Global Motor Systems Network: The International Energy Agency 4E EMSA Project[1]

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Abstract

Electric motor systems are used in industry, infrastructure and large buildings for pumps, fans, compressors for air and cooling, material handling & processing in industry, infrastructure and building systems. All kinds of electric motors use 45% of the global electricity demand. While motor manufactures sell new Premium Efficiency products and governments regulate Minimum Energy Performance Standards MEPS, the industrial community continues to use outdated and to purchase inefficient equipment. Least life cycle cost is rarely used for deciding on renewing existing and on optimizing new industry systems systematically.

A new Electric Motor Systems Annex EMSA has been launched by the end of 2008. EMSA is part of an IEA Implementing Agreement under the Efficient Electrical End-Use Equipment 4E program currently supported by 10 countries. Within EMSA the build-up of a Global Motor Systems Network in over 50 countries with some 1000 active participants is under way. Its goal is to speed up market transformation and focus on energy efficiency both in the participating countries and in the rest of the world. By sharing information on best available and cost effective technology and best practice in policy implementation the necessary market change can be made faster and more focused. EMSA uses international experience from pilot projects with advanced technology and proven policy programs including voluntary and mandatory instruments, financial incentives, training and capacity building in Energy Services Companies ESCOs.

EMSA contributes to the Global Motor Systems Network in building a system of qualified testing laboratories, continuously monitoring of motor systems sales by efficiency classes, helping regulation on national MEPS and securing enforcement through the provision of technical and policy guides for new motor system technology.

1. Background

1.1. Electric motor applications

The designation “electric motor” covers the products like motors in pumps, fans and compressors with the largest global electricity consumption. All kinds and sizes of electric motors are converting about 45% of the global electricity demand into mechanical power to move people and materials in gaseous, liquid and solid form (Figure 1). Their energy efficiency potential is the key to lowering demand and reducing carbon emissions because their conversion efficiency is only between 40% and 90%, the rest is heat (Figure 3).

The installed base of electric motors in industrial sizes (between 0.75 kW and 375 kW) has been first estimated in 2007[1]/[2] and recently been updated[3] to be 264 million, the annual sales 34 million pieces. Electric motor systems for industrial are estimated to use in this mid size (correct physical term would be “convert”) in the year 2009 about 5.1 PWh/a and have an installed total electrical load of 2.9 GWe. They are thus responsible for annual CO_2 emissions of 3.5 Giga tons. The energy savings potential of electric motor systems in a static 10 year replacement and improvement scenario compared with business as usual can reach 22%.

[1] International Energy Agency: Implementing Agreement on Efficient Electrical End-Use Equipment 4E, Electric Motor Systems Annex EMSA (www.motorsystems.org)

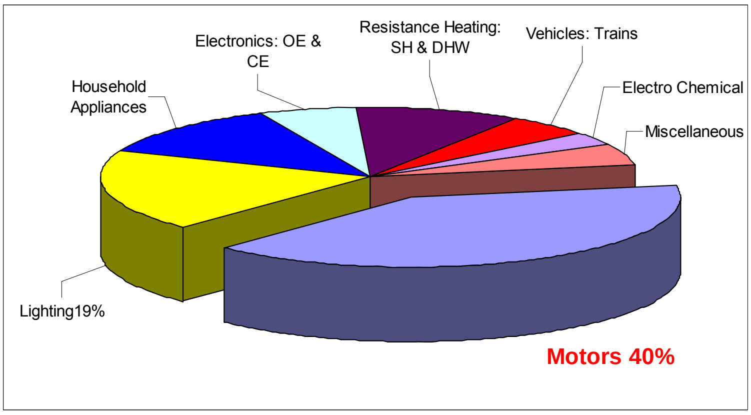

Figure 1 Global electricity demand
(Source: A+B International 2008)

The reaping of this huge energy savings potential has already gained attention for two decades in many international and national programs and projects, recent examples:

International activities:

