Energy Efficiency Series

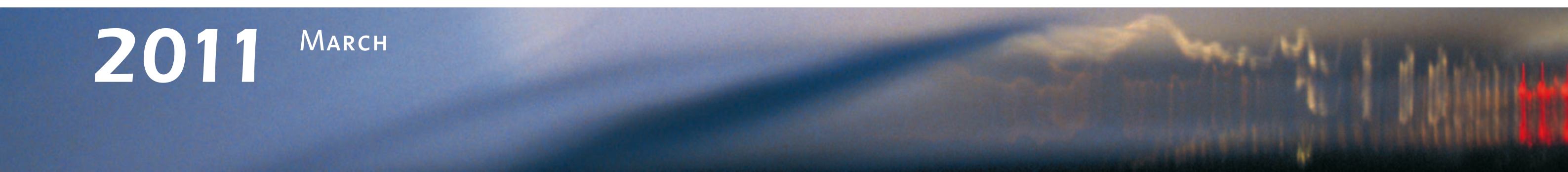
International Energy Agency

WALKING THE TORQUE

Proposed work plan for energy-efficiency policy opportunities for electric motor-driven systems

INFORMATION PAPER

Hugh Falkner and Shane Holt



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HUGH FALKNER AND SHANE HOLT

This information paper was prepared for the Energy Efficiency Working Party. It was drafted by IEA Energy Efficiency and Environment Division (EED). This paper reflects the views of the International Energy Agency (IEA) Secretariat, but does not necessarily reflect those of individual IEA member countries. For further information, please contact the Energy Efficiency and Environment Division at: eed@iea.org

2011 MARCH

INTERNATIONAL ENERGY AGENCY

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- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
- Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
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Executive Summary

Electric motor-driven systems (EMDS) consume the largest amount of electricity of any end use – more than 40% of global electricity consumption. Motor energy costs typically account for over 95% of a motor's life-cycle cost. Electric motors, driven devices and their components are also among the most highly traded goods on the planet. To capture energy-efficiency policy opportunities for EMDS, it is essential to develop an integrated policy response targeting the entire manufacturing and distribution system of efficient electric motors, together with a combination of regulation and companion support programmes.

This information paper aims to gain support from IEA member countries and other interested stakeholders for an ambitious work plan to deliver more energy-efficient electric motor-driven systems. Orchestrating a concerted global effort will save time, limit duplication and leverage available resources for all regions and countries involved.

Such a global proposal is now possible based on the findings of "Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems", a background paper commissioned by the IEA from Navigant Consulting (Europe) Ltd. (Waide *et al.*, 2011), which is the first global analysis of energy consumption in electric motor-driven systems. In addition a number of recent regional initiatives have proved to be successful models that other countries could adopt to accelerate their national schemes.

Past expert reports have promised major savings if EMDS could be transformed to adopt efficient solutions. This report also endorses the theoretical saving of 20% to 30% of electricity consumed by all EMDS if those systems were optimised, which would reduce total global electricity demand by about 10%. However, taking a more pragmatic view, the IEA suggests an ambitious but achievable target for the global work plan: improving the efficiency of electric motor-driven systems by 10% to 15%. If governments commit to the proposed work plan immediately and maintain resourcing levels, this could be achieved by 2030. Such savings are significant: avoiding the annual use of 1 400 TWh to 2 000 TWh by 2030. To put that improvement in context, it would be equivalent to reducing total global electricity use by around 5%.[1] Additional reductions in electricity demand will require national commitments to local education and on-ground support for motor-system best practice, both of which need to be undertaken within countries.

At the Clean Energy Ministerial (Washington, DC, July 2010), energy ministers from 24 countries launched 11 new initiatives to accelerate the global transition to clean energy. Within the super efficient equipment and appliance deployment initiative, electric motor-driven systems were identified as a priority. This work plan for EMDS could become a model for other initiatives to transform global markets toward improving the efficiency of widely used products and devices.

The overarching recommendation of this paper is to align regulatory settings within a globally applicable scheme. The IEA believes it is only through global co-operation leading to aligned national policy settings that countries can unlock the economies of scale that will result from using more energy-efficient EMDS. If inefficient motors are still being made and sold compliance problems will continue to undermine individual national actions.

This paper examines the current state of policies to encourage energy efficiency in electric motor-driven systems and promotes solutions that affect both individual components and motor

[1] The IEA modelling that underpins this report is subject to the speed with which countries implement the work plan and the major assumptions: that global regulations of Phase 1 priorities can be achieved by 2015; that countries currently without an efficiency programme legislate to commence a programme by 2015 and adopt the IEA recommendations; and that sufficient resources can be found to deliver the programme within countries and within the IEA.

systems as a whole. It also proposes a work plan that identifies and addresses all the elements necessary to maximise savings from this technology (Table 1).

Table 1: EMDS work plan summary

Phase	Project	Indicative timing	Proposed action
Highest priority	Variable speed drives Fans Pumps Induction motors	2011	IEA convenes a technical working group
Second-tier priority	Gears Hermetic compressors	2012	IEA convenes a technical working group
Third-tier priority	Air compressors Elevators Submersible pumps Other specialist pumps	Tender 2011/ Report 2012	IEA undertakes a preparatory study
Issues for the future	Appliance motors Maintenance Motor repair	Tender 2011/ Report 2012	IEA undertakes a preparatory study
Low priority	Large motors Specialist motors Sundry		

The proposed work plan encourages all countries to participate. Countries lagging behind the now widespread use of motor efficiency regulations will have an opportunity to catch up by adopting an internationally acceptable regulatory scheme. Using a set of transparent selection criteria, the work plan identifies the highest priorities for global co-operation projects. The work on pumps, fans and variable speed drives (VSD) leverages existing regional regulation as the mechanism for global alignment. The work plan also explains and prioritises other relevant end-uses in a manner that will make it possible for countries to choose to participate in projects of most interest or benefit to them.

The elements for a meaningful global debate on aligned standards for driven motor devices are relatively straightforward. It requires an agreed set of minimum energy performance standards (MEPS) distinguishing efficiencies in the marketplace and a standard test method to measure performance for each motor device type. The IEA has been the catalyst for aligning standards for other globally traded products, and it could do so for EMDS. The IEA already has working arrangements with bodies such as the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO). With the support of governments identifying electric motor components as a priority, the IEA and these bodies can deliver globally acceptable standards in more efficient manner.

This work plan is shaped to commence within 12 to 36 months, involving as many as 16 interrelated projects, as resourcing is found and made available. The IEA stands ready to manage this programme or, if countries prefer to manage particular projects themselves, to co-ordinate activities and evaluate progress.

By committing to such targeted and concerted actions, countries can accelerate market transformation and begin to realise the tremendous potential that EMDS offer for cost-effective energy savings.

This paper is based on the background paper that the IEA commissioned from Navigant Consulting (Europe) Ltd. (Waide *et al.*, 2011) as well as information published by national and international experts. The background paper made nine recommendations on energy performance policy, including regulatory and non-regulatory policy measures (Table 2). This work plan addresses only five recommendations – those that focus on regulatory policy action. Four non-regulatory measures recommended address the issues of incentives, awareness raising, capacity building and monitoring efforts. While the IEA acknowledges the importance of these recommendations, they are beyond the scope of this paper.

Table 2: Policy measures proposed in background report

Regulatory policy measures	Non-regulatory policy measures
Implementation of MEPS for all major classes of electric motors MEPS.	Development of large-scale awareness programmes.
Regulatory measures for packaged integrated motor driven energy end uses. Sundry	Development of incentive schemes.
Development of international test procedures for other electric motor types.	International capacity-building efforts and creation of a permanent support structure.
Development of international test procedures for other EMDS components.	Global market monitoring (to support national regulation and incentive programmes with market-transformational data).
Regulatory measures for gears and transmissions.	

1. Introduction

Background

This information paper is based on publicly available information published by international and national experts and on background work that the IEA commissioned from Navigant Consulting (Europe) Ltd. (Waide *et al.*, 2011). As the first global analysis on energy efficiency of electric motor-driven systems (EMDS), the background paper, explores:

- the type, design and use of electric motor-driven systems;
- EMDS energy consumption and associated greenhouse gas (GHG) emissions;
- the potential for technical improvement;
- the economic cost benefits of systems optimisation;
- standards and guidelines to measure performance of EMDS and facilitate adoption of good practice;
- causes of current poor practice;
- barriers to adoption of more efficient systems; and
- international policy experience in encouraging adoption of more efficient solutions.

Using modelling developed by a team of experts at Navigant and sub-contractors from around the world, the background paper estimates the savings. Overall, the 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%.

Context

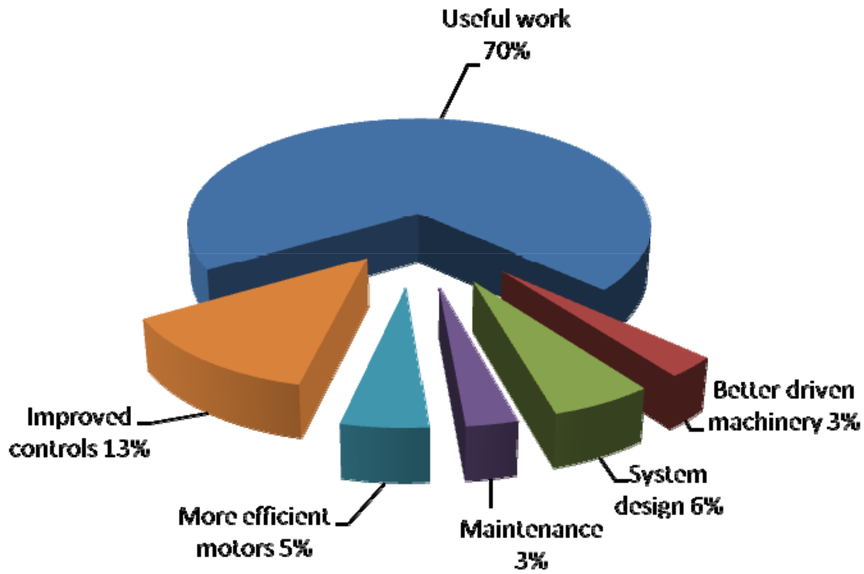
This report, prepared by the IEA with the support of Atkins Ltd., further refines these calculations to estimate the proportion of the potential savings that could be achieved in the near term through the practical policy action set out in the proposed work plan. It advocates undertaking the proposed work plan and adopting the resultant policies to overcome excessive energy use by EMDS. After outlining possible solutions for optimising policy settings in this field, the report offers a set of policy recommendations intended to promote debate on how to accelerate market transformation for EMDS, based on the findings of the opportunity and barrier analyses, and past experience in other technologies. More detailed analysis should be undertaken in this field, to map the detail of each of the projects within the work plan to the satisfaction of funding bodies.

