and Canada. On average, motors in China are about 2-5% less efficient than those in developed countries, and motor systems are estimated to be 20-30% less efficient (Eckhart, 2009). China appears to face the following barriers to adoption of high-efficiency motors and motor systems:

- <u>Over-sizing.</u> It is common for a manufacturing facility to use a larger motor than is required for the task at hand; designs often include redundancies and overcapacity
- <u>Low-cost focus</u>. The market is dominated by low-cost and low-efficiency motor manufacturers as well as customers seeking low-cost motors
- <u>Quality variation</u>. Domestic motor manufacturers exhibit large differences in quality
- <u>Limited adoption of key technologies</u>. Manufacturing facilities have little adoption of variable speed drives and of advanced technologies
- <u>Lack of information and training</u>. Final users are not aware of motor system efficiency issues and not trained to implement efficiency options, leading to low levels of actual use of high-efficiency motors
- <u>Incomplete execution of programs</u>. Some government energy-efficiency mechanisms such as preferential tax policies and energy management contracts have not been fully implemented or adopted
- <u>Lack of institutional structure</u>. Several supporting U.S. institutions helped lay the groundwork for adopting high-efficiency motors well before the U.S. government established official standards. Industry and non-profit agencies such as CEE and ACEEE have performed a crucial role in promoting awareness and training for end users in best practices for motors and motor systems. Achieving a similar effect in China will likely require involving different, but functionally equivalent, organizations and intermediaries that can perform this critical technical assistance/ education role.

Role of mandatory standards

Perhaps most important to China's future adoption of high- and premium efficiency motors is the role of mandatory standards. Although the Chinese government has taken many steps to show that motor efficiency is a priority, so far these steps have largely consisted of setting goals and *encouraging* efficient practices and technologies—thus falling short of establishing the type of mandatory standards in place in the United States and Canada. China's grading system includes three levels of efficiency: Grade 3 (standard efficiency), Grade 2 (equivalent to EPCA efficiency) and Grade 1 (equivalent to NEMA Premium efficiency). Grade 2, the level made mandatory in the United States and Canada with a 1999 compliance date, will not be mandatory in China until 2011. Grade 1 (December 2010 compliance date in the United States and Canada) appears likely to remain voluntary in China for the foreseeable future. Considering that even implementing the new 2011 standard for Grade 2 will take several years, it seems probable that a mandatory standard for Grade 1 will not occur until at least after 2015.

Chinese manufacture of high- and premium-efficiency motors

A valid question concerning the likelihood that China will make Grade 1 motors mandatory is whether the country could meet a significant portion of the resulting demand for premium-efficiency motors through China's own domestic motor manufacturers. The brief analysis that follows implies that this may be a chicken-and-egg question. While some Chinese motor manufacturers are producing motors equivalent to EPAct and NEMA Premium efficiency standards, they are primarily for export to the North American market, where these standards have been made mandatory. Chinese motor manufacturers so far seem to have had little incentive to produce high- and premium-efficiency motors for the domestic market, where the demand is primarily for low-priced motors even if their efficiency is low.

According to the China National Institute of Standardization, there are more than 3,000 motor manufacturers in China. Production is very decentralized and of varying quality (UK-China Market Transformation Programme, 2008). In 2001 a team of Chinese and U.S. researchers estimated that the top 15 manufacturers held about half of the market (Nadel et al., 2001).

A 2006 market study by the International Copper Association in Beijing found that, within Chinese motor production, the share of high- and premium-efficiency small and medium motors was less than 10%. The study further noted that of this 10%, about 70% was exported (UK-China Market Transformation Programme, 2008).

In 2008, China's exports of AC motors (including universal (AC/DC) motors, but excluding motors under 37.5 W) totaled about $3 billion (UN Comtrade, 2009). The three main markets are the United States, Italy and Japan (see Table 13). Since high-efficiency (EPCA) motors have long been mandatory in the United States, it can be assumed that within the $651 million in motors exported to the United States in 2008, the motors relevant to the standard met the EPCA level or higher. China also exports high-efficiency motors to the European market and standard-efficiency motors to Southeast Asia and the Middle East. The top five Chinese exporters are estimated to fulfill about half of the export market (Nadel et al., 2001).