- UNIDO training programs on motor systems pilot projects in China www.unido.org/index.php?id=o8947
- EC with *MotorChallenge* programs and ESCOs in Europe www.motor-challenge.eu/
- IEC with global standards on testing and classification www.iec.ch/online_news/etech/arch_2008/etech_0308/technology_1.htm
- ISO with energy management standards for entire industries www.iso.org/iso/hot_topics/hot_topics_energy/energy_management_system_standard.htm
- International Copper Institute with comprehensive means of t electronic raining and publications www.leonardo-energy.org/energy-efficient-motor-systems
- SEEEM Standards for Energy Efficient Electric Motor Systems, Zurich Switzerland www.seeem.org

National activities:

- DOE with EERE *MotorMaster+* programs in the USA www1.eere.energy.gov/industry/bestpractices/pdfs/motormaster.pdf
- EERE *Best Practices* www.eere.energy.gov/
- CEE with *Motor Decisions* Matter www.motorsmatter.org
- USA Federal Rebate Proposal 2009 www.nema.org/media/pr/20090331c.cfm
- Australia with MEPS and check testing www.environment.gov.au/settlements/energyefficiency/motors/index.html
- Canada with Assessement Guide http://oee.nrcan.gc.ca/cipec/ieep/newscentre/motor_system/motor_pub_Eng.pdf

- China with a new motor efficiency label (see Figure 2) www.energyrating.gov.au/pubs/2009-motors-session1-xin.pdf

- The UK with a comprehensive Market transformation programme www.mtprog.com

- Austria with a nation motor systems implementation program http://energytech.at/(de)/iea/results.html?id=5263&menulevel1=8&menulevel2=4

- Switzerland with a regular newsletter and an efficient motor systems implementation program www.topmotors.ch

- et cetera.

Figure 2 China Energylabel on electric motors, based on GB 18613 2006
(Source: Zhang Xin CNIS 2008)

Obvious conclusions so far are, that market transformation in industry and the commercial sector together with public infrastructure and large buildings, needs a complex approach with a combination of voluntary information & training, financial incentives and mandatory legal action. Since more than a decade it has been understood that there are two reasons for this:

- Energy efficiency progress can only be made with motor systems, which means a more complex approach to how electricity is eventually converted into mechanical power.

- Industry does not invest according to least life cycle cost because of manifold barriers that hinder a rational decision and an investment in cost effective solutions.

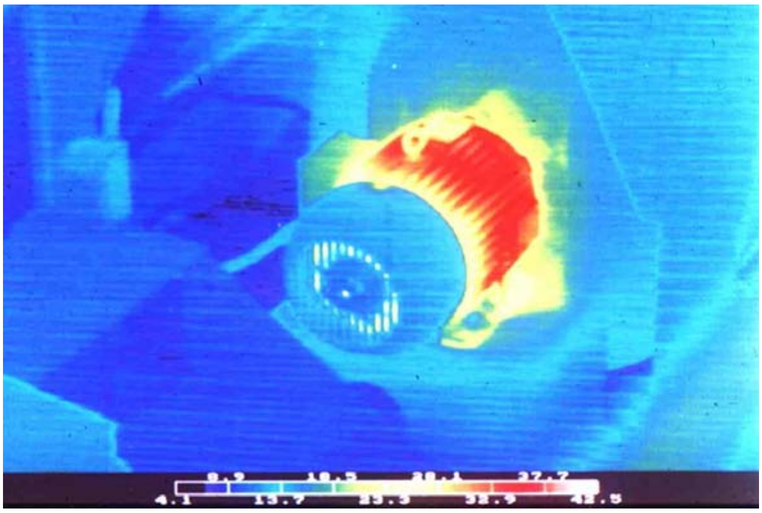

Figure 3 Infrared picture of running electric motor
(Source: Future Energy Solutions, 2009)

1.2. Electric motor systems energy use

The beauty about electric motors in the scale of 1 to 1000 kW - versus combustion engines running on gas, diesel or kerosene in cars, motor bikes, trucks, trains, ships and planes - is that they have a fairly good conversion factor between electricity input and mechanical output in the shaft in the form of rotational torque and speed. Where as combustion engines in vehicles try to reach every day efficiency from between 20% and 30% with gasoline or 30% to 40% with diesel, electric motors work under day to day reality conditions both in vehicles and stationary applications somewhere between 40% and 90%. The higher number is for larger motors (100 kW and up) running near nominal load, the lower number is for oversized machines running in partial load and also for smaller machines (below 10 kW). Of course, the production of electricity from primary energy sources like fossile and nuclear fuels is also depending on an efficiency of only 30% to 40%.