Electric motor-driven systems are by far the most important type of end-use equipment that consumes electricity. Typically, electric motors are a component in a motor system, responsible for the conversion of electrical power into mechanical power. In turn, this mechanical power drives equipment such as fans, pumps or compressors.

Globally, EMDS consume at least 7 000 TWh/yr, roughly equivalent to 45% of all end-use electricity consumption. This is the largest end-user of electricity by any form of equipment and hence is a prime target for co-ordinated government policy on a global scale.

The background paper suggests that the potential to improve energy efficiency of motor systems is in the order of 20% to 30%. This estimate reflects the wasted energy in current systems which could be saved if technology and expertise were optimised (Figure 1 and Figure 2).

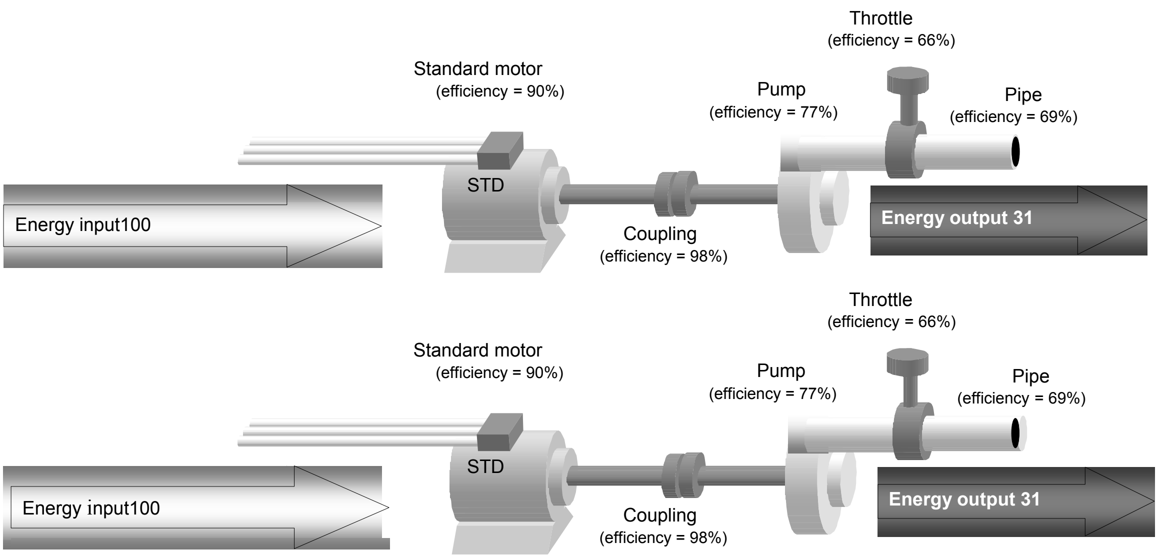
Figure 1: Potential for energy savings in EMDS



Source: IEA estimates.

If the all EMDS used the most energy-efficient technologies available, it would reduce total global electricity demand by about 10% – the objective targeted by this policy intervention. This estimate of potential savings, developed using North American and European experience drawn from the field of best practice motor system design, installation and use, is similar to past expert claims on the scale of the absolute efficiency potential (De Almeida et al., 2008).

Figure 2: Components of the motor system, showing the relevance of system optimisation



Source: De Almeida, A. *et al.*, 2001.

EMDS experts have long advocated for these interventions, but the need for site-specific support and concerns about public-sector funding for private-sector benefits have limited government action. Recent work in a number of countries now offers a foundation for improved international co-operation. The types of projects suggested by the IEA (for mainly regulatory policy measures) are also relatively cost-effective when compared to past EMDS programmes.

Purpose

To build on these developments, the IEA suggests that member countries plan for long-term and consistent policy intervention in this field, at least until 2020. North American best practice experience shows the need for consistent, stable support programmes to facilitate upgrades when EMDS lifetimes and funding permit. The IEA considers the state of international trade in EMDS components justifies aligned government action to intervene in what has become a global market. Savings of this magnitude cannot be delivered if government support is in available only in a few countries for only a few years. Global co-operation is crucial, no matter how much – or how little – funding is available in particular regions at any one time.

In its 25 energy-efficiency recommendations, the IEA recommends that member governments consider adopting minimum energy performance standards (MEPS) for internationally traded goods where market forces have not delivered optimum outcomes and it is cost effective to do so. Recommendation 6.2 specifically relates to electric motors (IEA (2008).

Box 1: IEA 25 energy-efficiency recommendations

Recommendation 6.2

a) Governments should consider adopting mandatory minimum energy performance standards for electric motors in line with international best practice.

b) Governments should examine barriers to the optimisation of energy efficiency in electric motor-driven systems and design and implement comprehensive policy portfolios aimed at overcoming such barriers.

This report outlines a range of actions governments could take to support implementation of this recommendation for improving the energy efficiency of electric motors and electric motor-driven systems.

2. Energy Usage in Electric Motor-driven Systems

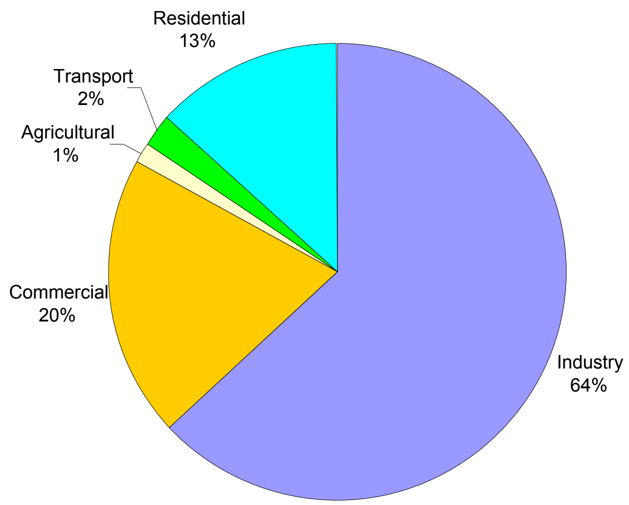
The background paper provides a detailed description of the methodology used to calculate a top-down estimate of global EMDS energy consumption. The authors used a base year of 2006, which has also been adopted in this report (unless otherwise indicated). As indicated earlier, total electricity use for all types of electric motor (industry, commercial and residential) is at least 7 000 TWh/yr or around 45% of all end-use electricity consumption.

Motor use by sector

The major applications for EMDS fall within the following sectors (Figure 3):

- **Industrial**: pumps, fans, compressed air delivery, conveyors, motive power for other machinery, etc.
- **Commercial building:** pumps, fans, conveyors, lifts, compressors in HVAC systems, etc.
- **Residential:** white goods (household appliances), air conditioners, IT fans/drives, cooking appliances, extractor fans, garden appliances, pool pumps – so many others, they are too numerous to list.

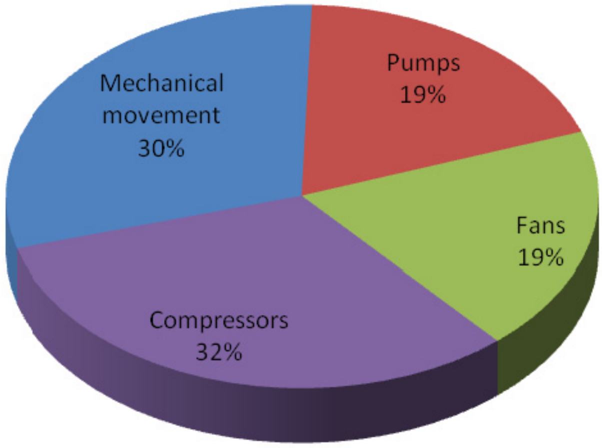
Figure 3: EMDS energy use by sector



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

It is also useful to view energy use by end-use application, showing clearly the main areas of driven devices (Figure 2). Table 3 provides examples to assist those unfamiliar with the tasks undertaken by EMDS in these end-uses.

Figure 4: Estimated share of global EMDS electricity demand by end-use application



Source: De Almeida *et al*. 2008; A+B International, 2009.

Table 3: Typical motor systems, by type of driven machine

Drive machine	Service delivered by motor system
Compressors	Air: pneumatics, blow moulding, aeration, material transportation.
	Refrigeration: commercial and domestic refrigeration/freezing, heat pumps. Other: gas liquefaction.
Mechanical movements	Stirrers, mixers, crushers, extruders, textiles, materials handling, lifts, escalators, machine tools.
Pumps	Water supply and treatment, hydraulic pumps, petrochemicals, food, boreholes. Circulators: in cooling, heating, cooling tower or chilling systems.
Fans	Ventilation, drying, boiler/industrial furnace combustion, equipment cooling.

