Harmonized Standards for Motors and Systems

Global progress report and outlook

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Abstract

The global process of harmonizing standards of electric motors is most important to make progress in global trade with Premium Efficiency motors (IE3) and energy efficient motor drive systems in pumps, fans and compressors, and industrial handling & processing. The standards include energy efficiency testing, labels and efficiency classes as well as setting mandatory performance requirements. Progress is reported with the Ecodesign policy in Europe joining the world of countries with Minimum Energy Performance Standards (MEPS) from 2011 while other countries like USA, Canada and Mexico have upgraded their existing mandatory requirements by the end of 2010 to reach IE3. Europe has also started to introduce system performance standards for fans and pumps.

Results from market shift of motor sales towards higher efficiency classes and analysis of resulting energy consumption in changes of the running stock is reported in key regions: Europe, USA, and China.

Based on this ongoing development the focus of global attention for major new policy developments can now shift from standard components like fixed speed induction motors in sizes from 0.75 kW to 375 kW to a wider scope: from 120 W up to 800 kW including all kinds of new motor technologies, running with variable speed and integrated into packaged systems like pumps, fans and compressors.

This means that both the existing IEC component standards for testing and efficiency classes and national MEPS have to be developed further. A systems optimization approach means dealing with a higher level of complexity with the definition of performance of several individual mechanical and electrical components and their interacting efficiency. Or it means resorting to an integrated systems efficiency scheme based on input/output performance in different load and speed profiles with predefined standard operation conditions.

An agenda for future efficiency policy development in motors and systems is presented with target regions and barriers to be lowered.

Energy Efficiency in Industry

The fact is slowly getting recognized [1] that electric motor systems in industrial applications are responsible for 45% of global electricity consumption. This means: start here! The electricity savings potential is huge, the technology ready, the barriers slowly lowered. Many studies reveal that the much hailed cost-benefit driven, modern technology oriented industry is not energy efficient. The major concern in industry is product volume and cost, thus profitability in competitive global markets. Many issues like Least Life Cycle Cost LLCC are hidden below everyday cost cutting efforts, split responsibilities of investment and operating costs and insecure future production plans. What we can see in many industry audits are outdated and even neglected machines, inefficient and oversized electrical equipment with mechanical throttles and V-belts where technology offers major improvements for more than a decade. These industries run at higher total cost than necessary and are an unnecessary high load on the environment.

Since the tragic nuclear accident in Japan in March of 2011 political and industrial leaders have shown more concern: the prospects of cheap energy and electricity in the near future are fading. No panacea is in sight that could replace the dream-turned-nightmare of cheap abundant nuclear power. Cogeneration and gas combined cycle are the next available technology for added capacity but are further increasing the CO_2-emissions. Energy efficiency is the best way to cut energy demand and to optimize total cost of ownership.

All sectors - commercial, industry, large buildings, infrastructure and traffic systems - have to review their potential of improved energy efficiency (see Table 1). All applications, like pumps, fans, compressors for air and cold, conveyer and other industry handling & processing equipment, need to be reassessed. The share of electricity from motor systems in all the sectors is considerable, with industry reaching almost 70%.

Table 1 Global motor electricity consumption by sector (2006)

Sector	Electricity consumption	Fraction of motor systems electricity	Fraction of sector electricity
	TWh/a	%	%
Industrial	4 488	64%	69%
Commercial	1 412	20%	38%
Residential	948	13%	22%
Transport and agriculture	260	3 %	39%
Total	**7 108**	**100%**	**45%**

Source: Waide, Brunner et al., 2011 [1]

There is a long path from the primary energy used in the power plant to generate electricity (which also is responsible for the CO_2 emissions) over the transmission, transformation and distribution losses, to the conversion of electricity into mechanical power in electric motors all the way to the net mechanical energy used at the demand end to pump water, blow air or turn gears (see Figure 1). The losses between the motor and the end use are the key focus of attention in motor systems. Today we still see oversized and outdated equipment driving in partial load with low efficiency a large number of mechanical devices (throttles, gears, transmissions, brakes, clutches) that result in low systems efficiencies.

The largest share of electricity (68%) is used by industry-sized motors between 0.75 kW and 375 kW (equivalent to 1 - 500 hp). Larger machines up to 100 MW account for 23%, smaller applications down to 1 W including millions of domestic appliances have a fraction of only 9% (see Table 2).

