INSTITUTO DE SISTEMAS E ROBÓTICA
UNIVERSIDADE DE COIMBRA

Technology options for IE4 efficiency level

Fixed speed vs. variable speed

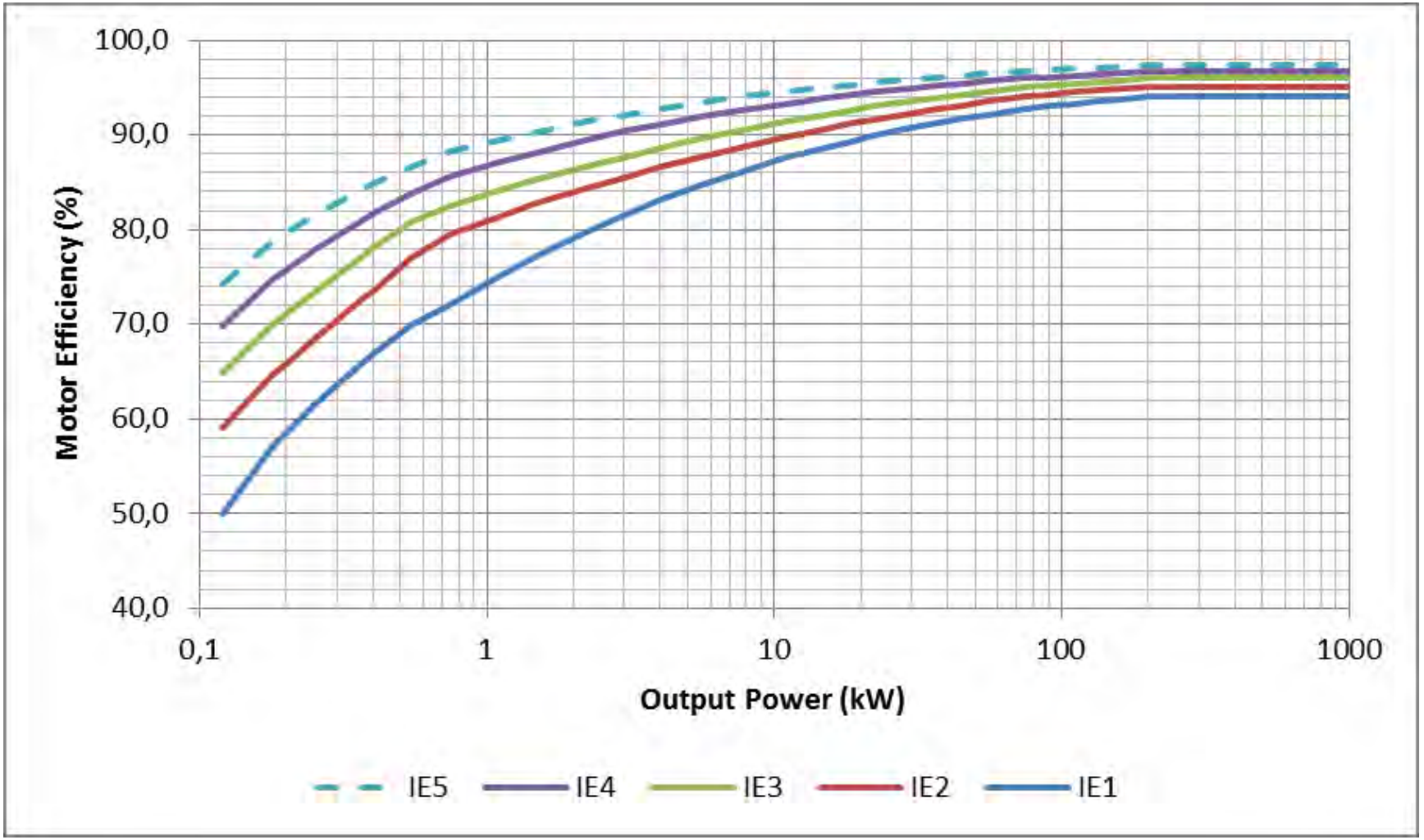
Anibal T. De Almeida

ISR-University of Coimbra

Motor Workshop 2017 - European Copper Institute

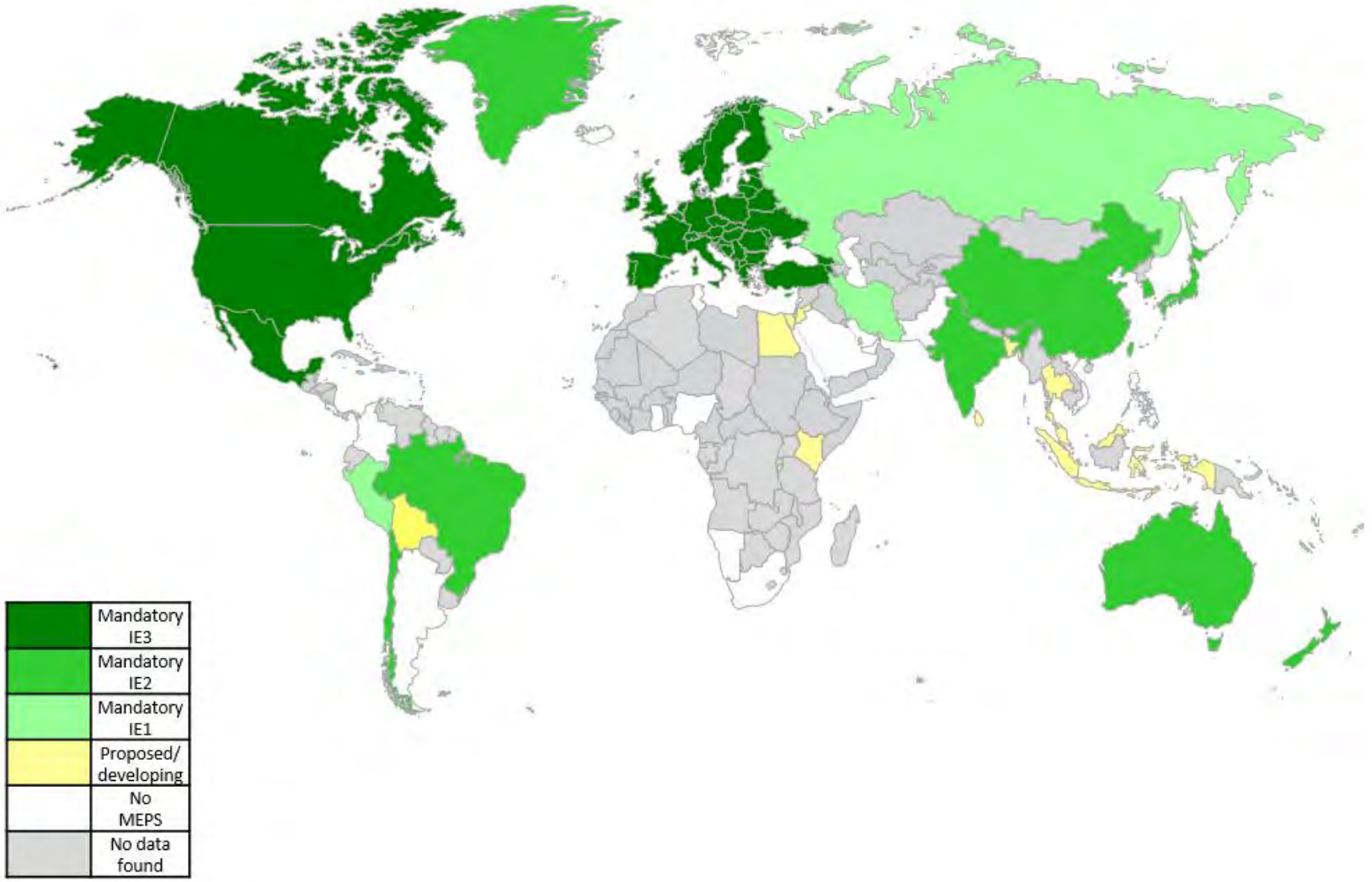
March 7th, 2017

IEC 60034-30-1 Ed.1 (2014)