Motor system energy use by country

Analysis shows that all types of motor electricity demand combined account, on average, for 45% of total global electricity demand. Among the individual countries considered the national average of EMDS demand ranges from 31% to 54% of total electricity demand. Table 4 provides a breakdown of 55 countries in order of the most power consumed by EMDS and of EMDS electricity use by sector within those countries.

Table 4: Electricity end-use by country and estimated demand for all EMDS by sector

	Country	Total electricity demand	Electricity demand for all kinds of EMDS by sector (TWh/yr)						
		TWh/yr	Industry	Commercial	Agricultural	Transport	Residential	Total motors	% total demand
1	United States	3 722	632	498	0	4	297	1 431	38.4%
2	European Union	2 813	787	282	13	44	177	1 303	46.3%
3	China	2 317	1 092	50	24	13	72	1 251	54.0%
4	Japan	981	221	138	0	11	62	432	44.1%
5	Russia	681	244	43	4	52	25	367	53.9%
6	Canada	499	141	51	2	3	33	229	45.9%
7	India	506	157	15	24	6	24	226	44.7%
8	Korea, South	371	131	46	1	2	12	191	51.4%
9	Brazil	375	126	34	4	1	19	184	49.0%
10	South Africa	198	78	11	1	3	8	102	51.4%
11	Australia	210	65	19	0	2	14	99	47.3%
12	Mexico	199	77	8	2	1	11	98	49.4%
13	Taiwan	207	70	11	1	1	9	92	44.4%
14	Ukraine	130	47	8	1	6	6	68	52.3%
15	Turkey	141	46	14	1	0	8	68	48.4%
16	Thailand	128	41	16	0	0	6	62	48.8%
17	Iran	151	36	10	4	0	11	62	41.1%
18	Norway	108	34	8	0	1	7	51	47.3%
19	Indonesia	113	30	10	0	0	10	49	43.8%
20	Argentina	99	33	9	0	0	6	48	48.6%
21	Saudi Arabia	143	9	16	1	0	19	44	31.0%
22	Venezuela	81	28	7	0	0	5	40	49.7%
23	Pakistan	73	15	4	2	0	7	28	38.2%
24	Switzerland	58	13	6	0	2	4	26	44.3%
25	Vietnam	49	16	2	0	0	5	22	45.9%
26	Israel	46	8	6	1	0	3	18	38.6%
27	New Zealand	38	10	3	0	0	3	17	43.2%
28	Bangladesh	22	6	1	0	0	2	9	42.8%
29	Costa Rica	8	1	1	0	0	1	3	38.1%
	Total (55 countries)	**14 465**	**4 193**	**1 324**	**89**	**153**	**862**	**6621**	**45.8%**
	Share of motor electricity	100%	29%	9%	1%	1%	6%	46%	
	Rest of world	1 195	295	88	12	6	86	487	
	World	**15 660**	**4 488**	**1 412**	**101**	**159**	**948**	**7 108**	**45.4%**
	55 countries share of world	92%	93%	94%	88%	96%	91%	93%	
	Sector share of total		68.9%	38.3%	25.0%	60.0%	22.0%		

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

The background paper reports on the considerable efforts to calibrate these estimates with specific published work already in the field. Based on the bottom-up modelling, several observations can be made about the differences and similarities found:

- Average motor size in terms of capacity varies considerably between countries (by more than a factor of three).
- Typical efficiencies in the marketplace vary by >3 %, suggesting scope for relatively easy efficiency gains through minimum energy performance standards (MEPS). Although >3% may not sound very significant, it may represent a reduction of >25% in the losses.
- Annual operation times are, to a certain extent, quite similar between countries, mostly between 2 500 and 3 000 hours. Average load factors and, hence, full load hours are also similar.

The IEA Secretariat notes that differing types of data collection and varying assumptions used in generating data make it hard to directly verify this data. It is included for indicative comparative purposes. The Operating Agent for the electric motors project within the IEA Efficient Electrical End-use Equipment Implementing Agreement published the following global estimate in 2009:

Table 6: Estimated electricity demand for EMDS, by type of electric motor

Motor type	Output size P_m (kW)				Operation		Number running stock	Life time	Sales	Motor efficiency		Power P_e	Electricity demand	
	Min	Max	Median	Total GWm	h/a	Load factor	Million	Years	Million per year	Nominal	Mean	Total GWe	TWh/a	Fraction
Small	0.001	0.75	0.16	316	1 500	40%	2 000	6.7	300	40%	30%	422	632	9.1%
Medium	0.75	375	9.5	2 182	3 000	60%	230	7.7	30	86%	84%	1 559	4 676	67.6%
Large	375	100 000	750	450	4 500	70%	0.6	15.0	0.04	90%	88%	358	1 611	23.3%
Total				**2 948**			**2 231**	**6.8**	**330**		**79%**	**2 338**	**6 919**	**100%**

Source: A+B International, 2009.

Table 5: Estimated motor electricity demand with particular factors from the bottom-up model for 13 countries with highest electricity consumption

	Base year sales	Sales (tsd. pieces)	Base year stock	Stock (million pieces)	Avg.pm (kW)[1]	Avg.pm (kW)[2]	National pm(GW)[1]	Efficiency (%)[2]	Annual op.time (h/a)[2]	Load factor[2]	Full load hours (h/a)	El. Cons. Bottom-up (TWh/a)
USA	2003	1532	2007	24.0	12.9	23.5	309	92.7%	3654	0.63	2302	758
EU25	2007	10395	2007	89.0	5.5	8.2	493	87.8%	2525	0.58	1478	824
China	2006	6152	2006	35.6	15.9	24.5	566	90.9%	2858	0.62	1764	1090
Japan	2008	1081	2008	16.4	8.8	14.5	144	89.5%	2769	0.60	1670	268
Russia[3]	2007	1282	2008	12.5	10.3		128	85.0%	2698	0.60	1619	244
Canada	ca. 2004	147	ca. 2004	2.6	12.9		33	91.4%	2402	0.60	1441	53
India	2003	1244	2003	12.2	4.3	5.8	53	85.5%	2863	0.57	1634	102
S. Korea[3]	2005	384	2005	4.2	5.5		23	84.6%	2410	0.60	1446	64
Brazil	2002	936	2002	9.1	8.2	14.5	128	89.6%	3059	0.68	2068	169
Australia	2004	236	2004	2.6	12.9	26.9	34	92.3%	3787	0.63	2403	86
Mexico[7]	2005	198	2005	1.9	4.1	5.2	7.7	80.3%	2581	0.56	1443	15
Taiwan[3]	2008	1147	2008	6.9	5.5		38	84.6%	2740	0.60	1644	74
Total		24734		192.9	9.9		1648	89.8%	2899	0.61	1775	3747

Notes:

1. Weighted by sales
2. Weighted by use.
3. No differentiation by size classes available.
4. Standard value.
5. Lower value due to data from literature for China for industry.
6. Based on average sales data 2000-07.
7. Mexico, consumption is for 300 hp to 500 hp motors.

Source: TEP Energy, 2009.

Of the various estimates of total energy consumed by EMDS, this is the smallest estimate, just under 7 000 TWh. The IEA has decided to use this most conservative figure as the likely consumption estimate.

Analysis

In support of the proposed work plan, the IEA draws attention to four observations that can be drawn from this data:

Need to focus policy attention on EMDS in the industrial sector

Analysis of overall energy structure shows that the industrial sector dominates motor-related energy use, with almost a two-thirds share (64%). The commercial sector accounts for 20% and the residential sector for 13% (Figure 3). The transport and the agricultural sectors contribute only marginally to global motor electricity demand. This heavy concentration in the industrial sector is supported by previous work (Xenergy, 1998).[2] More recent work also examines the commercial sector, which is also growing quickly.

Concentration of energy use in a few countries

Motor-related electricity demand is largest in the United States, the European Union and China, which account for more than half of world demand. These countries together with Japan, Russia, Canada and India represent most of the worldwide motor electricity demand. This finding might encourage decision makers to include these countries in discussions about globally aligned EMDS policies. As the global market is driven by sales in these countries, policy setting in these areas is vital to the success of any global policy. The converse is also true: alignment of policies among countries other than these will not be likely to motivate global suppliers to change MEPS to meet requirements of countries that are smaller players in the global market.

Importance of motors to energy consumption in all countries

Motor energy demand across all sectors is important to the electricity consumption for all countries examined. Within any national improvement scheme, EMDS should be a focus of policy intervention for energy and environmental reasons.

Difficulty of targeting small motors

Identifying meaningful policy interventions that target the 2 billion small motors mostly used in the residential sector3 will be challenging, particularly as the amount of power is comparatively small (9%). The residential sector is responsible for a very large number of small electric motors in appliances (refrigerators/freezers, room air conditioners and washing machines), together with an additional share in building technology (for pumps and fans) and housing projects (central heating, ventilation and air-conditioning systems). These small motors are used infrequently, and have various very specific design requirements. That makes it difficult to influence them through regulation. Purchasers of these goods will, at most, consider energy labels for the entire product. Meaningful policy interventions could be directed to product designers, who have a direct interest in the performance of components such as motors, rather than introducing labelling or other measures aimed at customers.

[2] Although dated, this remains the most comprehensive study of its kind.

[3] This figure is based on the estimate of motors operating in this sector, as reported in Table 6.

3. Barriers to the Uptake of More Efficient EMDS

Policy makers continue to consider why efficiency potentials for electric motor-driven systems (EMDS) are not realised, even when they are economically cost-effective. There are numerous impediments to the adoption and rapid diffusion of efficient EMDS; however, several non-economic influences could also be addressed through energy policy. These barriers include aspects of international trade as well as various economic factors, such as adopting life-cycle cost perspectives, traditional investment decision processes (so-called split incentives) or high transaction costs for investors. Electricity prices still do not reflect full costs, given externalities from electricity generation and distribution. To illustrate these issues, some examples and case studies are presented below.