Table 2 Global motor stock by size classes

All kinds of electric motors	Output size P_m (kW)						Operation		Number running stock	Life time	Sales	Motor efficiency		Power P_e	Electricity demand	
	Min	Max	Centre min	Centre 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	0.05	0.5	0.16	316	1'500	40%	2'000	6.7	300	40%	30%	422	632	9.1%
Medium	0.75	375	3	30	9.5	2'182	3'000	60%	230	7.7	30	86%	84%	1'559	4'676	67.6%
Large	375	100'000	375	1'500	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%**
	minimum and maximum available sizes		most often used sizes		geo-metric mean			average annual LF		quotient stock over sales		at full load	at average load			

Source: A+B International, 2010

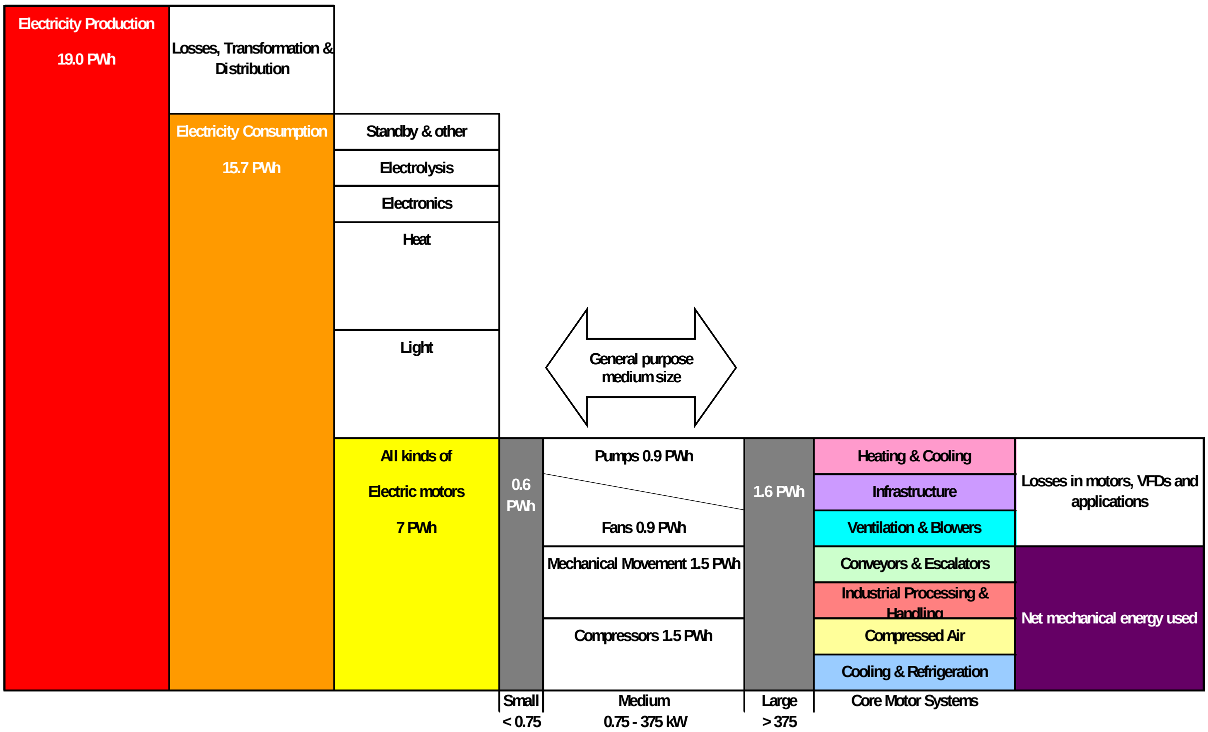

Figure 1 **Global motor market and energy use [1]**

Global Motor Systems Market

Data on energy use in the global motor market are not readily available. Various sources quote different numbers that mostly stem from an unclear definition of "motor". In order to make a more comprehensive and robust estimate a methodology was derived to link national electricity consumption, motor sales and motor stock (see Figure 2) [2]. The distinction is made between "all kinds of electric motors" and "general purpose motors in industry sizes" which are the largest segment of applications.