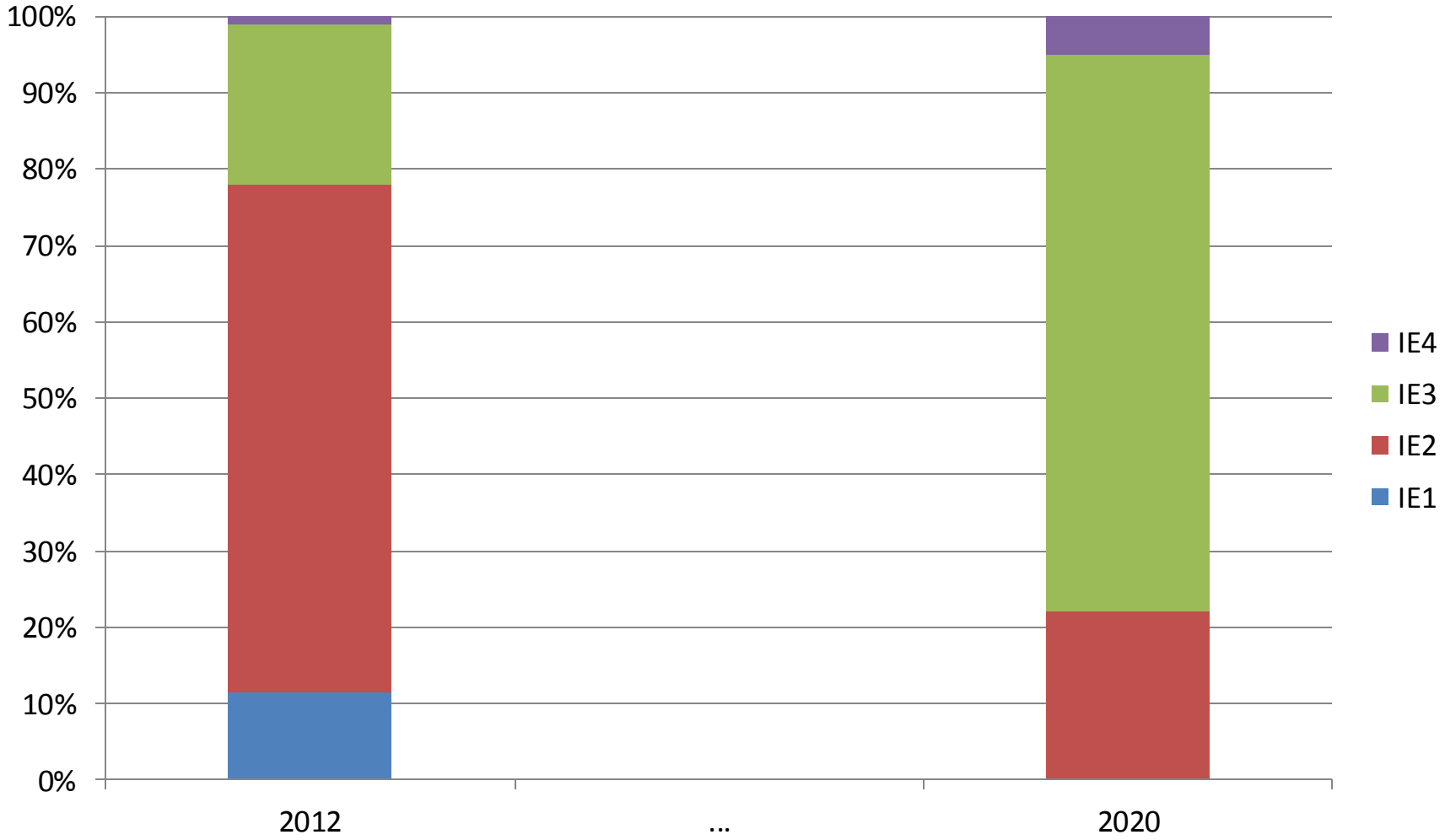


4 Poles / 50Hz

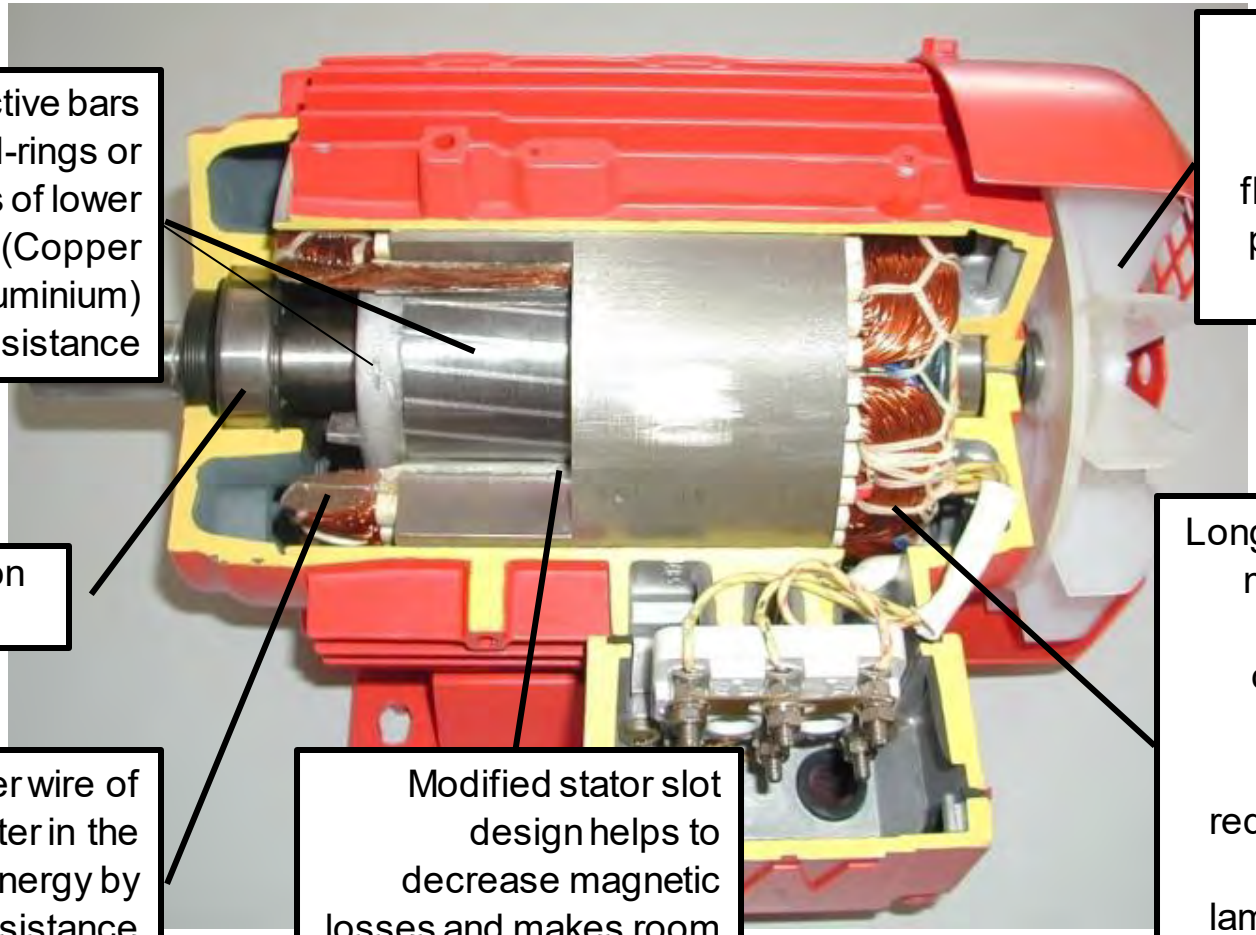
MEPS Worlwide



Motor Market Evolution
(source: CEMEP)



Options to increase Induction Motor Efficiency



Larger conductive bars and end-rings or conductors of lower resistivity (Copper instead of Aluminium) reduce rotor resistance

Efficient cooling fan design improves air-flow and reduces power required to drive the fan

Reduced friction bearings

Longer stator lowers magnetic density and increases cooling capacity. Premium grade magnetic steel reduces hysteresis losses; thinner laminations reduce eddy current losses.

More copper wire of larger diameter in the stator saves energy by reducing the resistance of the stator winding

Modified stator slot design helps to decrease magnetic losses and makes room for larger diameter wire

Motor Efficiency Evolution

Premium

IE3

Squirrel Cage Induction Motors

Super-Premium

IE4

PM Motor + VSD

SynRel Motor + VSD

Ultra-Premium

IE5

PM Motor + VSD

SynRel / PM Motor + VSD

IE6?

Comparison of Motor Technologies

Motor type	Needs electronic controller	Cost Premium Vs IE3	Cost of Repair	Power/ Weight Ratio
1 -Induction motor with copper rotor	No	20-30%	Low	***
2- Induction motor with aluminium rotor	No	20-30%	Low	**
3-Permanent magnet synchronous motor	Yes	100%	High	****
4-Line start permanent magnet	No	100%	High	*****
5-Synchronous Reluctance	Yes	50%	Low	***