A large number of barriers have been identified that limit market awareness and acceptance of cost-effective solutions for EMDS. These include: lack of knowledge; short-term thinking over long-term investment and operation; excessively risk-averse production practices; higher initial costs for high efficiency options; confusion in individual national standards and labels; lack of performance visibility within main production performance benchmarks; international trade barriers; and the fact that intermediate parties such as original equipment manufacturers (OEM) consume a large proportion of new motors but find it difficult to recoup the cost of more efficient components. Many of these barriers are common to other energy-using products and, hence, are subject to similar policy analytical practice and policy solutions. Some features of how these barriers manifest themselves are unique to motors and motor systems.

As has been found for all end-use energy-efficiency policy debates, there is no simple solution that lowers all barriers and alleviates all obstacles and market imperfections to transform all motor systems markets. This is not to suggest that policy interventions will not work in this field, but rather that they need to have a holistic view of solutions, be designed to work in alignment with similar national markets and be maintained over time.

For example, within any given motor output power rating, there is currently a spread of several percentage points in efficiency between more efficient and less efficient motors. Despite being slightly more costly to purchase than standard motors, medium-size (induction) high efficiency motors (HEM) are almost always more cost-effective for end-users. This reflects the fact that motor energy costs typically account for over 95% of a motor's life-cycle cost. The internal rate of return from the use of a HEM compared to a standard motor is often over 100%, but customers still hesitate to purchase them. Tendency in unregulated markets is for purchasers to choose motors with a low first cost (low purchase price), which results in underinvestment in HEMs that would offer much lower operating costs. Related market barriers include:

- A lack of awareness among motor purchasers of the potential savings from using more efficient motors.
- Company organisational structures that manage equipment procurement separately from operation and maintenance, giving the purchasing officer little reason to look beyond the lowest purchase price as sole criterion for selection.
- Many motors are integrated into equipment produced by OEMs before being sold to the final end-user. As a result, motor efficiency information is both difficult to obtain and generally given little weight in the final purchase decision.

Countries comprising at least one-third of the world's population have adopted mandatory energy performance standards (MEPS) for industrial electric motors in the mid-size range. Many more countries are in the process of considering such MEPS, as is urged by the IEA.

Market analysis has found that the average energy efficiency of new motors in countries that apply such regulation is demonstrably higher than in countries without such requirements. Mandatory energy performance standards imposed by law (including the Top Runner intervention in Japan) have been shown to be practicable to implement and a cost-effective means of saving energy. The background paper estimates that if all countries were to use efficient EMDS immediately, global savings would range somewhere between 24 000 TWh and 42 000 TWh of electricity demand by 2030. Such a saving corresponds to abatement of 16 Gt to 29 Gt of CO_2 emissions.

4. Optimising Electric Motor-driven Systems

The importance of the system

Optimising complete electric motor-driven systems (EMDS) for greater energy efficiency should start at the final output of the system and work back through the driven devices to the motor. This is because optimising the motor may be a wasted effort if the system that it is driving has not yet been optimised.

Over time, as demands on the system change, overall system efficiency will also change, unless its performance is periodically reviewed. This can also cause an efficient system to degrade over time as the load profile changes.

When examining energy savings within EMDS, experts should ask the following questions:

- What is the system trying to do? Is it the best way to do the job?
- What are the settings? Are characteristics (*e.g.* pressure, flow, temperature) optimised for the demand?
- Does the system have controls to optimise the output and energy input under all conditions? Are they set correctly?
- For fluid movement systems (fans, pumps and compressors), is the pipework designed for minimum energy loss?
- Is the driven machinery (*e.g.* fans, pumps, compressors) sized and selected for best efficiency for the demand?
- Is the transmission (*e.g.* belt or gearbox) sized and selected for minimum energy loss?
- Is the motor selected and sized for best efficiency?
- Is the equipment switched off when it is not being used?
- Is the maintenance of the entire motor system adequate to ensure ongoing best efficiency? (This might include actions such as cleaning filters, fixing leaks, re-conditioning worn drive equipment and correct lubrication.)
- What are the future expansion plans and how can these be incorporated into the current and future design?

A mix of policies is needed to encourage the implementation of energy-efficiency options to address these questions, with specific focus on areas such as: best selection of components, better controls, education on system design, control and maintenance, and good practice for pumping, air movement and compressed air systems.

Best selection of components

Government programmes have understandably focussed on those items that the regulator can directly control, in particular improving the efficiency electric motors through MEPS. Although this is easier to address, it is only a small part of the problem and so only part of the solution. The medium-size induction motor accounts for the bulk of energy use; being homogeneous and internationally traded, it has been the target of government performance regulation for over 20 years in leading countries. While this has proved successful and cost-effective, the IEA considers that it is long overdue to shift the focus to other parts of the motor system that are technically more complex but still possible to regulate.

The European Commission recently (June 2010) passed the Energy-Using-Products Directive[4], which includes regulations on fans, and is expected to soon pass performance regulations on pumps (spring 2011). With regulatory levels and accompanying technical standards now in place for these products in one region, it would be a logical next step for other countries interested in global collaboration to consider aligning with the European arrangements. Other driven devices such as compressors, gearboxes, elevators and VSDs could also usefully be regulated. These potentially globally consistent regulations should use the experience in leading countries or regions as the base from which to leverage alignment.

The elements for a meaningful global debate on aligned standards for driven motor devices are relatively straightforward. It will require an agreed set of MEPS distinguishing efficiencies in the marketplace and a standard test method to measure performance for each motor device type. The IEA has been the catalyst for aligning standards for other globally traded products, and it could do so for EMDS. The IEA already has working arrangements with bodies such as the International Electrotechnical Commission (IEC) and the International Organization for Standardization (ISO). With the support of governments identifying electric motor components as a priority, the IEA and these bodies can deliver globally acceptable standards in a matter of a few years, not the decades of debate associated with regulating some past products.

For many motor systems, correct sizing of system machinery with load will be as important as selecting a product with a high headline efficiency. Regulations also need to be carefully designed to take proper account of part load-performance, which is where the average system operates. While this is a component issue, the regulator cannot mandate the correct sizing of equipment that is designed for specific end uses. In this case, advisory information is needed to maximise regulatory effectiveness.

Wider adoption and correct setting of controls, especially VSDs

Using more efficient components is only one aspect of optimising EMDS. Poor matching of system demand to the power absorbed by the system is another major cause of energy loss. In fact, relatively efficient components can be combined to create a highly inefficient system (Figure 2). Better matching of load with system can be achieved, for example, by having two or more machines that switch on/off in sequence to match the load; this approach can result in large energy savings. The variable speed drive (VSD), which alters the motor speed to finely adjust the system output in response to instantaneous demands, probably offers the largest energy-saving potential of any single measure in EMDS with variable loads. Though technically a mature product market, recent advances in power electronics mean prices for sophisticated controls keep decreasing, and developments such as microprocessor controls offer new ways to improve systems. Over the last 30 years, these features have moved from a costly, low-volume extra to a component that is now widely accepted and available from many reputable, multinational suppliers – albeit still at a marginally higher cost.

The use of HEMs and VSDs represents a necessary step toward optimal motor systems, but it is insufficient. To go beyond the improvements gained through HEMs and VSDs, motor systems should be optimised through the use a step-by-step systems-optimisation approach within the factory or building setting. These two technologies alone represent a policy intervention that will yield substantial system savings opportunities, more quickly than other measures. This is important because analysis of losses in other parts of the system can be more time-consuming

[4] Ecodesign Directive (2009/125/EC).

and difficult (involving specific sites considerations), and so a quick solution that semi-optimises a system is a more pragmatic target for both governments and motor system users.

The first stage of any global work plan should include alignment driving toward use of HEMs and co-ordination of globally acceptable standards for VSDs. Installing a VSD is such a cost-effective decision for systems with variable load applications that governments can contemplate mandatory regulation, secure in the knowledge that regulatory proposals will be approved in the long term and that almost all users will save money. Users still need to be shown how to correctly commission VSDs to achieve optimum savings. While it may not be possible to directly legislate use of VSDs in every country, ongoing educational campaigns should inform users of the behaviour changes needed to optimise energy saving and match the claims of equipment suppliers. In addition, governments could consider indirect regulation that can help support the uptake of VSDs:

- MEPS for products that include motors: products such as circulators can have MEPS set such that target levels can only be achieved cost effectively with the use of VSDs (*e.g.* EUP regulations on circulators for heating systems).
- System energy requirements: regulations for building energy performance might call up the use of VSDs, as a simple way to reduce consumption (possibly as a "deemed-to-comply" option making compliance easy).

A useful project in this regard might be to have the IEA map the various methods different governments have chosen to encourage VSDs and benchmark their effectiveness.

Improved design, control and maintenance of systems

Optimal design of the entire system and controls relies on educating all actors, from the system designer to the person authorising expenditure. This means that key people across the decision-making chain need to understand the technical issues and financial implications of their choices. Ongoing promotion of best practice outcomes is needed so that this is well understood. This type of work needs to be tailored to the factory or building in which the system operates. Obviously, this is best done locally to take account of local circumstances. The global work plan can still support these national measures by developing some common elements within the IEA global work proposals for subsequent implementation by individual countries.

Structured approaches to system optimisation, such as the *ISO50001 Management System for Energy* provide an excellent foundation. The IEA could work with member countries to encourage adoption of these standards around the world for EMDS.

All motor systems deteriorate over time; if not regularly maintained, they will become progressively less efficient due to greater leakage, increased pressure drops, mechanical misalignment, and wear of fluid machinery or drift of settings. Unplanned shutdown of a plant can have huge energy implications, in addition to commercial difficulties (*e.g.* energy lost in the affected product during failure and start up, energy lost in overhead energy consumption while there is no useful plant output, additional plant hours needed to make up the output). Specification and promotion of maintenance best practice represents a significant area for energy savings: while energy efficiency is optional, repairing a failed plant is mandatory and companies can see the value in investing in this task. Rather than persuading organisations to set up separate plant-wide energy-saving schemes, building energy efficiency into existing plant maintenance plans could be highly cost effective and make it much more likely to occur.

