Executive Summary

The global assessment

This paper presents the findings of the first global analysis of energy consumption in electric motor- driven systems (EMDS)[1] and the options to reduce it. It assesses the energy currently used by EMDS and the potential for energy savings, examines market barriers to the adoption of energy-efficient solutions, and reviews current policy settings and outcomes. The report then proposes a comprehensive package of policy recommendations to help governments tap the huge potential for energy savings in EDMS.

Electric motors convert electrical power into mechanical power within a motor-driven system. The vast majority of the electricity used by an EMSD is consumed by the electric motor itself. Only a very small amount is used to power control functions or other ancillary circuits.

Electric motors and the systems they drive are the single largest electrical end-use, consuming more than twice as much as lighting, the next largest end-use. It is estimated that EMDS account for between 43% and 46% of all global electricity consumption, giving rise to about 6 040 Mt of CO_2 emissions. By 2030, without comprehensive and effective energy-efficiency policy measures, energy consumption from electric motors is expected to rise to 13 360 TWh per year and CO_2 emissions to 8 570 Mt per year. End-users now spend USD 565 billion per year on electricity used in EDMS; by 2030, that could rise to almost USD 900 billion.

Table 1: EDMS electricity consumption by sector

Sector	Electricity consumption	% of all EMDS electricity	% of sector electricity
Industrial	4 488 TWh/year	64%	69%
Commercial	1 412 TWh/year	20%	38%
Residential	948 TWh/year	13%	22%
Transport and agriculture	260 TWh/year	3 %	39%

Source: IEA statistics, 2006 (national electricity demand); A+B International, 2009 (motors calculations).

These daunting figures are the aggregate of the energy consumed by an array of different types of motors operating within a wide set of applications in every sector of energy use, with the greatest opportunity for savings in the industrial sector (Table 1).

Motor systems used widely across all sectors

The majority of electric motors in use draw less than 0.75 kW of power in a variety of small applications, mostly in the residential and commercial sectors. These motors account for only about 9% of all electric motor power consumption. In general, they are integrated into mass-produced packaged applications such as refrigerator compressors, extractor fans, computer hard drives, etc. Many of these applications are subject to policies that apply to the level of the packaged system, rather than the electric motor component, but many are still not subject to any policy requirements. In the European Union, for example, at the beginning of 2010, only about 38% of motor electricity consumption in the combined residential and commercial sectors was used in systems subject to minimum energy performance standards (MEPS).

[1] Throughout this report, the acronym EMDS is used to refer to electric motors and motor systems.

The largest proportion of motor electricity consumption is attributable to **mid-size motors with output power of 0.75 kW to 375 kW**. Many different motor technologies and design types are available, but asynchronous alternating current (AC) induction motors are most frequently used and consume the most energy. These motors are either sold to original equipment manufacturers (OEMs) and integrated into pre-packaged electromechanical products (such as pumps, fans, compressors, etc.) or sold as stand-alone motors that final customers then integrate into a specific application on site. Such stand-alone motors are produced in large volumes, according to standardised input power and size specifications, with varying channels to market and integration into electromechanical systems. This has a significant impact on the type of barriers to adoption of energy-efficient solutions for EMDS and, hence, on the most appropriate policy packages to overcome such barriers.

Motors in the mid-size range are most commonly found in industrial applications, but they are also widely used in commercial applications, infrastructure systems and, less often, in the residential sector. In general, their main applications are mechanical movement, compressors, pumps and fans, which in turn have many types of sub-application. At present, most OECD and many non-OECD economies impose MEPS on asynchronous mid-size AC motors sold as separate components. Very few countries have set such requirements for other types of electric motors, and the requirements are rarely applied specifically to motors integrated directly into a packaged system prior to sale.

Large electric motors with more than 375 kW output power are usually high-voltage AC motors that are custom-designed, built to order and assembled within an electromechanical system on site. They comprise just 0.03% of the electric motor stock in terms of numbers, but account for about 23% of all motor power consumption, making them very significant consumers of global power (about 10.4%). These motors are not currently subject to MEPS in any part of the world.