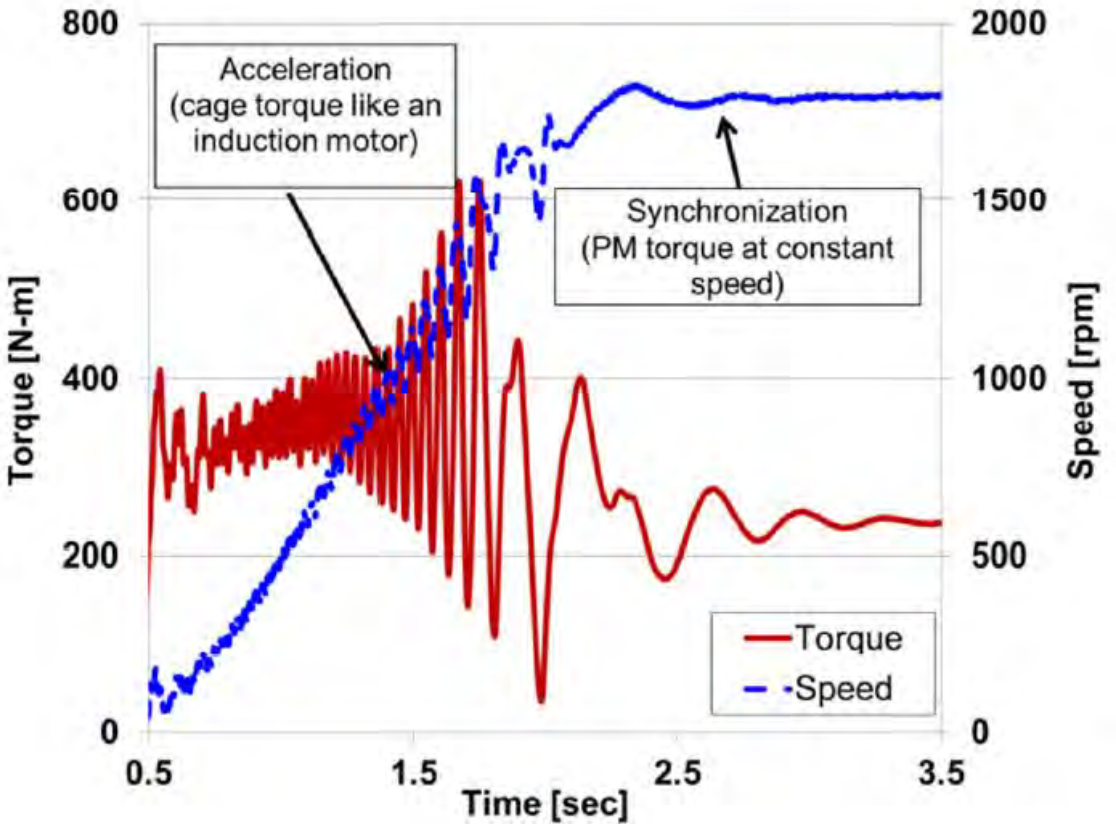
Line Start PM motor

- Hybrid motor with squirrel cage rotor fitted with high energy permanent magnets (NeFeB) making it suitable for direct on line start

- Available with **IE4** efficiency

Line Start PM motor - Starting

The starting “kick” of LSPMs is quite violent, which can lead to accelerated mechanical wear of the motor and load bearings and/or gears (if any).



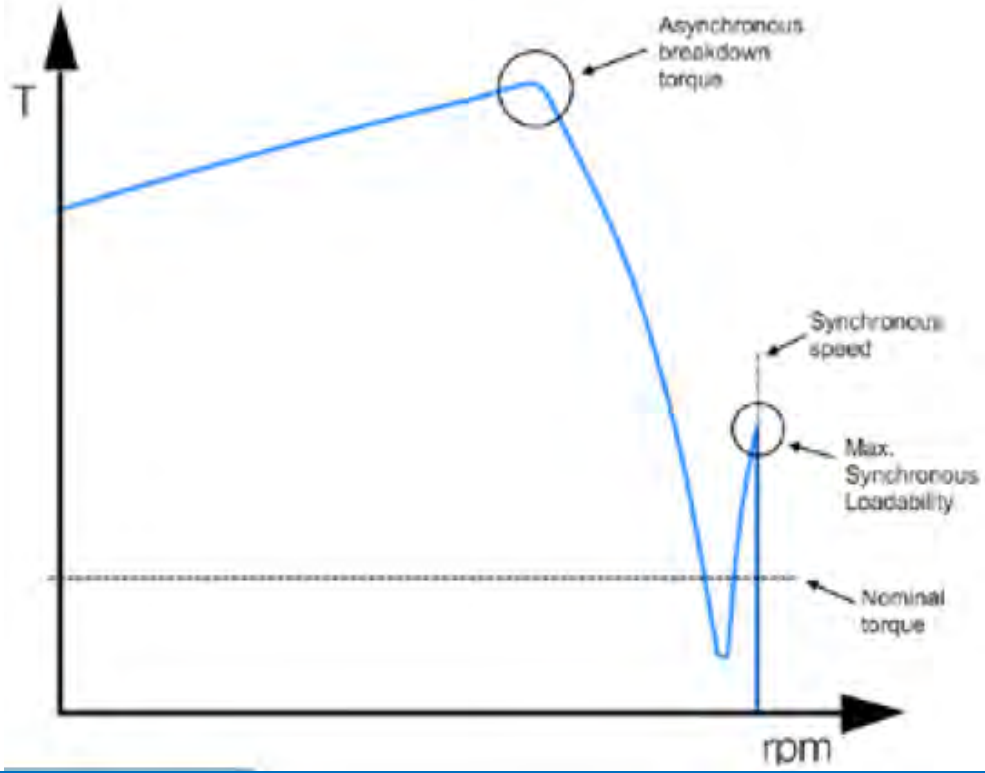
Robbie McElveen, Mike Melfi, Roger Daugherty, *Line start permanent magnet motors – Starting, standards and application guidelines,* Petroleum and Chemical Industry Technical Conference (PCIC), 2014 IEEE

Direct-on-line SynRM (DOLSynRM)

- An induction cage within the rotor which is used for starting.
- At the end of the starting phase reluctance torque pulls the motor to synchronous speed.
- **IE5** efficiency level

Direct-on-line SynRM (DOLSynRM)

The starting performance presents a noticeable dip in the torque curve just before the synchronous speed making this motors limited to applications with low load inertia.