The IEA could undertake a review of the specialised electric motor information programmes, as well as the more ubiquitous structured approaches, to offer models for governments contemplating initiatives in this field.

Examples of good practice for systems

As in any market transformation, an important practical consideration is the desire by crucial stakeholders to work towards the common goal. A proactive approach and support from the major trade associations is an important factor in prioritising projects involving devices driven by electric motors. This section explores energy-saving opportunities and design best practice in different applications of motor energy use. EMDS will only deliver savings toward their potential if such an approach is undertaken.

Pumping systems

Against the backdrop of this industry-engagement criterion, the pumping industry in many regions around the world appears well placed to initiate meaningful efficiency advances for pumping systems.

For example, in 2005 Europump (the trade association of European pump manufacturers) launched the "ECOPUMP" initiative, which aims to achieve eco-efficiency of pump systems in several market segments and also to communicate this to both pump users and policy makers. Europump works extensively with national and European programmes/agencies that promote and implement energy-efficiency measures and energy management. This concept is now being examined in China as a key initiative within the EC Motor Challenge Programme. In addition, Europump devised and leads an industry voluntary labelling programme for circulators, and has committed considerable resources in support of the development of EUP pump regulations. It continues to develop novel concepts for standards that could be the basis of future pump systems regulation. In the United States, the Hydraulic Institute plays a similar role and has co-operated extensively with US government authorities on “Pump Systems Matter” and other campaigns.

Some individual countries have led the way in by focusing on the pump itself. Denmark (*Sparpumpen*), China and Korea already have schemes to promote the most efficient types of pump. These early initiatives have helped give the European Commission confidence in devising MEPS for many types of pumps, which were designed through a close working relationship with Europump. The test standard ISO9906:1996 provides a robust and now well-established technical requirement to support pump regulations.

The pro-active role of these bodies provides a sound basis for the IEA to propose a global co-operative project on pumping systems. Furthermore, IEA work on pumping systems would have the advantage of building not only on the new EUP pump regulatory scheme, but also the support of many national trade associations active in this area. This should translate to support from industry representatives to ISO committees to produce technical standards.

Opportunities for energy-saving standards could be found within the following areas:

- **Use:** minimising misuse and waste.
- **Specification:** appropriate head and flow for the demand.
- **Pipework:** diameter, smoothness, number and severity of bends.
- **System matching:** use of controls (such as VSDs) and parallel pumps to meet the instantaneous demand.
- **Selection:** optimum efficiency, trimming impeller as required.
- **Compatibility:** matching pump selection of the best motor(s).
- **Maintenance:** pump and pipe leakage.

The IEA could confirm the interest of industry in participating in a regulatory process for pumps, and could help with related tasks such as using their expertise in life-cycle costs analysis to develop appropriate assessments for pumping systems and successful applications in variable speed pumping.

Air movement systems

Fan systems also offer strong prospects for global co-operation, as several countries already have in place regulations for fans or fan systems. The most significant of these is the European EUP regulations for commercial building fans, to be introduced in two regulatory phases (2013 and 2015) for several types of fans: axial, mixed flow, cross flow, radial, and centrifugal forward- and backward-bladed fans.

These regulations could be based on three ISO standards: ISO12759 – Efficiency classification for fans, and use tolerances; ISO13348 – Industrial fans: Tolerances, methods of conversion and technical data presentation; and ISO5801 – Industrial fans: Performance testing using standardised airways (referenced for testing procedures).

Additional national schemes were studied in developing the EUP regulations including: Spareventilator (Sweden), a voluntary labelling scheme for some types of commercial fans; ENERGY STAR, a joint programme of the US Environmental Protection Agency and the US Department of Energy that comprises a labelling scheme for ventilation and ceiling fans for bathrooms and kitchens; the Air Movement and Control Association (AMCA), based in the United States that has a rating scheme for agricultural fans through wall fans; and an MEPS programme in China for certain types of fans (it is not clear how widely this is adhered to).

Global co-operation could extend to regulating minimum specific fan power-consumption figures for building ventilation, and many programmes already provide educational materials to promote energy saving in fan systems. These schemes offer a very helpful starting point to develop a set of global standards.

The design and energy consumption of air movement systems can be optimised by following a logical sequence of checks:

- **Use:** minimising misuse and waste.
- **Specification:** appropriate head and flow for the demand.
- **Ductwork:** area, shape, flow distribution, number and severity of bends.
- **System matching:** use of controls (such as VSDs) and parallel fans to meet the instantaneous demand.
- **Fan selection:** optimum efficiency.
- **Motor selection:** optimum efficiency.
- **Maintenance:** fan and filter cleaning.

Compressed air systems

Air compressors represent the largest motor application that has not yet been subject to a rigorous analysis of regulatory prospects. Although compressed air is universally recognised as offering significant potential energy savings, to date no regulations on energy efficiency are in place worldwide. Over the last decade, major manufacturers have put considerable emphasis on energy efficiency, and the IEA concludes that the trade associations should be receptive to collaborating in this field. While the possibilities appear great, the lack of an existing regulatory framework in even one country on which to build an international scheme suggests that this activity should be postponed in favour of working with devices for which globally-coordinated policies would be a more certain outcome.

This is not to suggest taking no action, but rather delaying when this task should commence. Both the US Compressed Air Challenge and the Swiss Federal Energy Office programmes represent leading best practice in programmes to promote energy savings in compressed air systems. The well established ISO1217 Displacement Compressor Acceptance Test Standard, developed primarily by CAGI/Pneurop (US/European manufacturers associations), provides a good basis for regulation, but considerable work is needed to devise a protocol for defining efficiency that takes account of factors such as heat recovery, part-load control, air quality and pressure.

Opportunities for energy savings are found within the following areas:

- **Use:** minimising misuse and waste.
- **Alternatives:** such as blowers or electric motor driven equipment.
- **Specifications**: appropriate pressure and flow for the applications and use of separate systems for different pressure applications.
- **Design:** use of multiple compressors, controls and better part-load control of individual compressors.
- **Pipework:** examining diameter, isolating unused sections.
- **System matching:** use of controls (such as VSDs) and parallel compressors to meet the instantaneous demand.
- **Compressor selection:** optimum efficiency and use of heat recovery (hot water or air), where possible, using cold inlet air.
- **Motor selection:** optimum efficiency.
- **Maintenance:** fixing leaks, compressor maintenance, and filters.

5. Driving Factors for EMDS Policy Development

The background paper postulates sweeping changes to EMDS policy settings and advocates further work to map those interventions. The IEA encourages governments to co-ordinate planning and set common goals to maximise the prospects that future policy interventions deliver the full scope of potential benefits.

The IEA proposes that countries consider the following seven factors when developing policies on EMDS:

Lower costs: There is significant potential to reduce costs if markets for electrical motors and other motor components were no longer segmented by individual national standards but aligned to global standards. For example, industry would reduce its costs if regulation forced the choice of more efficient solutions. This could drive the change needed to make investments in premium efficiency solutions profitable – something that is not yet possible in some countries.

Multiple policies: A portfolio of measures, clearly introduced and consistently maintained in the marketplace, will have more impact than any single measure (such as efficiency standards) in delivering the full efficiency potential.

Regulatory compliance testing: Recent work by the IEA on compliance with regulatory standards shows very uneven results. As little enforcement effort has to date been targeted at EMDS, it seems reasonable to expect non-compliance toward the higher end of estimations for regulated equipment types. The IEA suggests that scope exists to co-ordinate compliance verification across national markets, because these products are so highly traded between countries. This should mean lower enforcement costs for individual governments.

Stakeholder engagement: Trade associations of manufacturers, wholesalers and investors as well as local chambers of industry and commerce, must play an active role to remove barriers, improve knowledge and ultimately change daily routines. While governments may need to fund information programmes, these projects are best carried out by experts well-versed in working with diverse motor systems and their operators, and by actively engaging industry groups in support and promotion activities. This is an appropriate role for energy agencies and for government funding in order to overcome inertia, impediments and imperfect market knowledge.

Policies should be a mix of public and private actions: Purchasing decisions have to be based on both the short-term profitability considerations of private investors and on the total cost to society (given the benefits of reduced electricity demand through more efficient motors and motor systems). This premise offers a rational economic argument for public sector subsidies of information campaigns, professional training or other policies to promote diffusion of highly efficient electric motors and motor systems, and for regulatory policy intervention. Direct and indirect subsidies to electricity prices must be eliminated or reduced if the goal is to make users pay the full price for their consumption. This change will make investments more attractive.

Programme stability: A global plan for the next decade would deliver a more certain future for industry allowing them to make investment decisions in a more stable, predictable global market. If government-funded programmes are suddenly dropped or regulatory standards increased with insufficient warning to facilitate orderly market development or adaption, manufacturers, retailers and service companies will become frustrated and incur unreasonable expense.

Promoting indirect (non-energy) benefits: Promotion of voluntary measures should be accompanied by efforts to raise awareness of the non-energy benefits, many of which will be attractive to the audience. For example, more efficient systems lead to greater productivity, quality or reliability for owners of energy-efficient motor systems, which also have financial benefits.

Decision makers should consider these factors when assessing their own policies and in reviewing the proposals in this paper. All governments will find that global co-operation will assist them to implement their policies more quickly, more effectively and using fewer resources than undertaking these tasks in isolation. Some governments may implement policies and programmes later than they might have done if acting unilaterally. Any such delays would be offset, to some extent, because there would less risk that early adopted national programmes might unravel if they were out of step with the final global programme.