In electric motor-driven systems, some energy losses occur in the motor itself, but energy losses are greater in the rest of the mechanical system to which the motor is coupled. A typical electromechanical system involves a motor, an electrical control system, a variable-speed drive (VSD) and a mechanical load. The magnitude of energy losses depends on the application and the degree to which an advanced technical solution is used. For any given power rating, there is a difference of only a few percentage points in energy efficiency between average motors and the most efficient motors on the market.

Small motors are less efficient than higher-powered motors. Large losses can occur due to mismatches between the output power of fixed-speed motors and the mechanical power demands of the electromechanical system. This is especially true when motors are used in mechanical applications with variable mechanical power needs, which have a highly non-linear relationship between input power and mechanical load (torque and speed) and an exponential relationship between input power and mechanical power (*e.g.* pumps, fans and compressors). In this case, there can be very significant savings from using variable-frequency drives (VFDs) with intelligent control, which regulate the output torque and speed of the motor to match the system mechanical loads. However, such control systems need a significant amount of power to operate and should not be used in fixed output power applications. In such applications, they will incur more energy losses and impose higher costs than a properly sized fixed-speed system.

For any given output power rating, there is currently a spread of several percent in efficiency between the most and least efficient motors on the market. Despite being slightly more costly to purchase than standard motors, higher-efficiency motors (HEMs) with over 1 000 hours of operation per year are more cost-effective over the system life for end-users in all applications, because motor-energy costs typically account for over 95% of a motor's life-cycle cost. The internal rate of return (IRR) from the use of a HEM compared to a standard motor is often well over 100%, but end-users rarely demand HEM applications, due to a host of market barriers. Mandatory regulations are usually the best way to ensure significant and timely market penetration of HEMs.

Policy intervention can stimulate significant savings

Overall, this analysis finds that using the best available motors will typically save about 4% to 5% of all electric motor energy consumption. Linking these motors with electromechanical solutions that are cost-optimised for the end-user will typically save another 15% to 25%. The potential exists to cost-effectively improve energy efficiency of motor systems by roughly 20% to 30%, which would reduce total global electricity demand by about 10%.

The three major routes to achieving these savings are:

- Use of properly sized and energy-efficient motors.
- Use of adjustable-speed drives (ASDs)[2], where appropriate, to match motor speed and torque to the system mechanical load requirements. This makes it possible to replace inefficient throttling devices and, in some cases with “direct-drive”, to avoid wasteful mechanical transmissions and gears.
- Optimisation of the complete system, including correctly sized motor, pipes and ducts, efficient gears and transmissions, and efficient end-use equipment (fans, pumps, compressors, traction, and industrial handling and processing systems) to deliver the required energy service with minimal energy losses.

Without policy intervention, many barriers make it difficult or impossible to realise these savings in the current market environment. In unregulated markets, purchasers tend to underinvest in higher-efficiency options and choose electric motor systems with a low first cost. This occurs for a variety of reasons, including:

- Lack of awareness among motor purchasers of the potential for energy and cost savings by using more efficient motors within energy-efficient EMDS.
- Company organisational structures that manage their equipment procurement budget separately from operations and maintenance budgets.
- The fact that motors are often integrated into equipment produced by OEMs before sale to the final end-user.

To overcome these barriers, many countries (now comprising over one-third of the world’s population) have adopted MEPS for the main class of industrial electric motors. More countries are in the process of developing such requirements. This policy instrument has been shown to be practicable to implement and a cost-effective means of saving energy. The average energy efficiency of new motors in countries applying MEPS is notably higher than in countries without such requirements. It is estimated that if all countries adopted best practice MEPS for industrial electric motors, by 2030 approximately 322 TWh of annual electricity demand would be saved, giving rise to corresponding savings of 206 Mt of CO_2 emissions.

[2] An **adjustable speed drive (ASD)** or **variable-speed drive (VSD)** is equipment used to control the speed of machinery. Many industrial processes such as assembly lines must operate at different speeds for different products. Where process conditions demand adjustment of flow from a pump or fan, varying the speed of the drive may save energy compared with other techniques for flow control. Where speeds may be selected from several different pre-set ranges, usually the drive is said to be "adjustable" speed. If the output speed can be changed without steps over a range, the drive is usually referred to as "variable speed". A **variable-frequency drive (VFD)** is a system for controlling the rotational speed of an alternating current (AC) electric motor by controlling the frequency of the electrical power supplied to the motor.