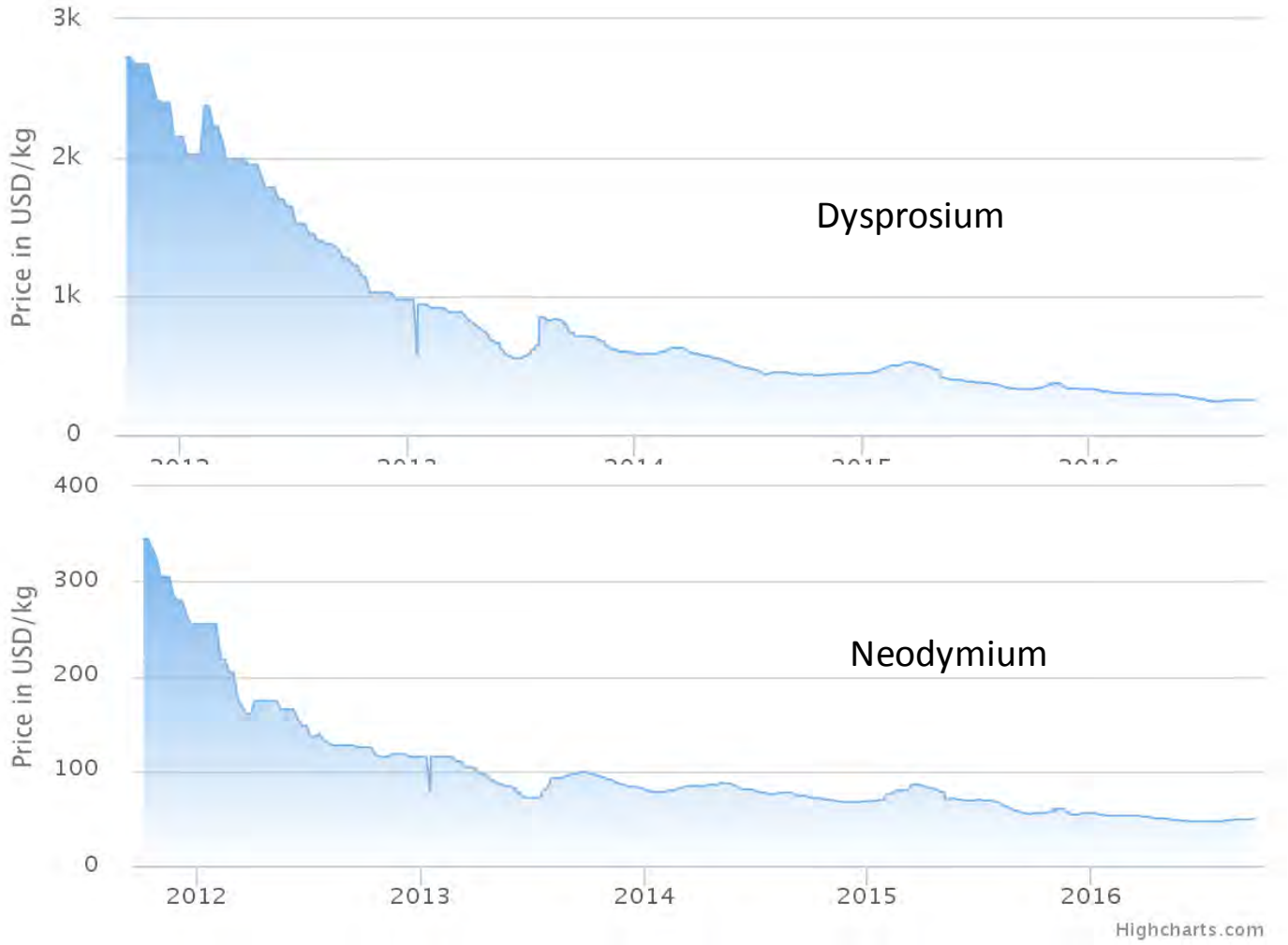


RE Magnet Disadvantages

- Price instability / uncertainty due to concentrated production (> 70% is in China).
- Limited supply of Dysprosium.
- Environmental impact of extraction / processing.

Baotou, China

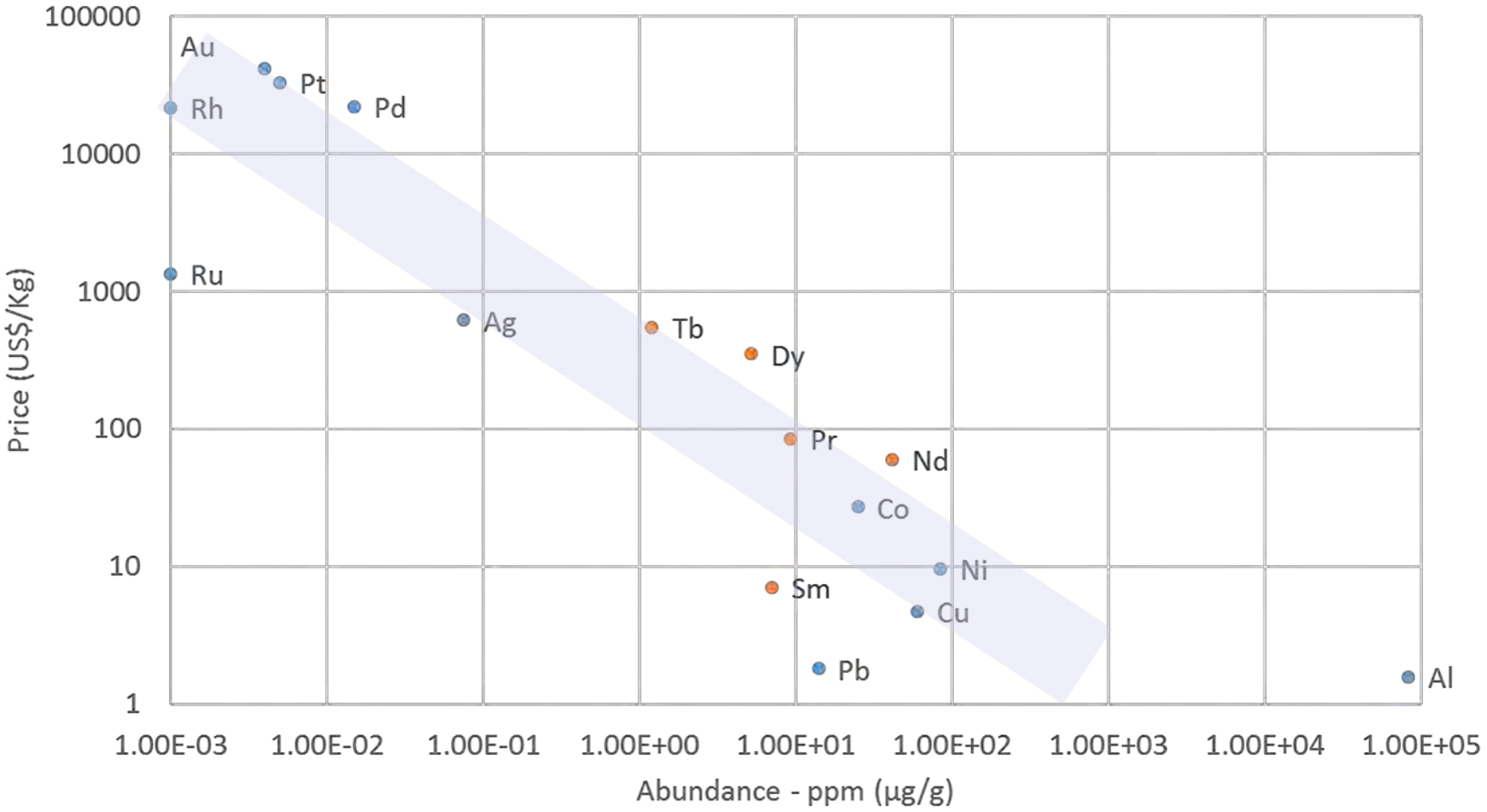
Rare-Earth Price



Rare earth prices have steadily trended downward since 2011.