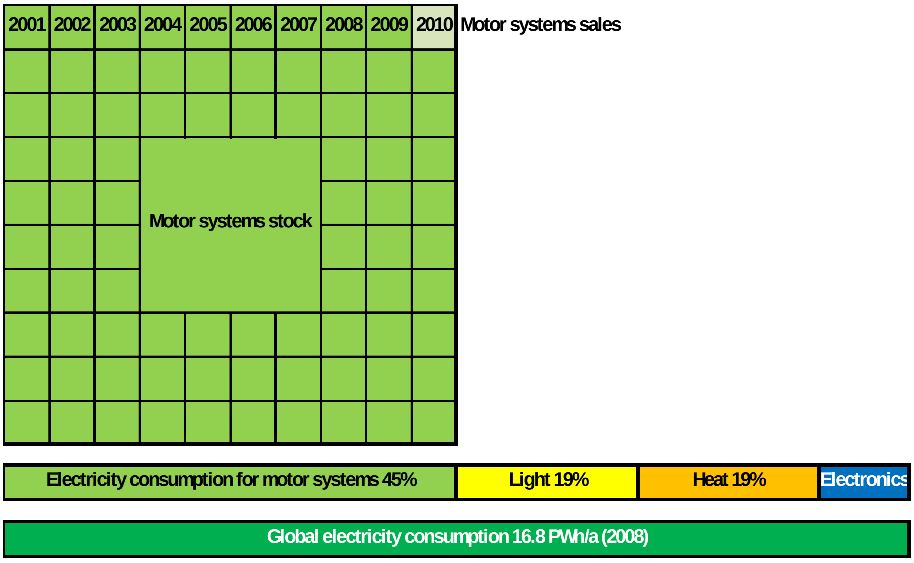

Figure 2 **Motor market model (source: A+B International, 2011)**

Concluding from an extensive survey of global motor sales of medium sized motors (Brunner, Jakob et al. 2009 [10]) market shares are gradually moving towards higher efficiency since 2000 mostly through technology driven market shifts (see Figure 3). Up to 2007 the global market is dominated by inefficient Eff3 motors (depicted as IE0) or IE1 (referring to the definition of efficiency classes according to Table 4). Underlying data of Figure 3 stem from various publically available sources (e.g. research reports, sales statistics), data surveyed from national administrations and private organisations by [10] and from estimations derived thereof, using a motor stock model. Only since 2008 the shift has been and is expected to be accelerated because large economies (USA, China, and Europe) have introduced mandatory regulations with minimum energy performance standards that have increased the market share of high (IE2) and premium efficiency (IE3) motors much more rapidly. In all other countries - non-MEPS countries - large sales volumes are still on low priced products because no life cycle considerations are made by most industrial users. In 2015 market share of inefficient IE1 motors still might be as high as 25% to 30%.

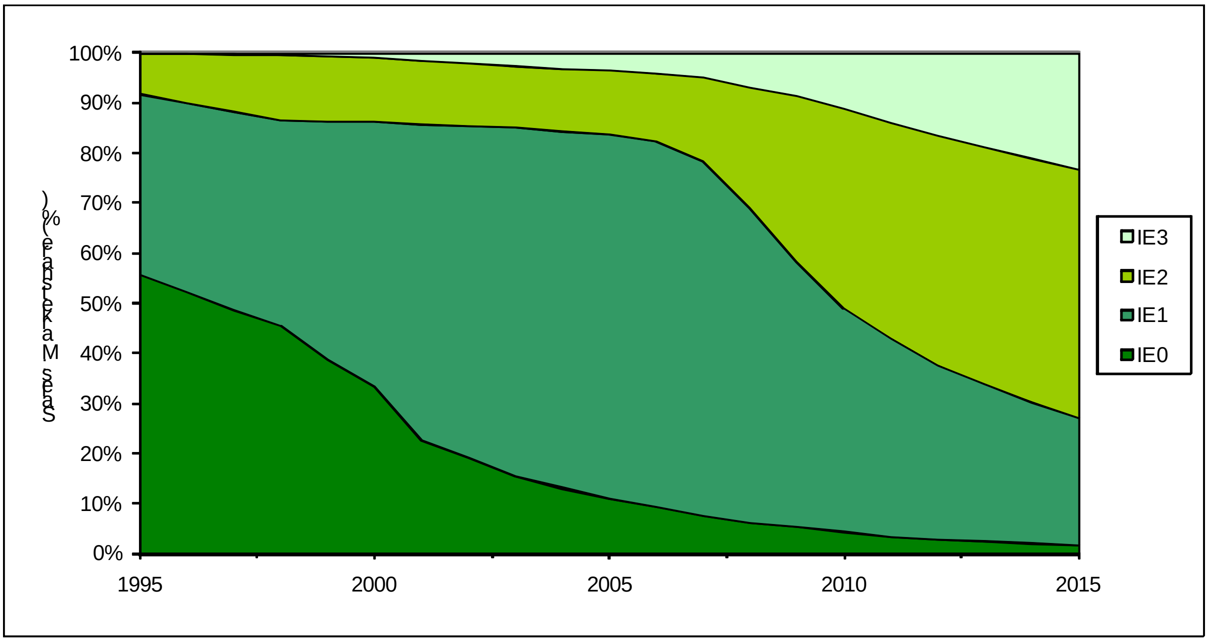

Figure 3 **Market shares of global electric medium sized motor sales shift from low to premium efficiency motors. IE1 to IE3 refer to Table 4, IE0 depicts former low-efficient Eff3 class (source: Brunner, Jakob et al. 2009, [10])**

To estimate the impact of increased market shares on respective shares of running motor stocks and thus on energy consumption a motor stock model was built [10] as data on motor stocks is even scarcer than sales data. To estimate the installed stock assumptions were made on the replacement of already operating motors and on the growth of the stock in each country or country group. Regarding the existing stock it was assumed that replacement is usually made after a normal life cycle. Earlier replacements are possible when a motor fails prematurely and repair is not feasible or when a machine is renewed before the life time is reached. If no specific country data are available from literature or our personal survey, assumptions on the size specific life time and the annual replacement rate are made based on the figures of De Almeida, Falkner, et al. New installations are bound to be directly related to the entire industry development: Growth rate of Gross Domestic Product, electricity use, industrial investments, etc. This leads in “saturated economies” in industrialized parts of the world like Europe and USA with smaller annual growth rates of new motor installations to 1 - 3% p.a. of the installed base, in developing economies (China, India, Brazil, Russia) with a much higher annual growth rate of the new installations can be in the range of 3 - 6% p.a. of the installed base. The total motor market in any country is therefore somewhere between 9% and 14% of the installed base which implies that the installed base is something like 7 to 11 times the annual domestic sales volume. From these considerations the stock model then provides figures about the development of the global stock by efficiency classes and by size class.