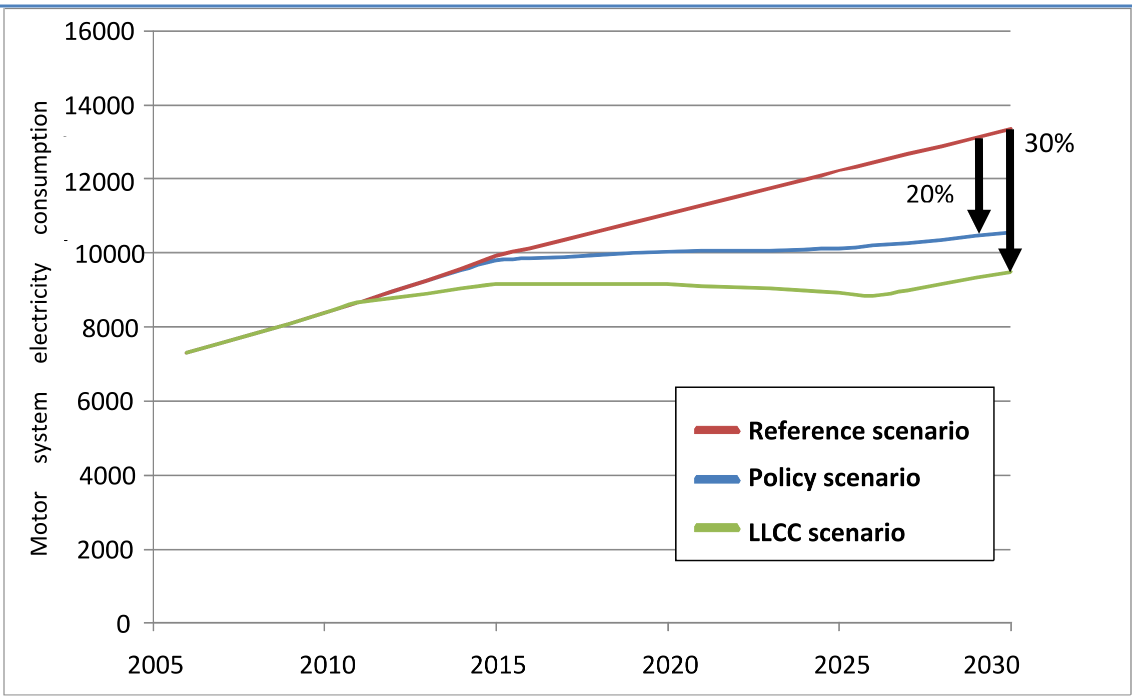
Policies needed for optimising packaged systems

Important as these savings are, much larger savings would accrue if all EMDS were properly optimised. Realising this objective is less straightforward from a policy perspective, but it is possible to make headway in the more complex domain of EMDS by carefully segmenting the applications in which motors are used, and by targeting regulatory policies at packaged motor systems applications with large savings potentials (*e.g.* certain kinds of pumps, fans and compressors). It is practicable to set MEPS and energy labelling requirements for a range of core motor-driven systems, including fans, pumps and compressors. In some cases, similar MEPS can be applied to entire motor-driven system applications (*e.g.* for municipal water pumping, elevators and escalators).

Regulatory measures should not necessarily be confined to devices and components that directly consume power; policies could also eventually target the large potential energy savings from improved energy performance of mechanical components (such as gears and drive belts). Certain common technologies (such as worm drives and V-belts) are fundamentally inefficient and could potentially be regulated out of the market in favour of more efficient options.