https://www.metalprices.com/

Metal Abundance vs Price



http://mineralprices.com/

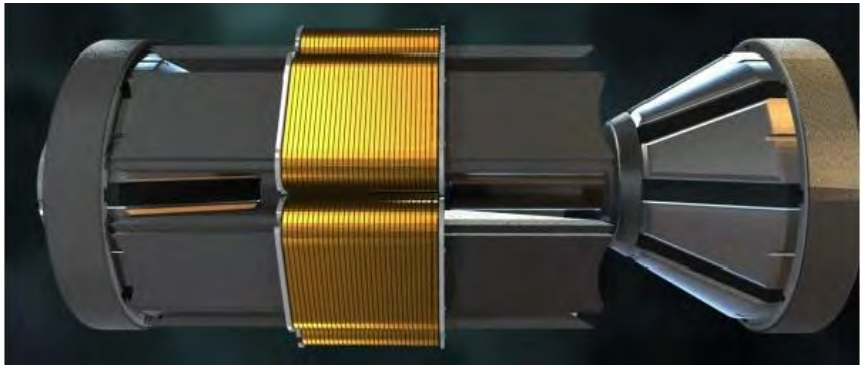
New / Alternative technologies

- Reduced-Dy magnet technology (e.g. Hitachi's dysprosium vapor deposition diffusion technology).
- Recycling (limited by economic feasibility).
- Development of new magnetic materials (some not yet commercially available): Iron Nitride, Samarium Iron Nitride, Cerium and Manganese-based compositions, magnetic nanoparticles and Iron Lithium Nitride.
- Using less costly and widely available Ferrite Magnets.

Super Premium PM motor using Ferrite magnets

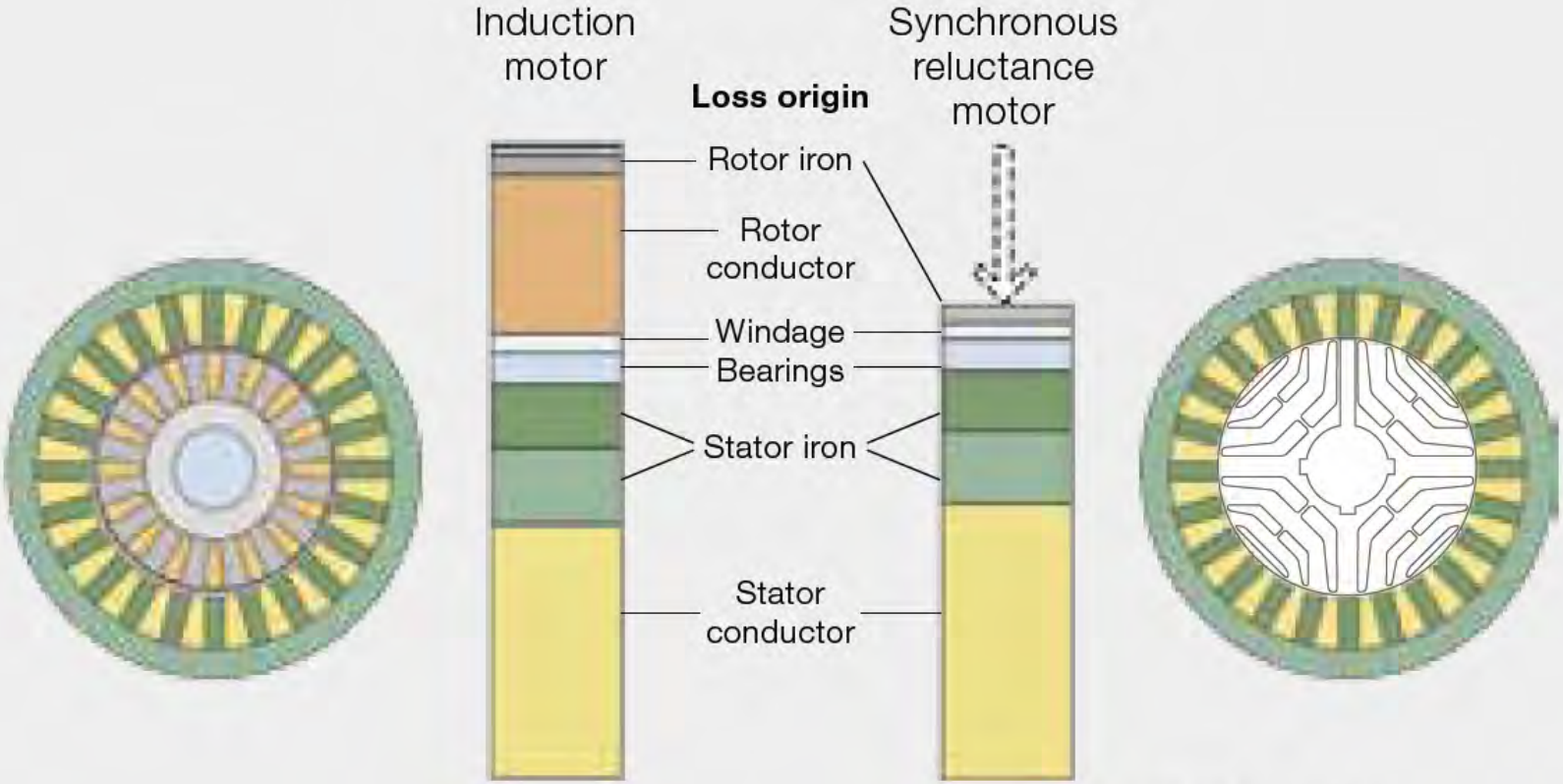
New designs using innovative geometry for the motor rotor and stator, use less costly ferrite magnets to deliver the performance level typically found in much more expensive rare earth-based permanent magnet motors.