The resulting transfer of increasing sales figures of high and premium efficient motors into running stock (see Figure 4) is very slow. With an average life cycle of 10 to 30 years (depending on motor size) the change to more efficiency is a matter of several decades. The shift in sales in the last decade will therefore trickle down to move the efficiency of the global motor stock only between 2020 and 2030. This means of course that also the electricity consumption of electric motors will only slowly be reduced. Any global or national electric motor renewal program needs more than 10, rather 20 to 30 years to have a complete turnover of system efficiency. It therefore has to be designed as a long and continuous effort. The sales volume for the high (IE2) and premium efficiency classes (IE3) will go in waves and follow the staggered implementation of mandatory MEPS.

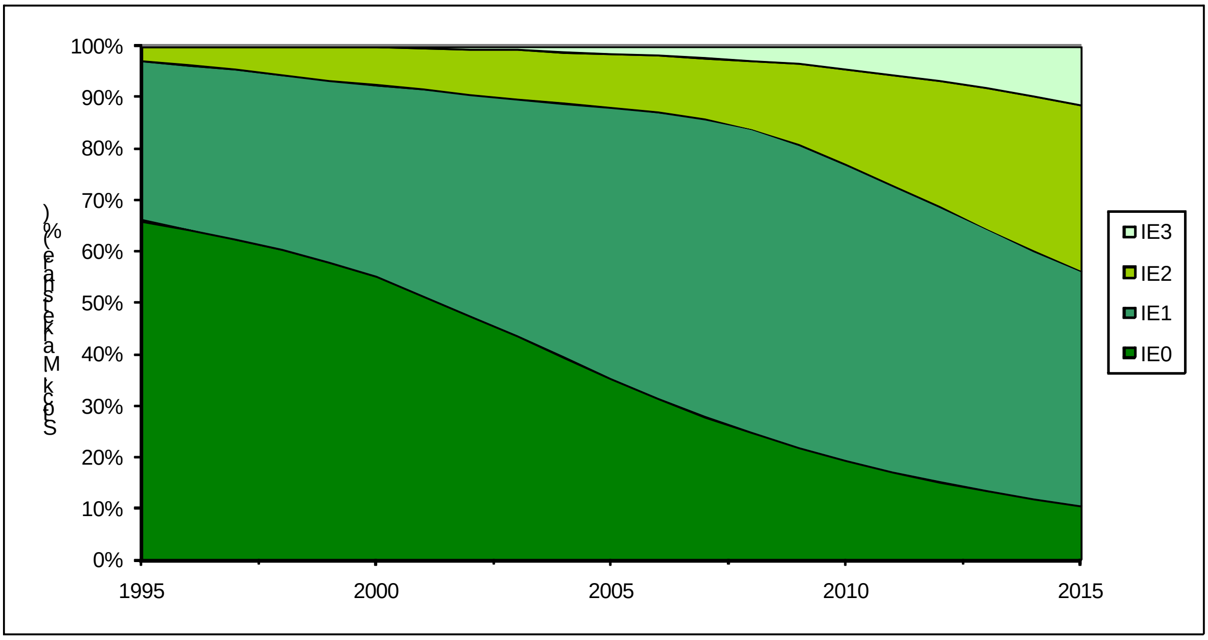

Figure 4 **Shift in running stock from low to premium efficiency motors IE1 to IE3 refer to Table 4, IE0 depicts former low-efficient Eff3 class (source: Brunner, Jakob et al. 2009, [10])**

Technology shift

The asynchronous alternate current squirrel cage induction electric motor is still the workhorse technology of the global industry. It is cheap and reliable. It comes in standardized frame sizes and can be modified for many individual tasks. It has also been going through a large series of energy efficiency improvements in the last 20 years. The most recent induction motors can reach very high performance levels just with more careful engineering, manufacturing and more copper wires. These motors are basically fixed speed but can be operated with a variable frequency converter (VFC) to adapt the torque and speed to the necessary load. This development has great potential by eliminating mechanical throttles and bypasses, especially for pumps and fans run with square torque.

- Now new motor technologies have entered the market: Permanent Magnet (PM) and Reluctance Motors (they come as synchronous reluctance, variable reluctance, switched reluctance and variable reluctance stepping motor) among others. Meanwhile some older technologies like DC motors are less used because of their high maintenance. Brushless DC motors are taking their place. New technologies also have a huge potential in smaller sizes and integrated design: the motor, the VFD and the pump, fan or compressor are packaged into on piece of equipment that is both smaller and cheaper and can also have efficiency advantages because the components are closely matched.

The electronic controls are also important on a higher level of integration in factory automation. Motors are turned on and off, guided to their necessary tasks and loads via integrated control networks. These networks can prevent "Operation Without Use [3]" that is a frequently observed source of energy waste.

IEC Motor Standards

A very important measure for wider market acceptance is harmonized standards. These standards include performance testing, efficiency classifications and display of ratings. The International Electrotechnical Commission IEC has successfully made a huge effort in the last decade to advance global harmonization of motor standards (see Table 3). Several key fields have been treated in the Technical Committee 2, responsible for all rotating machines, like motors and generators.