6. Rationale for a Globally Co-ordinated Policy Framework

The IEA considers that a globally coordinated policy system should be the foundation for any policy scheme for electric motor-driven systems (EMDS). The case for policy makers to engage in market transformation is very strong in all economies examined.[5]

For countries just beginning to develop policies in this field and for countries that lag world best practice in mandating MEPS for motors, it makes sense to focus on creating or improving the policy framework/regulatory scheme for three-phase induction motors (the major energy user). It is most logical to align national schemes with a global scheme.

For other countries that are already committed to regulatory programmes for motors that reflect best regulatory practice, the IEA considers that it is time to shift the focus to other product components and to system design. Since product regulation is both time consuming and costly, the IEA proposes that the order of global attention be ranked according to these criteria:

- Energy consumption of the product.
- Volume and similarity of the product.
- Costs and benefits of the measure.
- Technical energy-saving potential.
- Economic energy-saving potential.
- Existence of technical standards upon which to assess product performance.
- Existence of test protocols for defining and measuring product efficiency.
- Possible support and engagement of stakeholders, especially manufacturers and their associations.

The following matrix (Figure 5) gives a qualitative view by the IEA Secretariat of the weighting of various factors to establish priorities for different projects within the global EMDS market.

As noted earlier, some governments may realise some short-term time savings by using a simple national approach to regulate motors and driven devices. But in the long run, they will be forced to reassess and repeat the analysis when they subsequently seek to participate in the globally inclusive scheme. The global framework must ensure regulation takes account of all products sold in the global market (not just those sold in early-adopting national markets) in order to facilitate any governments joining the global scheme at a later date. If early-adopting nations do not incorporate that goal, there is a risk that unique national schemes will proliferate, ultimately generating negative trade consequences and adding to everyone's costs.

[5] If it were of interest to individual countries, the IEA could assist them to identify the size of electric motor use and hence the size of savings through regulation. Upon request, the IEA could also articulate the case for regulatory intervention within those countries.

Figure 5: Factors influencing the priority of different EMDS projects

	Pumps	Fans	Gears	Hermetic compressors	Variable speed drives	Air compressors	Elevators	Submersible pump motors	Other pumps	Motors embedded in household appliances	Very large motors	Special motors	Other fans	Motor repairs
Total device energy consumption	3	3	1	3	1	3	1	2	3	3	3	3	2	2
Units sold and homogeneity	2	2	1	3	3	2	2	3	2	2	1	1	2	2
Cost benefit of measures	2	2	?	?	2	2	2	2	2	1	?	?	?	2
Technical energy saving potential (stock)	3	3	2	?	2	2	1	2	3	3	1	1	2	3
Existence of technical standards	3	3	3	?	1	2	2	2	2	1	3	2	2	3
Prior engagement of stakeholders	3	2	?	?	2	1	1	2	3	1	3	1	2	3

Note: Priority is ranked on a scale of 1 to 3 with 3 for the highest, 2 for the mid-level and 1 for the lowest priority. Categories with a question mark (?) could be determined after dialogue with participating countries.

7. Proposed Work Plan

Recognising the significant opportunities offered by this very large end-use of electrical energy, the IEA encourages a joint effort to map a comprehensive work plan covering the entire field of electric motor-driven systems (EMDS). Such a plan would explain to suppliers and users the reasons for priority decisions and give certainty to corporate boards making research and development (R&D) investment decisions. This section outlines a proposed package of projects, ranked by priority categories to facilitate staging and scheduling work.

The proposal outlines a role for the IEA Secretariat in managing the overall package of work. Given the number of projects, the links between them and the capacity for various projects to develop beyond their original tasks, co-ordination of the projects is a crucial task. The IEA considers that an overarching management committee structure is necessary to ensure effective co-ordination between the various technical and policy groups, avoid overlap and duplication, and ensure that project, financial and reporting responsibilities are well managed. However, it is clear that the proposed work plan cannot be delivered by a single group of experts comprising one management committee. The breadth of the work, the need to recruit country champions to communicate outcomes and the duration of many of these multi-year projects make the proposed work plan a very significant undertaking.

The IEA Secretariat has broken down the EMDS work plan into five priority phases, each comprising a number of linked projects. While individual countries may wish to choose those projects for which they will provide in-kind or financial support, the proposed work plan covers the field and must be undertaken in full to maximise the benefits. The work plan is analogous to the motor system it is trying to improve. If too much effort is focused on only a few of the elements, the systemic benefits of the work plan will not be optimised. If too many funders focus on only a few projects, the entire work plan will fail to reach a critical mass that achieves the projected efficiencies.

The complete work plan is presented in five groupings to assist in scheduling work and matching available resources and priorities. The first four phases show the division of priority among tasks. The last grouping records projects that the IEA Secretariat feels do not need further consideration until at least after the first review of the entire programme (some two to three years after the programme commences, when more information may be available to review these initial classifications).

Phase 1: Highest priority

The first stage involves projects of the highest priority for EMDS, and is proposed for immediate commissioning:

1. Variable speed drives: VSDs can offer major energy savings in the system, but they have varying efficiencies, particularly at part load and no load, and so could be the target of regulation based on existing regulatory schemes. In addition to their inherent design features, there is considerable scope for encouraging users to optimise the benefits of VSDs through more attention to control systems and settings.

Support is needed to help users to adopt the forthcoming VSD test standard[6], and to ensure the new standard is successfully applied to help users identify which VSDs are most efficient. Canada

[6] IEC 60034-2-3

recently published some new research that sheds light on this poorly understood subject (Angers and Friesland, 2007). The project should await the final draft of IEC 60034-2-3 on the specific test methods for converter-fed AC motors standard (a first version is expected in 2011). This will at last provide a foundation on which to base regulations for performance standards. Test labs and manufacturers will need to install and learn how to use the equipment required testing VSDs to this standard. An international round robin test would be useful for facilitating this, and would help to promote use of and confidence in this standard.

IEA proposal: The IEA could convene a technical working group in 2011 to assess the wider adoption of a globally aligned VSD regulation. The working group would consider an expert team paper mapping possible pathways for implementation, building on regional efforts to date.

1. a) Protocol for assessing the energy efficiency of VSDs: Based on the new IEC 60034-2-3 standard, the IEA could assist in devising a protocol for using the detailed test data from this testing to provide a single energy-efficiency value. This value could then be used as the basis for actions to promote more efficient VSDs. A working party would be needed to undertake this work and to devise other detailed technical points needed to form accurate and fair regulations.

IEA proposal: The IEA could convene a technical working group to look at the issue in 2011.

2. Fans: Denmark (Sparventilator) and China already have energy-efficiency schemes for promoting the most efficient types of fans. AMCA (based in the United States and now also very active in the Pacific Rim and Europe) is the leading organisation for testing of fans, and has produced excellent practical guides on testing. New European regulations for certain classes of fans provide a technical basis for other countries to follow. This project would use the methodology in the new ISO12759 Fan efficiency standards document. The fans included are:

- axial fans
- centrifugal forward-curved fans and centrifugal radial-bladed fans
- centrifugal backward-curved fans with and without housing
- mixed-flow and cross-flow fans

These products are manufactured and traded internationally, so almost all suppliers will be affected by the European regulations. It is likely that industry will support a globally aligned system in preference to a proliferation of national standards of varying stringency and test conditions.

IEA Proposal: The IEA could convene a technical working group in 2011 to look at the wider adoption of globally aligned fan regulation. The working group would consider an expert team paper mapping possible pathways for implementation, building on regional efforts to date.

3. Pumps: New European regulations for certain classes of clean cold water pumps, based on this earlier work, now provide a firm technical basis for other countries to follow. The technical basis for these regulations derives from comprehensive analysis undertaken by a Europump working group. The pumps included are:

- single stage close-coupled (end suction close coupled) pumps
- in-line ESCC pumps
- single-stage water (end suction own bearing) pumps
- submersible multistage pumps (4” and 6”)
- vertical multi-stage water pumps
- circulators (primarily for central heating systems)

These products are manufactured and traded internationally, and so most multi-national suppliers will be affected by these European regulations.

IEA Proposal: The IEA could convene a technical working group to look at the wider adoption of a globally aligned pump regulation in 2011. The working group would consider an expert team paper mapping possible pathways for implementation, building on the regional efforts to date.

4. Induction motors: As discussed in Annex A, there is considerable activity in the introduction of mandatory MEPS for induction motors. However, some countries lag far behind, and technology developments mean that the economic conditions for improved stringency continue to shift. Ongoing and broader international collaboration remains important to fully realise the economic energy-saving potential of induction motors. The IEA considers this a priority area because of the large number of major economies that could create a regulatory scheme, or possibly increase the stringency level in cost-effective ways.

IEA proposal: The IEA could convene a technical and regulatory group in 2011 that would build on existing European Maritime Safety Agency (EMSA) and International Electrotechnical Commission (IEC) working groups to pursue the introduction of MEPS globally at the highest feasible levels.

Phase 2: Second-tier priority

The next phase includes two projects that are very important but do not have the same level of industry commitment or well-established regulation upon which to build regulatory consensus. It makes sense to slightly delay commencing these projects while concentrating on the highest priorities which already have industry support (or are easier to generate global stakeholder interest).

5. Gears: Gears are needed for high speed (e.g. air compressor) or high torque (e.g. winch) duties that ungeared motors cannot produce. These have varying efficiencies, which should be more widely considered at the time of purchase. Labelling and possibly MEPS would be appropriate. A scoping study on efficient gears is needed to inform policy makers of the technical energy savings possible from the use of higher efficiency gearboxes. This would include the features required of gears in different applications, typical efficiencies for different types of gears, a breakdown of the total number sold per year, and the savings from improved lubricant practice. There is a growing trend to design direct-drive gearless systems, due to the availability of motors with improved torque and speed characteristics that offer multiple benefits.