The motor system includes the electric motor with both its electric (VFD, transformators, power factor correction) and mechanical components (gears, brakes, clutches, transmissions, etc.). This core motor system is efficient when the product of all efficiencies is high, or in other words any component can have a negative effect on the entire performance.

1.3. Motor systems efficiency technology

The key to market transformation towards energy efficiency in electric motor systems is system integration, correct sizing in respect to full and partial load conditions and using optimalized energy efficient components.

In existing situations the major impact comes from downsizing and applying high efficiency motors as well as - especially in cube power applications with changing loads - variable frequency inverters.

The benefit of one single (expensive) component with very high efficiency can be overcompensated by another (cheap) component with a very low efficiency. The economic path to least life cycle cost is thus system integration with a careful study of all possible interaction in typical operation conditions. This is a complex matter and it is one reason for late development of an industry energy efficiency culture.

2. Market transformation

2.1. Motivation for change

The dominant reasons for market transformation in industrial equipment and domestic appliances have changed over time. The three major motives of owners in industrial and commercial plants have not changed:

- Economic advantages
- Environmental consciousness
- Safety and stability of operation

Direct intervention with government regulations for safety, avoiding hazardous working conditions, energy efficiency as well as lower emissions and pollutions have also influenced industry investment decisions. The motivation of national governments, NGOs and international organizations can somehow differ as it generally places mid and long term economical stability and ecological advantages (reduced energy consumption and CO_2 and pollutant emissions) higher than short term economical benefits for the industry. The mutual understanding is growing that economical benefits can help both sides and improve the overall economy and ecology without permanent government subsidies. The current global financial downturn has inspired some actors in government and industry to acknowledge that the time has come for progressive green investment.

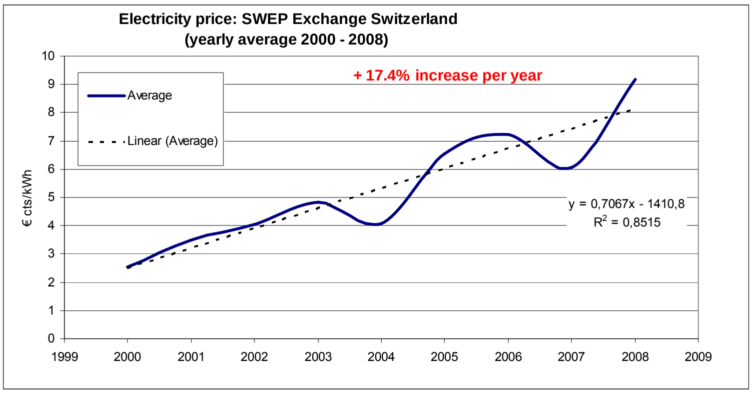

Figure 4 Electricity prices in Switzerland:
17.4% annual increase of average whole sale exchange price
(Source: SWEP 2009)[4]

Economic advantages

Today with volatile energy and constantly rising electricity prizes (Figure 4) the economic aspect has been the key element in cost conscious industry investment practices. An electric motor is fairly cheap to buy and rather expensive to run: It usually exceeds its original purchase prize after the first 30 days of continuous operation.

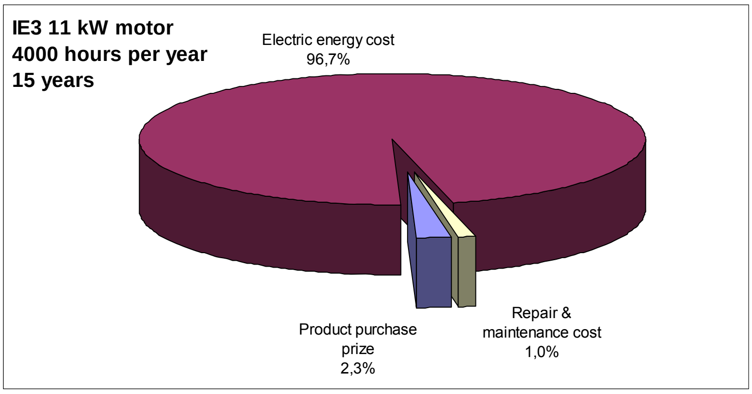

Figure 5 **Life cycle cost of 11 kW motor**
(Data Source: EuP Lot 11 2008)

Industrial electric motors stand out from other appliances by an unusual high percentage of energy cost in their life cycle (Figures 5 and 6). Over 90% of their life cycle cost (purchase, service, energy) is electric energy. This number has been confirmed by several technical studies for the implementation of Ecodesign Directive in Europe[5].