Table 3 IEC motor standards

Topic	Standard	Title	Year published	Covered motors
Rating & performance	IEC 60034-1	Rating and performance	2010	
Testing of efficiency	IEC 60034-2-1	Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)	2007 (under revision)	Standard motors (AC, DC and synchronous)
	IEC 60034-2-2	Specific methods for determining separate losses of large machines from tests - Supplement to IEC 60034-2-1	2010	Special and large motors
	IEC 60034-2-3	Specific test methods for determining losses and efficiency of converter-fed AC motors	2011 (draft)	Converter-fed motors
Efficiency classes	IEC 60034-30	Efficiency classes of single-speed, three-phase, cage-induction motors (IE-code)	2008 (under revision)	Induction motors 0.75 - 375 kW, 2-, 4-, 6-pole with 50 and 60 Hz
Guide for the application	IEC 60034-31	Selection of energy-efficient motors including variable speed applications - Application guide	2010	Motors and variable frequency drives

Source: IEC Technical Committee 2: Rotating machines

The largest contribution for increased market transparency has been coming from a globally harmonized motor efficiency classification (IEC 60034-30) that distinguishes efficiency classes from IE1 to IE4 (see Table 4). The rating plate defined in IEC 60034-1 clearly marks on every new motor the indication of the efficiency class and the respective nominal efficiency (see Figure 5).

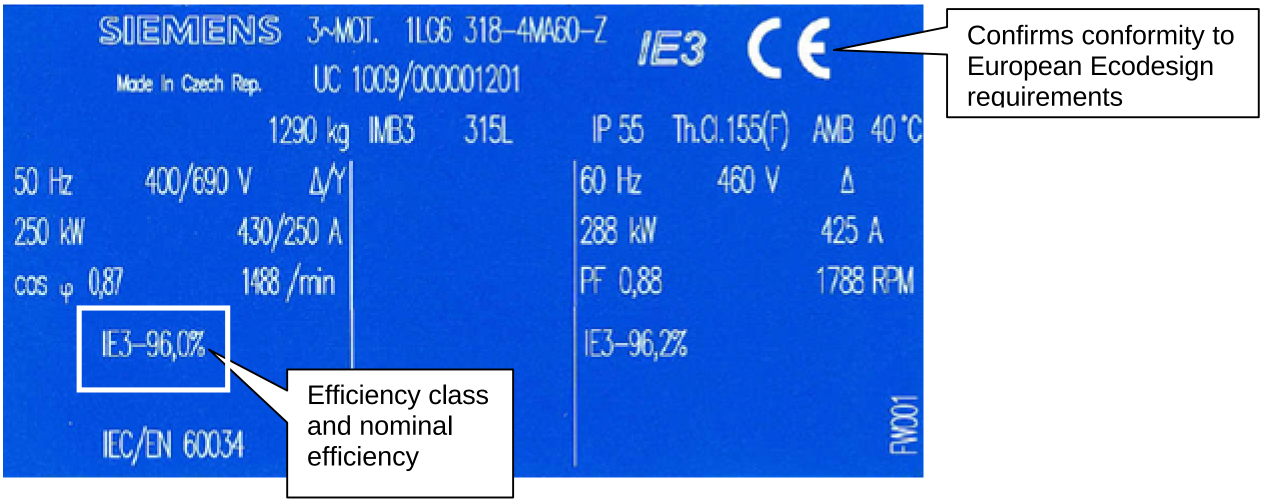

Figure 5 Rating plate of IE3 motor with standardized information according to IEC 60034-1 and Ecodesign requirements (source of image: Siemens, 2011)

Currently several new projects are under way to expand the scope beyond squirrel cage induction motors and include more kinds of electrical motor technologies:

The scope of the new IEC 60034-30 will most likely be expanded to include output sizes from 0.12 up to 800 kW, 2-, 4-, 6- and also 8-pole induction as well as permanent magnet motors (see Figure 6). The efficiency classes will be extended to IE4 Super Premium Efficiency with a window for the definition a future IE5 Ultra Premium Efficiency class which is currently not yet available. See also EEMODS'11 paper: Martin Doppelbauer: The new EU-Mandate and IEC 60034-30 Energy Efficiency Classes. The publication of this revised standard is planned for 2012.