Motor Compared in Size to Conventional Motor

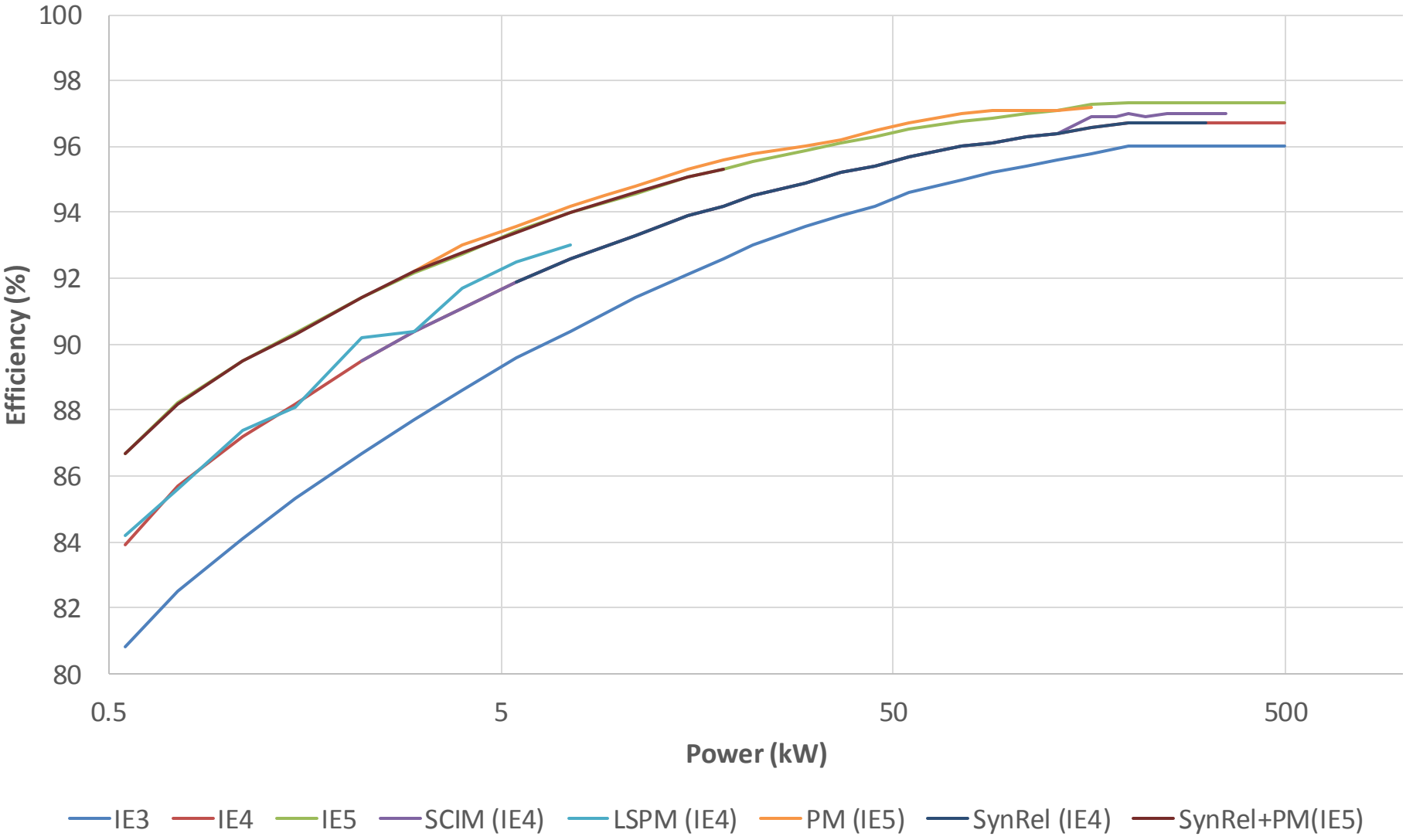


NovaTorque Motor Exploded View

Potential efficiency increase due to rotor loss reduction in SynR Motors

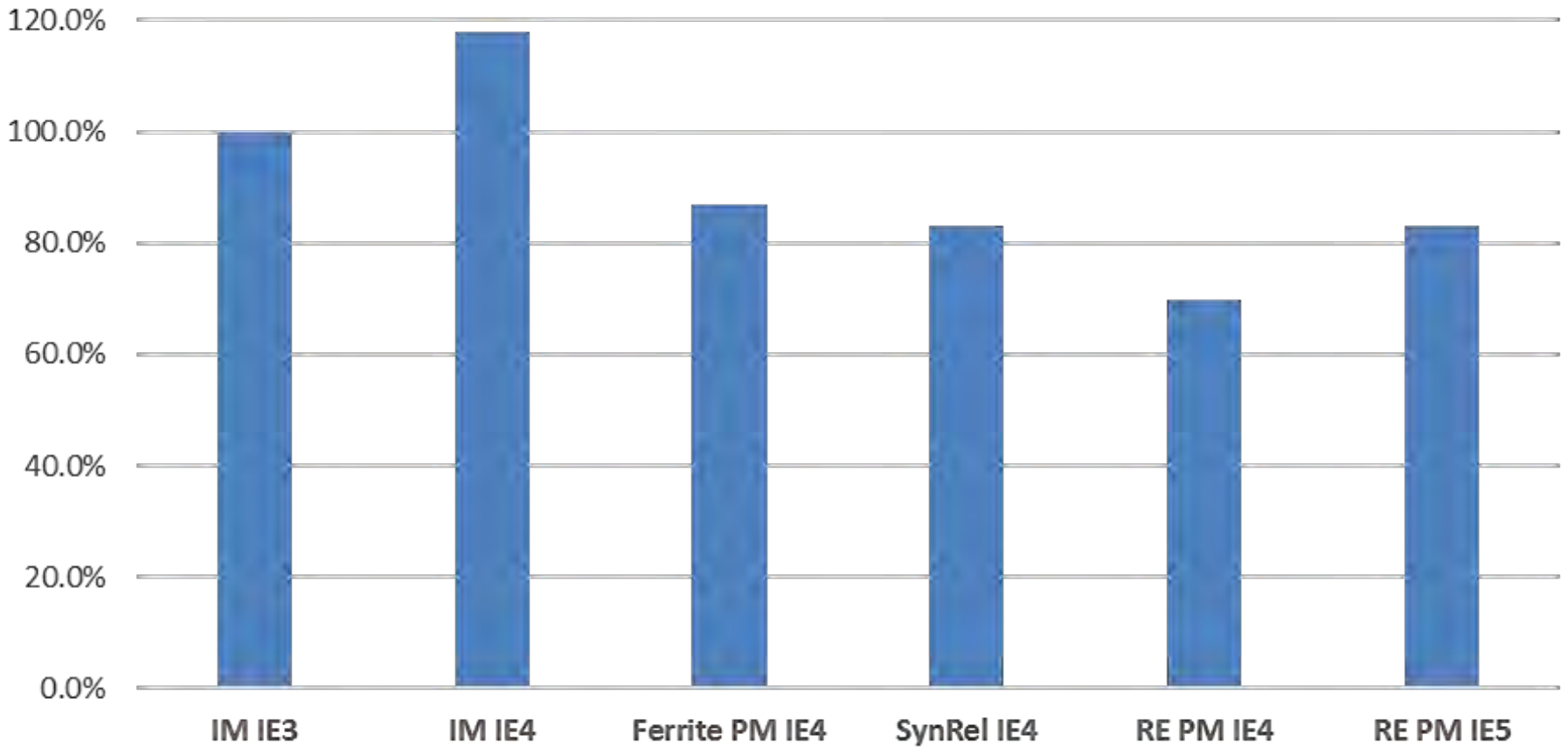