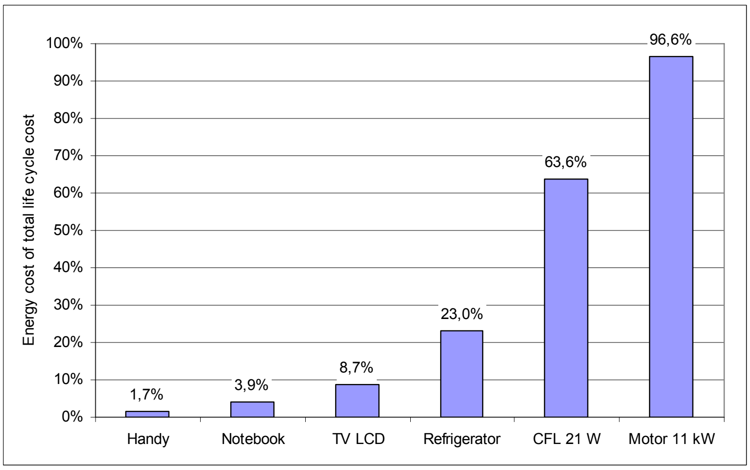

Figure 6 **Relative share of energy in life cycle cost**
(Source: A+B International 2008)

Environmental consciousness

Besides economical also environmental concerns have risen on the ladder of key points for industrial decision makers. With all global and many large industries publishing annual reports with balance sheets including environmental performance the awareness of the general public and the financial advisors have shifted towards sustainability in operation. Thus many investment rules in industry and the commercial sector had to be adapted from a mere financial "one year pay" back rule to include both a more life cycle cost and energy & environment oriented decision making concept. Furthermore the introduction of CO_2 with a price (European Trading System, Joint Implementation and Clean Development Mechanism)[6] has introduced a very real economic reason to go for long term investments in energy efficiency where the mitigation of CO_2 emission pays for a part of the additional initial investment. The internationally harmonized classification and uniform labelling of energy performance of industrial equipment - like electric motors - has become an important issue in order to identify quickly efficient products in the market.

Safety and stability of operation

The safety and the stability of production and plant operation has been the key reason of non intervention so far. General inertia to let a running production system run and not change it is elementary industry wisdom. After lengthy installation and adjustment procedures usually the nominal operation and performance is greeted with great relief so as to have no further motif for changing and improving the smoothly operating installation. The fear of disruption of production is the key to a no change attitude. Only lately the better performance record of energy efficient products has been shown: Premium efficiency motors tend to run cooler and smoother which accounts for less wear and longer operation between failures. Also the introduction of adjustable speed drives that let machines start and stop more smoothly and operate at the necessary load only and not waste time in full speed with throttled down flow. The Preventive Maintenance Scheme developed in the UK[7] has given ample notice to understand that

2.2. Motor efficiency barriers

If all engineers would be trained in systems design integration and least life cycle cost as a goal the problem of inefficient industrial equipment should be solved by now. The *paradox* is that cost effective measures are not taken because of several non-economical and non-technical barriers as elaborated in detail in Table 1:

Economic barriers as market failures	Imperfect information
	Adverse selection
	Principal agent relationships
	Split incentives
Economic barriers as market barriers	Hidden costs
	Access to capital
	Risk
	Heterogenity
Behavioural barrier	Form of information
	Credibility and trust
	Values
	Inertia
	Bounded rationality
Organizational barriers	Power
	Culture

Table 1 Systematic list of barrier types
(Source: Patrik Thollander)[8]

Technical barriers include 50/60 Hz grids and SI/Imperial measuring systems as well as non harmonized testing standards and efficiency classification. Newly harmonized standards for energy efficiency testing (IEC 60034-2-1:2007)[9] and efficiency classes (IEC 60034-30:2008)[10] have contributed to lowering barriers in global trade for energy efficient motor systems. Table 2 and Figure 7 show the present motor efficiency classification.