IEA Proposal: The IEA could convene a technical working group in 2012 to look at the wider adoption of a globally aligned gear regulation. The working group would consider an expert team paper mapping possible pathways for implementation, building on regional efforts to date.

6. Hermetic compressors for domestic and light commercial equipment: Many types of smaller heating/cooling equipment (such as refrigeration and heat pumps) are regulated at the complete product level. However, regulations targeting the compressor alone could accelerate progress towards improving compressor efficiency. Most use an induction motor, with any losses having a double energy impact through the heating of the working fluid. An Australian research team has committed to exploring this issue in some depth, and further alignment could await publication of that report.

IEA Proposal: The IEA could convene a technical working group in 2012 to look at the wider adoption of a globally aligned compressor regulation. The working group would consider an expert team paper mapping possible pathways for implementation, building on regional efforts to date.

Phase 3: Third-tier priority

The third phase includes projects that are more in the vein of preparatory work, and proposes commissioning experts to scope the work involved for later development by interested nations and experts from stakeholder groups.

7. Air compressors: Air compressors represent the largest proportion of motive power use not currently subject to widespread efficiency regulations. Measures to encourage the selection of better types of compressors (such as labelling or regulation) would be a useful addition to the regulatory programme, as considerable savings are possible through better control of individual and multiple compressors.

8. Elevators: Elevators are a special class of motor system with considerable variation in energy consumption, for which labelling would be attractive. The European Commission's Intelligent Energy Europe Programme report, *E4 Energy-Efficient Elevators and Escalators* (March 2010), has shown significant variation in performance of elevators – a ratio of more than 10 to 1. The report, led by Portugal, suggested that a labelling scheme is possible, based on the existing German Standard VDI 4707. Such a scheme would follow from regulations on motor efficiency, and possibly be incorporated into the forthcoming IEC VSD standard. The IEA could establish a Working Group to establish regulation for elevators once the IEC VSD standard is at near final draft.

9. Submersible pump motors: The pumps used in submersible pumps are already included in the EUP pump regulations. However, the induction motors used in submersible pumps are unique to this application, and so fall outside existing induction motor regulations. A Working Group would consider whether to regulate the motor alone or whether to regulate the complete motor and pump product. This could be followed by a market survey to explore a reasonable regulatory levels based on market practice. Many of these pumps are used in remote areas; improved efficiency would reduce demand for electricity on exposed parts of the network.

10. Other pumps: Other pumps outside the new EU regulations could also be regulated, such as those for chemical or wastewater pumps. Such pumps have special requirements that make it impossible to apply the standards used for clean water pumps. However, this is a large group of pumps, with some manufacturers interested in progressing efficiency standards. Some manufacturers have already expressed an interest in regulations for these pumps in order to help boost sales of more recent and efficient types. The working group would identify technical issues with efficiency classification of these pumps and devise appropriate efficiency levels for regulation.

IEA proposal: The IEA would project manage commissioning of experts to undertake preparatory studies to devise the technical basis for possible regulation for air compressors, elevators, submersible and other non-regulated pumps. These reports could be tendered in 2011 for further consideration by country delegates in 2012. With proposals suggesting the projects can move forward, working groups would be established in 2012 or 2013 as priorities and resources permit.

Phase 4: Issues for the future

This phase includes other preparatory projects that are of lower priority when assessed using the IEA-proposed criteria. They represent projects that could be commissioned as resources allow.

11. Embedded motors: Electric motors are often integrated into household appliances, consumer goods and office equipment. These small motors typically have low operating hours and are treated as components in systems that already have test standards, energy-efficiency classes and labelling schemes that apply at the whole system level. Scope exists to undertake a preparatory study on motors embedded in household appliances. This is a diverse range of products that warrants a major study to understand key factors including: the applications they are used in; the existence of energy-efficiency standards that might apply to the products they are integrated into; features required in each application; sales; typical duties; technical basis for regulation; potential for energy saving and the cost-benefit ratio of possible regulations.

12. Maintenance management: Promotion of best practice in maintenance management will keep EMDS in optimum condition and reduce the energy cost of unplanned downtime due to motor failure. Maintenance practices used by motor system personnel include: shaft alignment, motor current signature analysis, vibration analysis, lubricant analysis and thermography. Effective maintenance management is essential for cost-effective operation of facilities. Finding ways to integrate energy-efficiency best practice with maintenance programmes can be a good way to embed energy efficiency in the culture of an organisation.

13. Motor repair: Motors are on average repaired 2 to 3 times through their lifetime; poor repair can lead to a decrease in efficiency of up to 2% (a significant figure when applied to motor efficiency). The promotion of best practice repair to minimise these losses is important for maintaining motor efficiency over its life. The Electrical Apparatus Service Association (EASA) in the United States and the Association of Electrical and Mechanical Trades (AEMT) in the United Kingdom have published comprehensive guides on this subject that could form the basis for globally applicable information materials.

IEA proposal: The IEA would project manage the commissioning of experts to undertake preparatory studies to devise programmes for household appliance motors, system maintenance and repair. These reports, which could be tendered in 2011 or 2012, may generate ideas for consideration by national governments.

Phase 5: Low priority

Some stakeholders may want all possible features of EMDS reviewed to ensure all opportunities are pursued. Projects in this field are noted, but the IEA Secretariat does not recommend ranking them as priorities; they are recorded to demonstrate that they have been assessed. Other projects or future developments could also be included in this category while initial priority assessments are made. These other projects may still need to be investigated if particular stakeholders seek their inclusion, but the IEA Secretariat suggests that proponents of these projects agree to fund the work (to obtain information or conduct the analysis) from their own resources rather than proposing them as projects from common funding.

14. Larger motors: Larger motors (> 375 kW) generally run in mid-voltage and high voltage; they are manufactured on demand in relatively low quantities, according to specific requirements of industrial users. These motors are used in a range of applications, and will often have custom features specified by the user. This diversity means that it may be difficult to devise regulations fair to all different applications. While this group of motors consume a large share of total energy, they are already highly efficient, and customers are already aware of the importance of energy efficiency. The potential for further savings is thought to be small. The new IEC 60034-30 standard extends only to 375 kW, so it would need to be consulted about extending the standards to larger sizes. To verify the energy-saving potential for these motors, a study is suggested to characterise the different types and features of this market.

15. Specialist motors: These electric motors are used for specialist tasks in vehicles (trains, trams, cable cars, motor cars and aeroplanes). They serve either as main traction systems (electric trains, trams, trolley buses, etc.) or as auxiliary motors within fuel systems (cars, trucks, buses, diesel trains, aeroplanes) to operate all kinds of devices (windshield wipers, window motors, servo motors for brakes and steering, air conditioning, etc.). Smaller motors (< 0.75 kW) are often single phase and (although manufactured in millions) usually tailor-made for a specific purpose and integrated into a packaged machine. There are currently no definitive standards for testing or sizing, making efficiency classifications of such motors difficult. Many of these motors have low running hours, but in some applications (such as pumps and fans) they can have long hours of operation.

This is a highly diverse category of motors, with a tremendous variation of size, application, types, duties and savings potential. As a grouping of types of motors that do not fit into the other categories described, the priority would be to do a swift analysis to sift out those types that it would be inappropriate to seek to regulate. A summary of the benefits of regulating the remaining products could then be used as the basis for deciding on further work in this area. However, as with the large and small motors category, it is thought that the potential for savings will be modest.

16. Miscellaneous: It may be necessary to conduct a set of studies to scope out the remaining elements in EMDS to respond to stakeholder enquiries or complaints as to why other motors and driven devices are not considered feasible to regulate. This grouping would include other general types of motors and fans outside the EUP regulations. The report could explore if there are industrial applications in which such motors may be subject to high temperatures, entrained particulates or corrosive gases – and assess whether it would still be feasible to regulate. Following on from EUP regulations on ventilation fans, fans for less benign applications might also be regulated. However, it would be wise to allow the impact of the EUP regulations to be understood before tackling the more complex matter of regulating fans used in the diverse range of aggressive environments.

The three projects in this category complete the proposed work plan. The IEA does not propose any action in 2011 for projects in this phase and suggests the parties agree to conduct investigations only if stakeholder groups make a strong case for undertaking these tasks before the results of projects in the other categories are available.

8. Conclusion

This paper seeks to gain support from IEA member countries and other interested stakeholders for an ambitious work plan for global action to deliver more energy-efficient electric motor-driven systems and transform the market for EMDS. A concerted global effort will save time, limit duplication and leverage available resources for all regions and countries involved.

Electric motor-driven systems consume more than 40% of global electricity; using efficient motor systems to optimise load could save 20% to 30% of this consumption. The ambitious work plan proposed by the IEA is projected to deliver at least half of this potential saving by 2030 if commenced immediately and sustained over the coming decade. Expressed differently, successful implementation of the IEA work plan would reduce total global electricity used in 2030 by around 5% from levels it would otherwise reach. Few other initiatives offer this measurable saving in that timeframe.

Table 7: EMDS work plan summary

Phase	Project	Indicative timing	Proposed action
Highest priority	Variable speed drives Fans Pumps Induction motors	2011	IEA convenes a technical working group
Second-tier priority	Gears Hermetic compressors	2012	IEA convenes a technical working group
Third-tier priority	Air compressors Elevators Submersible pumps Other specialist pumps	Tender 2011/ Report 2012	IEA undertakes a preparatory study
Issues for the future	Appliance motors Maintenance Motor repair	Tender 2011/ Report 2012	IEA undertakes a preparatory study
Low priority	Large motors Specialist motors Sundry		

The IEA seeks expressions of interest from member countries in collaborating on this work plan. With that interest, the IEA Secretariat could prepare precise proposals scoping implementation issues such as management arrangements, funding requirements and evaluating progress of the work plan. By committing to such targeted and concerted actions, countries can accelerate market transformation and begin to realise the tremendous potential that EMDS offer for cost-effective energy savings.