Table 4 IEC motor efficiency classification (IE-Code)

IE-Code	Efficiency Class
IE4	**Ultra Premium Efficiency**
IE3	**Premium Efficiency**
IE2	**High Efficiency**
IE1	**Standard Efficiency**

Source: IEC 60034-30:2007; under revision

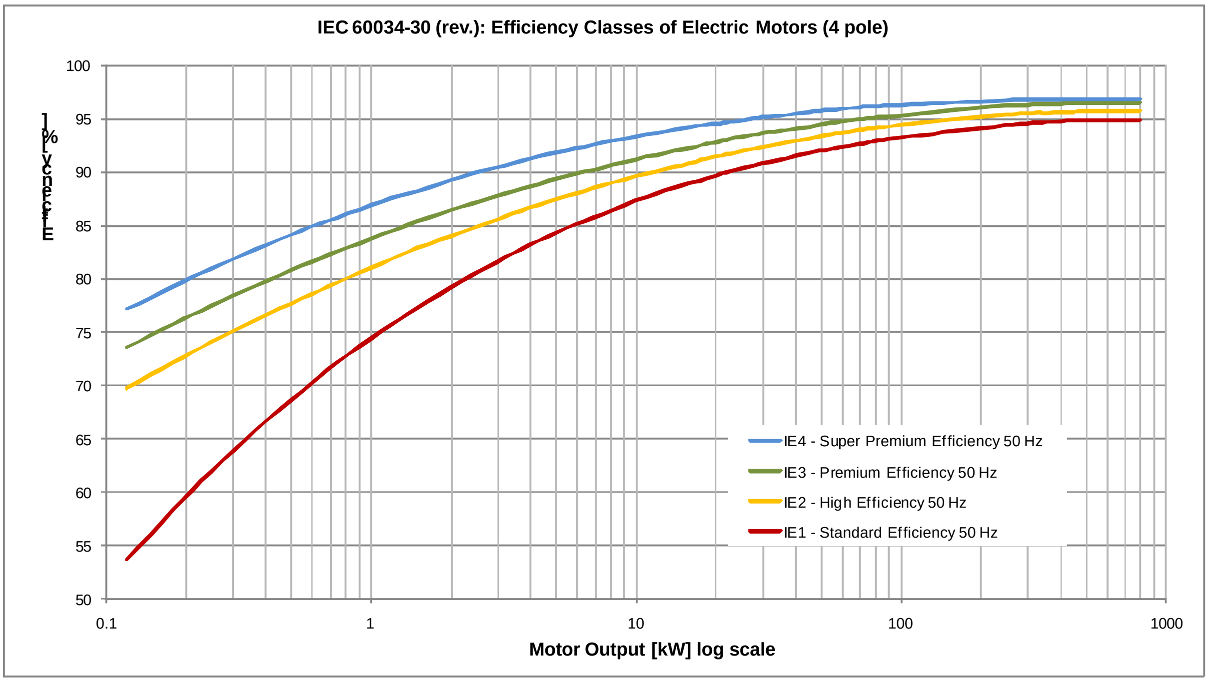

Figure 6 IEC 60034-30 Efficiency Classes: Planned revision with classes from IE1 to IE4 and output sizes from 0.1 kW to 800 kW (source: IEC TC2 WG31, 2011)

The revision of the testing method IEC 60034-2-1 is under way in order to make the efficiency results more accurate and repeatable (see also EEMODS'11 paper: Andrew Baghurst, Pierre Angers and Martin Doppelbauer: A standard algorithm for the calculation of induction motor efficiency based on International Standard IEC 60034-2-1. The revision of the testing standard profits from the results of the IEC Round Robin [4] test campaign that was conducted with a total of 194 tests on 75 motors in 17 test laboratories situated in 11 countries (see also EEMODS'11 paper: Axel Möhle: The Round-Robin-Test for the improvement of IEC 60034-2-1). The testing methods will change from the older concept of "low uncertainty" that was never to be quantified to the more MEPS-oriented philosophy of the "preferred method" that every laboratory has to use in a predetermined sequence of procedures. The publication of the revised IEC 60034-2-1 is planned for 2012.

The total energy performance of an entire motor system containing the VFD, the motor plus the driven equipment (pump, fan, compressor, conveyor, etc.) is currently under study in Cenelec SC22X WG6. See also EEMODS'11 paper: Martial Patra: Standardization for ASD**.** The publication of an eventual standard will most likely not be before 2013.

Minimum Energy Performance Standards

The best means to move performance levels of mass produced pieces of equipment has proven to be minimum energy performance standards MEPS [5]. The current situation of MEPS around the globe is shown in Table 5. With the now globally harmonized efficiency classification and testing standards it has become easier for legislators to introduce mandatory requirements into national law. Currently over 70% of global electricity use is in countries with electric motor MEPS.

Table 5 Global Efficiency Classes, Testing Standards and MEPS for Electric Motors

Efficiency Levels 3-phase induction motors	Efficiency Classes IEC 60034-30 Global classes IE-Code 2008; rev. 2012 *	Testing Standard IEC 60034-2-1 incl. stray load losses 2007; rev. 2012 **	Performance Standard Mandatory MEPS **** National Policy Goal
Super Premium Efficiency	IE4	Preferred Method	
Premium Efficiency	IE3		**Canada** **Mexico** **USA** Europe*** 2015 / 2017
High Efficiency	IE2	Summation of losses with load test: P_{LL} determined from residual loss	**Australia** **Brazil** **China** **Europe** **South Korea** **New Zealand** **Switzerland**
Standard Efficiency	IE1		**Costa Rica** **Israel** **Taiwan**

bold means in effect

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*) Sizes 0.12 kW - 800 kW, 50 and 60 Hz

**) for 3-phase machines, rated output power < 1 MW

***) Europe* 2015 (below 7.5 kW), 2017, IE3 or IE2 + Variable Speed Drive

****) Minimum Energy Performance Standard

Source: A+B International, 2011

From the 13 MEPS countries there are three key regions - both in terms of motor manufacturing and motor use in industry - to determine global market shift are USA, Europe-27 (especially Germany) and China. Their motors use 56% of global motor electricity. The Figure 7 shows the late change from voluntary to mandatory of policy in Europe. The Chinese progress is well planned; doubts have been mentioned whether the necessary enforcement is stringent enough.