As some aspects of motor-system energy use do not lend themselves to simple regulatory approaches, softer policy measures can be beneficial. It is especially important to strengthen market awareness through educational efforts targeting multiple decision-making levels (OEM, system specifier, plant manager, energy manager and senior manager/executive level). This would include user-friendly technical assistance through enhanced technical standards, system specification and operational/energy management tools and services. There is also a need to better align fiscal and financial incentives throughout the value chain, which could be complemented by well-targeted economic assistance to encourage the uptake of energy-efficient EMDS.

Figure 1: Projected global electric motor-system electricity consumption



Abbreviation: LLCC = least life-cycle cost.

Notes:

Reference scenario: when the current situation is maintained without additional policy measures.

Policy scenario: when all countries adopt a broad-based and rigorous policy package on EMDS.

LLCC scenario: when all EMDS are moved toward the least life-cycle cost level.

Source: IEA estimate.

Above all, it is essential to scale up the operations and resources committed to realising the vast savings potential of optimised EMDS. By comparison with other sustainable energy opportunities, the energy efficiency of EDMS has been relatively neglected, and nowhere do such systems currently benefit from the scale of support that is offered to sustainable supply-side options. While governments are starting to become more proactive on this issue, and many have implemented some useful policy measures, none has yet put in place the resources or policy processes likely to realise substantial savings.

If a broad-based and rigorous policy package were put in place, it is estimated that globally, by 2030, it would save some 24 000 TWh in electricity demand, avoid some 16 Gt of CO_2 emissions, and generate cost savings of about USD 1.7 trillion (Figure 1). These savings would come at less cost than supplying this energy. Annual savings in 2030 would be in the order of 2 800 TWh in electricity demand, 1 790 Mt of CO_2 emissions and USD 190 billion in electricity costs.

If it were possible to move all EMDS towards the least life-cycle cost level as rapidly as technically possible, it is estimated that some 42 000 TWh of electricity demand, 29 Gt of CO_2 emissions and USD 2.8 trillion in electricity costs would be saved globally by 2030. Annual savings in 2030 would be of the order of 3 890 TWh in electricity demand, 2 490 Mt of CO_2 emissions and USD 264 billion in electricity costs.

Comprehensive integrated policy package

To help realise the tremendous potential for cost-effective energy savings in electric motor-driven systems, governments should consider, as a first measure, adopting mandatory MEPS for electric motors, in line with international best practice, subject to due process and cost-effectiveness analysis.

These standards should apply to as many types and sizes of electric motor as it is feasible to address and should not be confined to mid-size asynchronous AC motors sold as separate components. The level of these standards should be set at no lower than the least life-cycle cost, which is generally at IE3[3] or higher for mid-size asynchronous AC induction motors. Even larger energy savings can be achieved by using VFDs, which dynamically match the output power of motor systems to the power demanded by the drive train. Further savings can be achieved by using efficient transmission and gear systems, and through better sizing and management of electric motor-driven systems.

Overall it is estimated that it is cost-effective to save about 20% to 30% of total global electric motor demand (*i.e.* roughly 10% of all global electricity consumption) through the use of more efficient electric motors and drives. Achieving such savings will require individual and concerted action on the part of all players, including regulators, policy makers and standards development agencies.

It is proposed that IEA member countries and non-member economies apply a market-transformation package based on the portfolio of energy performance policies set out in the following package of policy recommendations:

Regulatory policy measures

1. **MEPS** should be introduced in IEA member countries in line with international best practice for all major classes of electric motors. They should not be set at levels less than IE3 for asynchronous motors. These requirements should apply to motors sold individually or integrated into pre-packaged electric motor-driven systems, and should apply to motors with as wide a range of output power as is practicable (100 W to 1 000 kW).

[3] Premium efficiency level as defined within IEC60034-30 and IEC 60034-31.

2. Regulatory measures, such as **MEPS and energy labelling**, should be introduced for packaged integrated motor-driven energy end-uses between 100 W and 1 000 kW, including fans, pumps, circulation pumps and compressors that are produced in sufficiently large volumes to have significant energy consumption.
3. Regulators, policy makers and standards development agencies should ensure that **energy performance test procedures are developed for all motor types** that use significant amounts of electricity and are not covered by existing internationally agreed test procedures.
4. Regulators, policy makers and standards development agencies should commission the development and application of **energy-performance test procedures to cover other essential components** of electric motor-driven systems, including transmissions, gears and system control devices (*e.g.* VFDs). In addition, efforts should be made to develop energy-performance test procedures and guidelines that apply to whole electric motor system applications, such as utility water-pumping, lifts (elevators), escalators, conveyors, etc.
5. Regulators should explore the feasibility of developing **minimum energy performance standards for certain classes of gears and transmissions** to discourage (and later prohibit) the use of inefficient solutions such as worm gears and V-belts.