Annex A: Regulation of Electric Motors

This short history of regulation of electric motors (as distinct from motor systems) demonstrates how uncoordinated country and regional endeavours can lead to long delays and confusion. Electric motors are not a new technology and have been the subject of detailed consideration by nations and standards bodies around the world. Not surprisingly, this spawned a number of different national approaches to improve efficiency.

The international standard-setting body, the International Electrotechnical Commission (IEC), only recently completed the task of aligning on a single scale the existing national or regional efficiency classifications. The timescales adopted by individual nations make a compelling case for global co-operation to accelerate similar regulations and co-ordinated action to accelerate that change.

In 2010, there are four standardised efficiency classes (which still vary slightly in their adoption in some countries). IEC 60034-30, introduced in 2008, defined an open-ended international efficiency classification scheme, using a simple progression mark of IE1 (lowest regulated efficiency) through to IE3 (most efficient motors available at the time) and IE4 (to be defined later when further information is available from North American sources). Table 8 shows the previously existing regional classification schemes in comparison against the new globally applicable scheme.

Table 8: Motor efficiency classes in different countries and the corresponding international standard

Motor efficiency class	International	United States	European Union (old system 19981)	European Union (new system 2009)	China	Australia
Premium	IE3	NEMA Premium	–	IE3	–	–
High	IE2	EPAct	Eff1	IE2	Grade 1 (under consideration)	AU2006 MEPS
Standard	IE1	–	Eff2	IE1	Grade 2	AU2002 MEPS
Below standard	IE0 (used only in this paper)	–	Eff3	–	Grade 3 (current minimum)	–

Abbreviations: EPAct = US Energy Policy Act, 1992; MEPS = minimum energy performance standard; NEMA = US National Electrical Manufacturers Association.

Note: 1. With the backing of the European Commission, manufacturers representing 80% of the European production of standard motors agreed to establish three efficiency bands or classes designated EFF1, EFF2, and EFF3 (with EFF1 being the highest band).

Source: Waide *et al.*, 2011.

Experience shows that when a higher efficiency product is introduced into one region or market, it takes time to diffuse into other national markets. This rate of diffusion depends on market circumstance, which for electric motors is a mix of many factors: the capacity of national versus global motor producers; the additional price or premium attached to efficiency; local electricity cost; tax investment opportunities and financial incentives; and regulatory settings. This basic economic fundamental is demonstrated by the very different national market results delivered around the world through national regulation.

Aggressive motor regulatory policy and the common market for the United States and Canada have led to the world's best regulatory practice in North America. These governments set global motor energy-efficiency performance levels that are eventually considered by other governments for their future regulation. The United States required IE2 by law in 2001 and IE3 as of December 2010. Many other countries are following that regulatory lead, but regulations elsewhere have been less stringent. That outcome may be because those countries needed to take into account available supply, local industries' capacity to pay and other national considerations. Given the ubiquitous nature of EMDS around the world, it is likely that the difference in regulatory approach is also because information about North American developments has not been made available to key decision makers at the right time. While the global scheme has the capacity to allow for variation for good economic or environmental reasons, it is not always easy to determine what reasoning is driving another country's regulatory decisions.

As early as 2002, China defined a regulatory standard for electric motors at levels appropriate to that country. It subsequently decided to increase the stringency from IE1 to IE2 equivalent, commencing from 2011. Similarly, Brazil, Korea, Mexico and Taiwan originally also imposed regulation at IE1 but are moving or have moved to IE 2 levels. Australia and New Zealand have IEC 2 regulations in place but have yet to announce the timing of any proposed move to IEC 3 in line with their stated policy goal of "matching world best regulatory policy".

In 2009, the European Union passed efficiency legislation for electric motors for the first time, as an implementing measure under the Eco-design Directive. Between 2015 and 2017, these regulations will require the use of either an IE3 motor, or an IE2 combined with a variable speed drive. Some large motor-using economies (such as Russia and India) have not yet adopted regulations for electric motors, although they are understood to be under consideration.

This snapshot of current positions shows the diversity of policies – as well as the complexity this creates for global suppliers. If member economies and other stakeholders partner in the IEA electric motor initiative, the global policies should not lag behind the North American leadership to such an extent in the future.

Figure 6: Electric motor efficiency classes, testing standards and regulation over time

Efficiency levels	Efficiency classes	Testing standard	Performance standard
	IEC 60034-30	IEC 60034-2-1	Mandatory MEPS
Premium Efficiency	IE3	Low Uncertainty	USA 2010 Europe 2015/17
High Efficiency	IE2		USA 2001 Canada 1997 Australia 2006 Korea 2008 Brazil 2009 Europe 2011 Switzerland 2011 China 2009
Standard Efficiency	IE1	Medium Uncertainty	China Taiwan 2003 Switzerland 2010

Source: A+B International 2009 (updated by the IEA).

The background paper cites with approval an expert assessment of the time lag in the electric motor field. This analysis was done using 2009 as the base or reference year. It showed the time lag then for electric motor efficiency of other economies compared to the most advanced countries (Canada and the United States). This analysis also suggests that policy intervention can accelerate once such comparisons become known. Later in 2009 when the European Union passed its Eco-Design Directive, its performance was rated more highly; still it trails the United States and Canada in both timing and, for some applications, stringency.

Table 9: Lag of countries or groups of countries in diffusion of energy-efficiency classes

Country or group of countries	Lag compared to the reference t=0
Canada and the United States	+2 to 0 years
Mexico	-2 years
Australia and New Zealand	-3 to -4 years
China and South Korea	-5 to -6 years
Taiwan and Brazil	-7 to -8 years
European Union	-8 to -10 years
Other countries with no MEPS or VA	-12 to -15 years

Source: A+B International 2009 (updated by the IEA).

Annex B: Why a Policy Focus on Medium-sized Electric Motors

An electric motor is a device that converts electrical energy into mechanical energy. Motors range from a few watts up to many hundreds of kilowatts in terms of power output, though almost all policy debates have focussed on mass produced (medium-sized) motors which consume the most power and offer the greatest saving opportunity.

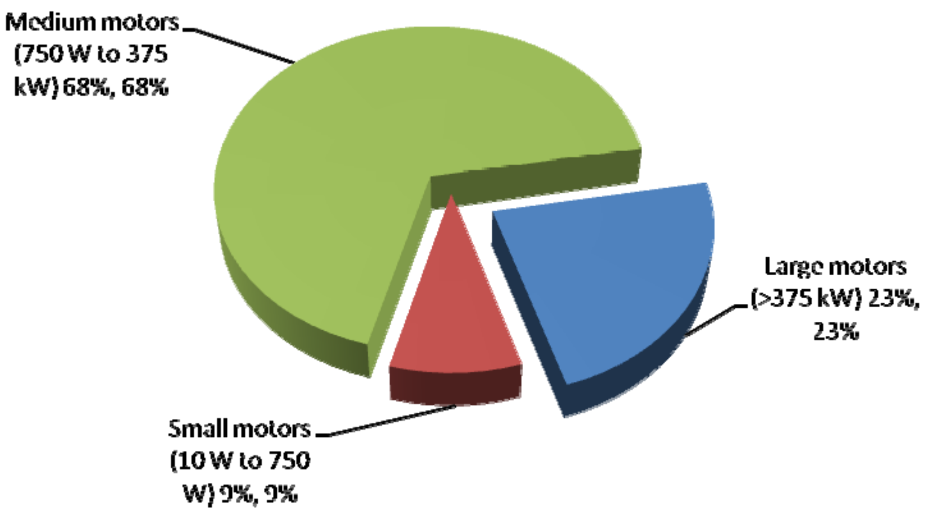
The large amount of energy used by medium-sized electric motor systems explains the proposed policy focus.

Small motors with a power rating of 10 W to 750 W account for about 90% of all electric motors, but these motors use only about 9% of the total electricity consumed by electric motors. They are used in small appliances, to drive pumps and fans. These motors are often single-phase and are induction, shaded-pole, or shunt-wound motor types, which are typically custom made in large series to be integrated into specific machines or appliances. They often operate at, or at less than, mains voltage.

In contrast, **medium motors** in the power range 0.75 W to 375 kW account for 68% of the electricity used by electric motors. For the most part, these are asynchronous AC induction motors of 2, 4, 6 or 8 poles, but some special motors (such as direct current, permanent magnet, switched reluctance, stepper and servo motors) are poly-phase motors operating at voltages of 200 V to 1 000 V. They are manufactured in large series, usually with short delivery lead times and according to standard specifications that can be ordered from catalogues. These motors account for about 10% of all motors sold and are used with pumps, fans, compressors and conveyors, primarily for industrial handling and processing applications.

Large motors, defined as electric motors with a rated power of from 375kW up to 100MW, are poly-phase, high voltage motors operating in the 1kV to 20kV range. They are custom designed; some are of the synchronous type and are generally assembled on site and used in industrial and infrastructural applications. They account for only about 0.03% of the stock of all electric motors, but account for about 23% of the electricity used by electric motors. Figure 7 sets out the main types of motors as a function of their power and associated characteristics.

Figure 7: Electric motor definitions, global stock and estimates of electricity consumption



The recent EU study parameters also explain the policy focus on medium-sized motors. Under the Eco-design Directive for energy-using products, electric motors in the output power range of 1 kW to 150 kW were targeted. These boundaries closely correspond to the lower bound of 0.75 kW and an upper bound of 200 kW, also in IEC 60034-30 (the efficiency classification standard on motor efficiency). Almost all motors in this power range are of low voltage; however, medium voltage motors are typically used in very high power applications of above 500 kW. These are sold in very small numbers, are of non-standard design and are not included in any targeted energy-efficiency policies.

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