Table 13. 2008 motor exports from China (SITC Rev. 3 code 71631)*

To	Trade Value ($ millions)	Units (millions)	Ave. Unit Value ($)
World	$3,045.5	215.2	14.15
USA	$651.1	39.0	16.69
Italy	$233.4	8.9	26.22
Japan	$200.3	5.4	37.09

*AC motors including universal (AC/DC) motors, but excluding motors under 37.5W
Source: (UN Comtrade, 2009)

The current low demand for high- and premium-efficiency motors in the Chinese market implies that, in the near future, domestic motor manufacturers are not likely to focus on premium-efficiency motors other than for the export market. Presumably, domestic production of high-efficiency (G2) motors for the Chinese market can be expected to increase substantially in response to the 2011 compliance date for the new mandatory G2 standard.

Priorities for future adoption

The U.S. experience with high-efficiency motors has yielded several lessons that continue to apply domestically and are also relevant to future adoption in other countries. Based on the U.S. adoption story, we have identified eight priorities for encouraging more widespread adoption of high-efficiency motors and motor systems in the United States and elsewhere, especially in China. Many of these priorities require collaboration among different actors in the value chain, from motor manufacturers to governments, industry organizations, non-profit agencies, system integrators, distribution channels, external consultants, and buyer companies.

Table 14 provides a detailed summary of the following eight priorities:

1) Regulations are a critical factor in countries where they are not yet in place, with mandatory standards serving as the single most effective mechanism for encouraging adoption

2) Adequate testing ensures that all losses are adequately accounted for, so that efficiency is not overestimated

3) Education and collaboration are largely achieved in partnership between governments, industry organizations, and non-profit groups

4) A focus on motor replacement instead of repairs to inefficient motors makes use of complete evaluation systems that accurately account for energy savings

5) A focus on motor system efficiency yields far greater overall efficiency by improving not only the motor but also the drive and application

6) Financial incentives can affect users' motor decisions, especially in favor of replacement

7) Use of variable speed drives makes it possible to match the energy requirement to the actual need

8) Technology advances, to a large extent, will probably lie elsewhere in motor systems—outside of motors, where the potential for additional marginal improvement is limited and costly to achieve

Table 14. Priorities for future adoption of high-efficiency motors and motor systems

Area	Promoting/Pivotal player	Leverage Points	Limitations
1. Regulations	Government agencies	National mandatory standards such as that set by the U.S. Energy Independence and Security Act of 2007, requiring premium-efficiency motors	The elimination of previous standards, for instance the U.S. EPAct standard, will limit the market to the more expensive premium efficiency motors, perhaps causing end users to delay decisions about replacing motors

2. Adequate testing	Laboratory accreditation programs	Accredited testing laboratories; networking among testing facilities	Harmonization of testing standards and protocols is a complex challenge.
3. Education and collaboration	Government agencies, industry organizations, non-profit groups, consultants	Technical assistance, evaluation systems, on-site analyses, decision software	Effective partnerships such as those in place in the United States and Canada require an institutional framework that may be absent in countries that are more public-centric
4. Emphasis on motor replacement, repairing only when clearly beneficial	Buyer companies Influencing actors: government, system integrators, external consultants	Use of more complete evaluation systems that take energy savings into account Tax incentives to cover higher costs (especially for early replacement)	For motors used intermittently and relatively few hours per year, replacement has a longer payback To perform sophisticated evaluation techniques that accurately account for energy savings, many companies would require additional training Buyers' interest in energy efficiency fluctuates with the cost of energy Plants face high down time costs
5. Emphasis on motor system efficiency	Buyer companies Influencing actors: government, system integrators, external consultants	Redesign of entire system including motor and application Use of variable speed drives and right-sizing the motor to its specific task	System focus entails higher investment costs, possible longer payback period Requires a case-specific business plan
6. Financial incentives	Government agencies, electric utilities	Tax credits, rebates, cash-for-clunkers-style incentives for early retirement of low-performing motors	Even financial incentives are sometimes inadequate to convince end users who do not consider full life-cycle costs in their motor decisions
7. Use of variable speed drives	Buyer companies Influencing actors: government, system integrators, external consultants	Downsizing of motor and use of variable speed drive to fit energy requirement to actual need	Will not provide any benefit in cases where fixed motor speed is required
8. Technology advances	Motor manufacturers	Use of more copper in motors Use of new materials (aluminum, rare earths, permanent magnets)	Increases exposure to price fluctuations in copper and rare earths Involves recent supply chain uncertainties for rare earths Most feasible improvements have already been made; additional possible increments in efficiency are limited Remaining possible improvements are expensive; high R&D expenditures reaching $.5M to $1M in non-recurring engineering costs. The resulting high purchase costs may encourage end users to avoid replacing older, low-performing motors.

Source: CGGC, based on (Almeida et al., 2008; Bernatt & Bernatt, 2008; Sorrell, 2004)

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