Motor Efficiency Classes	New	Old		
	IEC	CEMEP	USA	China
Super Premium Efficiency	IE4			
Premium Efficiency	**IE3**		NEMA Premium	
High Efficiency	**IE2**	Eff 1	EPAct	Class 1
Standard Efficiency	**IE1**	Eff 2		Class 2
Below Standard Efficiency	**-**	Eff 3		Class 3

Table 2 Harmonized international motor efficiency classification

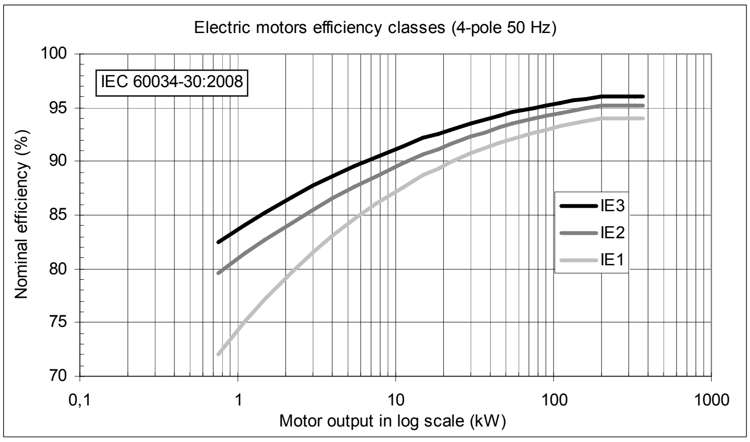

Figure 7 Motor efficiency classes
(Source: IEC 60034-30:2008)

2.3. Motor systems efficiency activities

In order to get these technical and operational measure into place at factory level a series of concrete activities are necessary.

- Training of plant operation personnel and new plant and machinery design engineers with life cycle cost and systems optimalization. The provision of easy tools and databases with cost and performance data is necessary for rapid cost benefit analysis and informed investment decisions. Also the stimulation of activities of industry-qualified ESCOs to work on the task at their own financial incentive.
- Design and manufacturing of quality products with fewer losses in VFD and motors, in gears and transmissions. This means adaptation in a lot of SME who have problems in upgrading their design, manufacturing, testing and quality control. And also training courses for manufacturers, OEMs and wholesalers in LCC in order to make them capable of selling the right product to their client.
- International standards for testing, efficiency classes and labels to facilitate global trade and competition of energy efficient components and systems.

- Data base with best practice technology for comparable and typical applications and successful policy experiences.
- Subsidies for compliance above present legal levels, using future technology and helping with this the mass production and thus lowering of any additional cost for special efficiency features.
- National mandatory minimum energy performance standards to avoid cheap imports and cheap low quality products flooding the market.
- Accredited motor and systems testing laboratories that can both check compliance and also help industry to improve design. The international collaboration of testing facilities in Round Robin in order to improve testing quality.
- Restraint on repair and rewinding activities to avoid the cheaper used motor being a large loop-hole in a MEPS scheme.

2.4. Motor systems efficiency instruments

In market transformation there are voluntary, mandatory and financial instruments available to push the mentioned activities into the market transformation program. EMSA will try to rally government for mandatory and voluntary measures and the market stake holders also for financial incentives.

The key mandatory instrument is Minimum Energy Performance Standards (MEPS). The SEEEM project (2006 - 2008)[11] has made the harmonization of standards and the increase of the number of countries with MEPS one of its major goals. Meanwhile 10 countries representing almost 50% of global motor electricity demand have adopted MEPS for motors at IE1 or IE2 level (see Table 3). Until 2011 we see 39 countries (including EU27) representing over 70% of global electricity demand for motors joining in MEPS at IE2 and IE3 (USA) level (see Figures 8 and 10). The goal by 2015 will be to reach countries representing more than 80% of global electricity demand for motors with MEPS eventually at IE3 level.