Motor MEPS	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
USA	IE2													IE3						
Europe EU-27														IE2				IE3*		IE3**
China P.R.					IE0				IE1					IE2				IE3		

*) > 7.5 kW or IE2+ VFD
**) all sizes or IE2+ VFD

Figure 7 Shift in motors MEPS from standard IE1 to premium efficiency IE3 (source: A+B International, 2011)

The underlying national efficiency requirements are diverse. A current account of some of the national legal standards shows that both the scope (motor size and speed) as well as the numerous exemptions are not yet internationally harmonized. The leading group of countries with MEPS at IE3-level as of today (USA, Canada, and Mexico) represent only 25% of global electricity consumption.

European developments in the Ecodesign directive

According to the European Ecodesign framework regulation (EC 2005/32 and EC 2009/125), all relevant and mass produced "Energy-using Products" or the now more expanded term "Energy-related Products" (sales and trade volume more than 200'000 units a year within the European Community) undergo a standard study based on a common methodology to assess the environmental impact, life cycle cost, market analysis and improvement potential [6] and to determine the need for a market regulation.

After the publication in 2008 of the Technical Studies on motors, pumps, fans and circulators [7] currently motors (No 640/2009), small pumps (No 641/2009) and fans (No 327/2011) have mandatory performance standards in effect (see Table 6).

Table 6 European Ecodesign Regulations in the motor field (status 2011)

- ELECTRIC MOTORS with output power between 0.75 and 375 kW: Commission Regulation (EC) No 640/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to Ecodesign requirements for electric motors. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:191:0026:0034:EN:PDF

- CIRCULATORS with hydraulic output power between 1 W and 2500 W: Commission Regulation (EC) No 641/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to Ecodesign requirements for glandless standalone circulators and glandless circulators integrated in products. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:191:0035:0041:EN:PDF

- FANS between 125 W and 500 kW: Commission Regulation (EU) No 327/2011 of 30 March 2011 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:090:0008:0021:EN:PDF

Work is currently ongoing on larger pumps, small fans and air conditioners. The important new element in Energy-using Products is that not only the standalone electric motor but also combined applications (core systems with motor, frequency converter, and applications) are regulated. The added complexity has also increased the necessary information and algorithms for the products.

Motor Systems Programs

Many countries have engaged in national activities to support energy efficiency in specific programs for electric motors and systems (see table 7). These are government supported information campaigns, capacity building and training, tools; some are also financial incentive and Energy-label programs, MEPS, et cetera. Some programs give special guidance to repair and rewind (New Zealand). Many of these activities are based on a series of pilot studies and audits which demonstrate best practice. All of the mentioned programs are manufacturer independent, i.e. they give advice on energy systems optimization without preference of specific products or brands. Also many power utilities (USA, others) provide independent advice for industrial motor system users as part of their demand side management programs. France and Italy have special White Certificate programs. Besides this there are a number of manufacturer tools that are giving interesting advice which is mostly linked to specific products and brands.

Table 7 National motor energy efficiency programs

Coverage	Name of program or leading agency	Internet URL
Global	4E EMSA	www.motorsystems.org
Australia	Energyrating E_3	www.energyrating.gov.au
Austria	Klimaaktiv	www.klimaktiv.at
Brazil	Procel	www.eletrobras.com
Canada	NRCan OEE	www.oee.nrcan.gc.ca
China	China Motor Challenge	www.motorsystem.org.cn
Europe	Motor Challenge Programme	www.motor-challenge.eu
India	Bureau of Energy Efficiency BEE	www.bee-india.nic.in
New Zealand	EECA electric motors programme	www.eeca.govt.nz
South Africa	Eskom IDM	www.eskomidm.co.za/industrial
South Korea	KEMCO	www.kemco.or.kr
Switzerland	S.A.F.E. Topmotors	www.topmotors.ch
USA	Motor Decisions Matter	www.motorsmatter.org

Source: A+B International, 2011

Agenda for Tomorrow

Energy efficiency is the key global program for at least one decade to come. Industrial electric energy is the largest piece of electricity consumption. A sustainable energy efficiency policy consists of three key elements:

1. Mandatory minimum performance requirements for components and systems
2. Financial incentives for industry investment and for utilities to profit from lower electricity sales
3. Information initiatives to train and inform industry both as equipment producers and users, government on all levels and also Heating, Ventilation and Air Conditioning engineers.

The focus for expanding the number of MEPS countries will shift from key industrialized regions (Europe, and USA, with Japan lagging behind) to rapidly expanding BRICS economies (China, India, Brazil, Russia and South Africa) plus other large Asian economies (South Korea, Thailand, Indonesia, Turkey, etc.). From this alter group nly China, South Korea and Brazil have already started with motor MEPS.