Non-regulatory policy measures

6. Large-scale **awareness programmes** should be developed and put in place to inform industrial and commercial electricity users of the significant savings potentials possible through the use of efficient electric motor-driven systems. These programmes should target those responsible for procurement of electric motors and motor-driven systems, including operations and maintenance managers, production and plant managers, and company executives and decision makers responsible for overall company policy on energy, carbon and cost reduction.
7. **Incentive schemes** should be developed and applied to encourage adoption and use of best practice motor sizing, management and integration, including the appropriate use of VFDs. These should be targeted at the systems producing the highest benefit, namely for pumps, fans and other applications with variable mechanical loads (where torque increases nearly as the square of the rotational speed of the motor). In most cases, cost-effective savings can also be achieved when VFDs are used for conveyors, hoists, escalators and similar applications (where torque is more or less independent of the motor speed). Incentive schemes are also likely to be beneficial for these applications.
8. **International capacity-building efforts** should be substantially expanded to create permanent support structures, at a scale sufficient to support ongoing needs in the domain of energy-efficient electric motor-driven systems.
9. **Global market monitoring** should be established at defined intervals, to support national regulation and incentive programmes with market-transformation data.

Putting ideas into practice

Realising these savings opportunities by 2030 will require a clear a plan of action and rapid implementation of an effective set of structural and consensus-building endeavours. It is proposed that IEA member countries establish a timetable for implementation of the nine policy recommendations. To aid that process, the authors have identified timelines for completion of the steps necessary to progress EMDS toward the identified energy-savings goals by 2030 (Table 2).

Table 2: Proposed timetable for implementation of recommendations

Recommendations	Phase 1 In 2011	Phase 2 2012-15	Phase 3 2016-20	Phase 4 2021-25	Phase 5 2026-30
Regulatory policy measures					
Implementation of MEPS for all major classes of electric motors.	COMMENCE	COMPLETED			
Regulatory measures for packaged integrated motor-driven energy end-uses.	COMMENCE	COMPLETED			
Development of international test procedures for other electric motor types.	COMMENCE	CONTINUE	COMPLETED		
Development of international test procedures for other electric motor system components.		COMMENCE	COMPLETED		
Regulatory measures for gears and transmissions.		COMMENCE	COMPLETED		
Non-regulatory policy measures					
Development of large-scale awareness programmes.		DEVELOP	ROLL-OUT	ROLL-OUT	ROLL-OUT
Development of incentive schemes.		DEVELOP	IMPLEMENT		
International capacity-building efforts and creation of a permanent support structure.	COMMENCE	COMPLETE	ROLL-OUT	ROLL-OUT	ROLL-OUT
Global market monitoring (to support national regulation and incentive programmes with market-transformational data).	COMMENCE	REPORT 2015	REPORT 2020	REPORT 2025	REPORT 2030

To support the underpinning recommendation regarding the adoption of mandatory minimum energy performance standards for electric motors, it is proposed that IEA member countries adopt a policy position as quickly as possible, with an IEA report on it before 2015. IEA member countries can then be positioned as lead actors in a push for globally co-ordinated action on motors, with supporting project work to engage with major motor-manufacturing countries (such as China, Brazil, India and others).

In addition, it is proposed that the IEA immediately undertake a comprehensive study, completed in 2011, to assist member countries in their efforts to implement these measures within the proposed timeframes. As binding policy decisions are taken by IEA member countries, this study should evolve into a regular update on implementation plans.

The IEA Secretariat should also work with the non-member economies that produce and export significant volumes of electric motors and electric motor-driven components to ensure that this co-ordinated plan will gain their support.