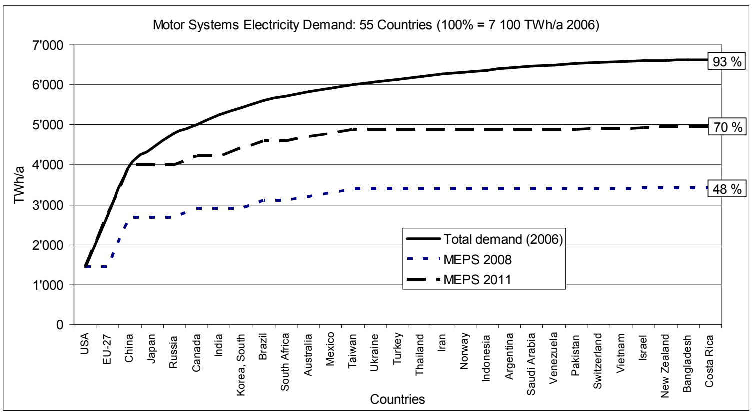

Figure 8 Global electricity demand for motors of the 55 largest economies
(Source: Electricity demand: IEA 2006, calculation: A+ B international 2009)

The experience with MEPS for motors will have to be evaluated. Only Australia and the USA so far have a track record of implementation and enforcement using verification and sanctions for non compliance. The success of fast market change is compelling (see Figure 9) with over 65% at mandatory IE2 level (EPAct) only three years after enforcement plus another 10% at voluntary higher IE3 (NEMA Premium). It will have to be studied to use MEPS for other components (like VFD, gears) and applications (pumps, fans) as well to transform markets mote rapidly.

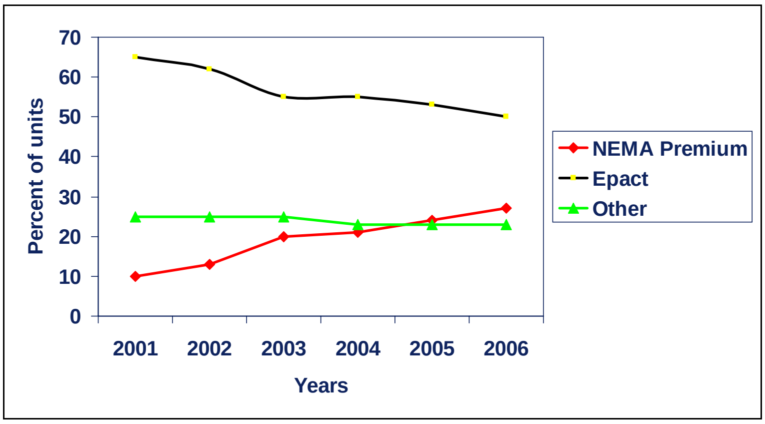

Figure 9 USA market change development after MEPS at EPAct level IE2
(Source: Rob Boteler, Motor Summit 2008)

Economy	Minimum Standard	Labeling	National Test Standard	Reference Test Standard
Australia	Ym(1)		AS 1359.102.1-1997 AS 1359.101-1997 AS/NZS 1359.102.3:2000	IEC 61972:2002
Brazil	Ym(1)	Ym(1) Yv(1)	RESP/004 NBR 5383/1:1999 (ABNT 1999)	
Canada	Ym(1)		CAN/CSA-C 390-98	CAN/CSA C390 CSA C 390-93
Chile	U(1)	U(1)	NCh 3086: 2008	
Chinese Taipei	Ym(1)		CNS 14400	
Costa Rica	Ym(1)	Ym(1)		
EU Member Countries	Yv(1)			IEC 61972 IEC 60034-9
India	Yv(1)	Yv(1)	IS 12615 IS 4029 IS 325	
Israel	Ym(1)		SI 5289	
Malaysia	Yv(1)	U(1)		
Mexico	Ym(1)	Yv(1)	NOM-016-ENER-2002	
New Zealand	Ym(1)	Yv(1)	AS 1359.101 AS 1359.102.1 AS/NZS 1359.102.3	
Nicaragua		U(1)		
People's Republic of China	Ym(1)	Ym(1) Yv(1)	GB/T 1032-1985 GB 755-2000	
Republic of Korea	Ym(1)	Yv(1)	KS C 4202-97 KSC 4203 KSC 4201 KS C IEC 61972	
Thailand	U(1)	Yv(1)	TIS 867-2532	
USA	Ym(1)		10 CFR Part 431 Subpart B App B	ANSI/IEEE 112-1984 (Method B)
Viet Nam	U(1)		TCVN 2280-78	