Based on a survey of current motor policy experiences now available in the **Motor Policy Guide**, Part 1 [8] 4E EMSA will develop in Part 2 a **Motor Policy Guidebook** with a Road Map for comprehensive motor policies that can be adapted nationally (see EEMODS'11 paper: Konstantin Kulterer: EMSA-Analysis of Motor Policies around the World). It will benefit also from the analysis presented by Falkner & Holt [9], 2011.

The successful further development of global policies for efficient motor systems has to include six key issues in parallel:

1.	Increase number of countries with mandatory motor MEPS: include India, Russia and South Africa
2.	Develop compliance programs with check-testing and continuous market survey
3.	Expand scope to all types of electric motors with sizes of 0.12 kW to 800 kW
4.	Continuously rise the efficiency level of MEPS to IE3
5.	Expand motor MEPS to pumps, fans and compressors including variable frequency drives
6.	Develop policies to speed up renewal of old existing motor systems

Current motor policy with MEPS is basically focussed on sales of new motors and systems only. The very large segment of motor systems under operation is not touched with this. As our industrial pilot projects in Europe show there is considerable stock of over-aged and over-sized systems in operation that are far from running efficiently. Policy measures to reach out for this segment are fairly limited. An interesting approach comes from New Zealand: to go both for "Quality repair and rewind" plus rules for which type of motor is allowed to be repaired and which ones need to be replaced. Also financial incentives work with a contribution for new premium motors plus an added subsidy if the old motor is brought in and is shown to be replaced.

Based on the shift towards a more efficient motor stock and based on additional assumptions on efficiency improvements of the rest of the motor systems (e.g. controls, conducts, operation management) the impact of an integrated motor policy on global electricity consumption has been calculated [1] (see Figure 8). 20% to 30% of electricity (and the equivalent volume of CO_2-emissions) can be saved if efficient motor systems technologies and practice succeed and are implemented in a necessary global policy framework. Only a motor systems approach covering old and new equipment can harvest this potential benefit for the economy and the environment.

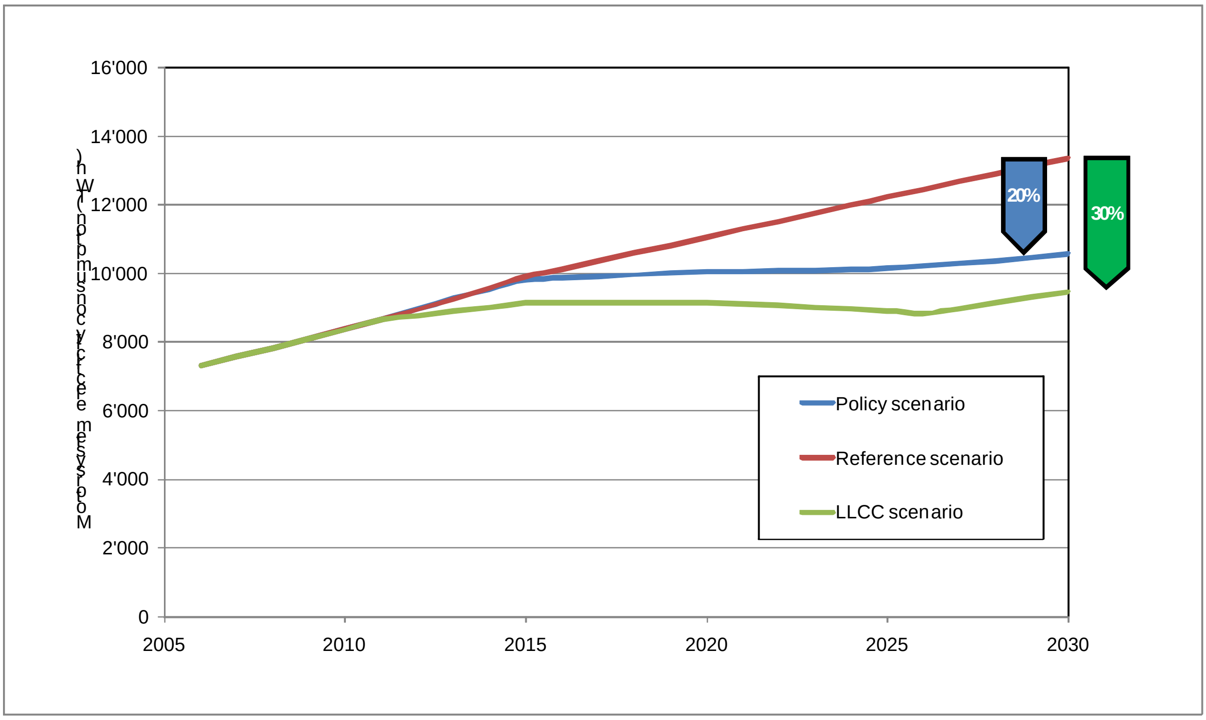

Figure 8 Future development of global motor system electricity consumption (source: IEA estimate [1])

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