Table 3 Overview of voluntary and mandatory standards on electric 3-phase motors
(Source: CLASP, April 2009)[12]

Efficiency Levels	Efficiency Classes IEC 60034-30 Global 2008	Testing Standard IEC 60034-2-1 incl. stray load losses 2007	Performance Standard Mandatory MEPS Policy Goal
Premium Efficiency	IE3	Low Uncertainty	USA 2011 Europe* 2015 (≥7.5 kW), 2017
High Efficiency	IE2		**USA** **Canada** **Mexico** **Australia** **New Zealand** **Korea** **Brazil** China 2011 Switzerland 2011 Europe 2011
Standard Efficiency	IE1	Medium Uncertainty	**China** **Brazil** **Costa Rica** **Israel** **Taiwan** Switzerland 2010
Below Standard			

bold means in effect
*) IE3 or IE2+VSD

Figure 10 Global development of electric motor standards 2009
(Source: A+B International 2009)

3. The IEA Implementing Agreement

3.1. IEA 4E

The IEA Implementing Agreement on Efficient Electrical End-Use Equipment (4E) was launched in 2008 with the fact in mind that mass produced products traded globally need a consistent approach to technology improvement and policy design. Market transformation towards energy efficient products demand a coordinated use of policy experience and a more rapid exchange of know how on new technologies. The focus is both on industrialized and on developing countries with the latter becoming large manufacturers of many kinds of end-use products both in household and industry equipment.

The collaboration in 4E has started with so far by the end of 2008 in 10 countries:

- Australia
- Austria
- Canada
- Denmark
- France
- Korea
- Netherlands
- Switzerland
- UK
- USA

Work was initiated in four defined 4E Annexes:

- Electric motor systems (leading country: Switzerland)
- Mapping and benchmarking (leading country: UK)
- Set-top boxes (leading country: USA)
- Standby power (leading country: Australia)
- further Annexes are planed.

3.2. The EMSA project

The Electric Motor Systems Annex EMSA acts as know how centre for motor systems within 4E.It was officially launched in November 2008 at the Motor Summit in Zurich. At the same event the transition from the SEEEM project (www.seeem.org 2006 - 2008) to EMSA (www.motorsystems.org) was announced.

The Motor Systems Annex in IEA 4E tries to bundle best technical practice and policy know how in order to stimulate market transformation towards energy efficiency in the field of electric motor systems applications in industry, infrastructure and large building.

The goal of EMSA is to propagate energy efficiency in electric motor systems of advanced technology and engineering by coordinated policy and market mechanisms. The reduction of electricity demand will reduce global CO_2 emissions. Energy efficiency improvements of 20% to 30% on average have been proven by industrial efficiency programs.

The range of electric motor systems to be treated in EMSA is clearly defined. Major focus are the poly-phase electric motors between 0.5 and 500 kW that carry the bulk of the load to drive pumps, fans, compressors and mechanical drives. These machines are produced worldwide in large quantities and are used globally in industry, building technology and infrastructure systems. The majority of the motors are AC, 2-, 4- and 6-pole and with 200 V to 1000 V. EMSA will also include new emerging motor technologies with higher efficiencies and integrated motor controls.

The electric motor and its core motor system (pump, fan, compressor, et cetera including the auxiliary components adjustable speed drive, gear, transmission belt, etc.) will be treated in this Annex; they will be approached in the Tasks as separate work items. The complete motor system (the entire heating, cooling, ventilation system in a building, etc.) with pipes, ducts, et cetera which has the largest energy savings can not be considered within the scope of the EMSA because of its broader complexity.

EMSA works in Tasks (see Figure 11) that are lead by individual country representatives. The overall coordination, implementation support and outreach are provided by the Operating Agent. The project plan for the next 3 to 5 years has been decided by the 4E Executive Committee in October 2008. The budget is shared by all the partners.

The work on EMSA was started by the end of 2008 by the following six participating countries:

- Australia
- Austria
- Denmark
- Netherlands
- Switzerland
- UK

Many countries have voiced interest in active participation but have not yet concluded their decision making and the formal application procedure in IEA: Brazil, Canada*, China, Finland, France*, Korea*, South Africa, Sweden, USA* (* means already member of 4E, not decided for EMSA).

Tasks	Countries	Australia	Austria	Denmark	Netherland	Switzerland	UK	Contact (Task Leader)	
OP	Operating Agent					Task leader		Conrad U. Brunner	
A	Implementation Support & Outreach	Participant in Task	Participant in Task	Participant in Task	Participant in Task	Task leader	Participant in Task	Conrad U. Brunner	
B	Technical Guide for Motor Systems		Participant in Task	Task leader		Participant in Task		Sandie Nielsen Ture Hammar	
C	Testing Centers	Task leader		Participant in Task		Participant in Task		Sarah Hatch	
D	Instruments for Coherent Motor Policy	Task leader	Task leader			Participant in Task		Sarah Hatch Konstantin Kulterer	start later
E	Training & Capacity Building		Participant in Task	Task leader	Participant in Task			Sandie Nielsen Ture Hammar	
F	Energy Management in Industry	Participant in Task		Participant in Task	Task leader		Participant in Task	Frank Hartkamp Rob de Klerck	
G	New Motor Technologies	Participant in Task		Participant in Task	Participant in Task	Participant in Task	Task leader	Charles Gaisford	
H	Total Motor Systems Integration	Participant in Task		Participant in Task	Participant in Task		Task leader	Charles Gaisford	start later

Participant in Task

Task leader

Figure 11 4E EMSA matrix with tasks and participating countries

Industry and industry associations have been invited to participate in EMSA events and share their knowledge. IEA has prescribed a special - non-voting - status of industry collaborating in Implementing Agreements. ICA has already voiced interest in collaboration.

3.3. The Global Motor Systems Network

So far over 1100 motor experts from academia, industry, government and other fields from over 50 countries have voiced interest in energy efficiency of electric motor systems and subscribed to the GMSN newsletter since early 2009 and thus receive the constant flow of information on new technological and policy developments. We anticipate the development of large global community of practise that will share experiences in technical development and policy implementation. International fora like the Motor Summit in Zurich (2007 and 2009, www.motorsummit.ch) and EEMODS (in varying places since 1996) together with more specialized and regional events can raise the level of information and understanding more rapidly.

4. Conclusions

EMSA as a market transformation program is based on the **input** of financial and personal resources from the participants and member countries of 4E.

The **output**, this means the technical results of EMSA, are in general terms clearly the dissemination in web, a newsletter, motor events and printed documents. In partnership with regional projects also training, teaching and capacity building programs are possible products.

The specific products to be designed and delivered to an interested public will be:

- Technical guides for the design, selection and application of energy efficient motor systems for plant operating engineers. The new IEC 60034-31 Guide for the selection and application of energy-efficient electric motors (draft 2009)[13] will be used as a reference.

- Tools for managers and engineers to optimalize existing and new installations

- Policy advice in procedural guides, reports from market analysis to legislation, enforcement, check- testing and sanctions. The Electric motor MEPS Guide[14] will be used as a first partial element.

- Lists of qualified testing facilities for governments that have up to date equipment and use a standard testing procedure and protocol. The IEC Round Robin[15] will be used as a first reference.

- Platform for the discussion and introduction of new standards.

The **outcome** means the direct effects on participants who understand about the motor systems context, see potential from new motor and drive technologies, learn the concept of integral systems design and least life cycle cost and are now able to use software tools and guide books to decide their projects on a higher information level. It can also be the number of countries with motor MEPS of financial incentives, etc.

The **impact** is - like in most dispersed energy efficiency programs - difficult to design and to measure precisely. I.e. the growing market share of Premium efficiency IE3 motors can be monitored, the sales of VFD also. On the other hand the development of national electricity demand in the project region and during the project time can be accounted for. The more difficult task is to establish the “soft”-link between the contribution of the EMSA output and the “hard” energy demand. Many parallel activities, the general development of the economy, the appearance of new products with special technical features, etc. can influence the market transformation as well and make the identification of its specific share very difficult.

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