Efficiency of commercially available IE4 and IE5 motors (2016 catalogue data)



Motor total weight

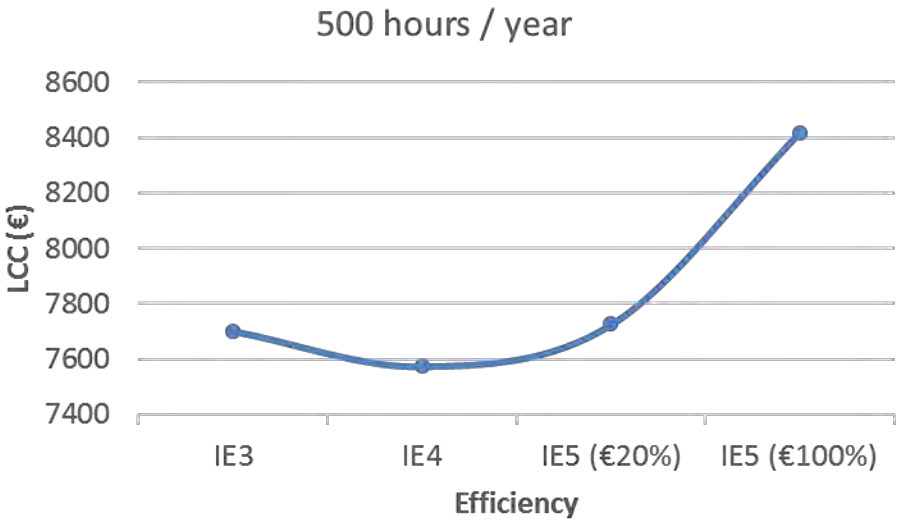
2016 catalogue data

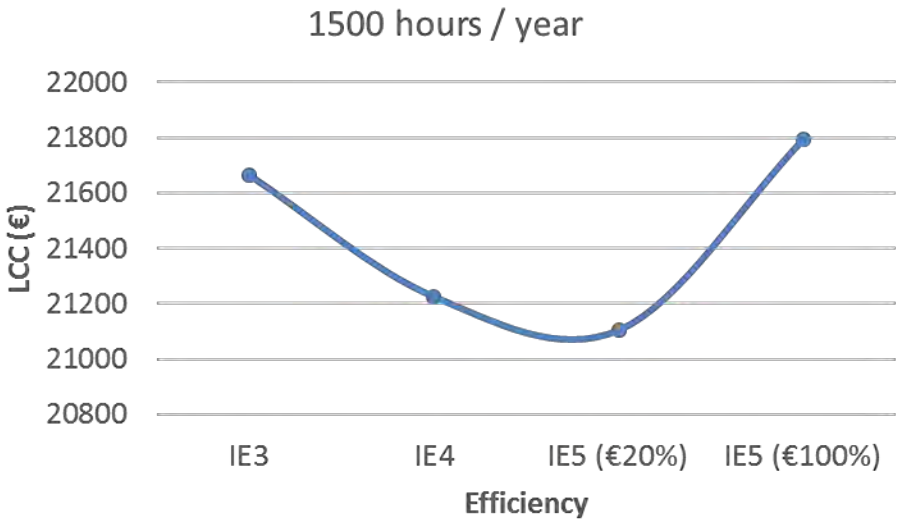


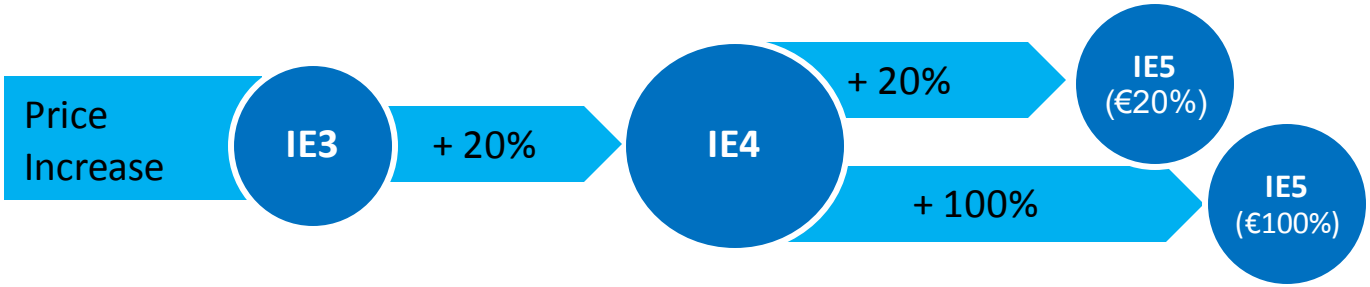
11 kW; 1500 rpm; aluminium frame

Motor Total Life-Cycle Cost

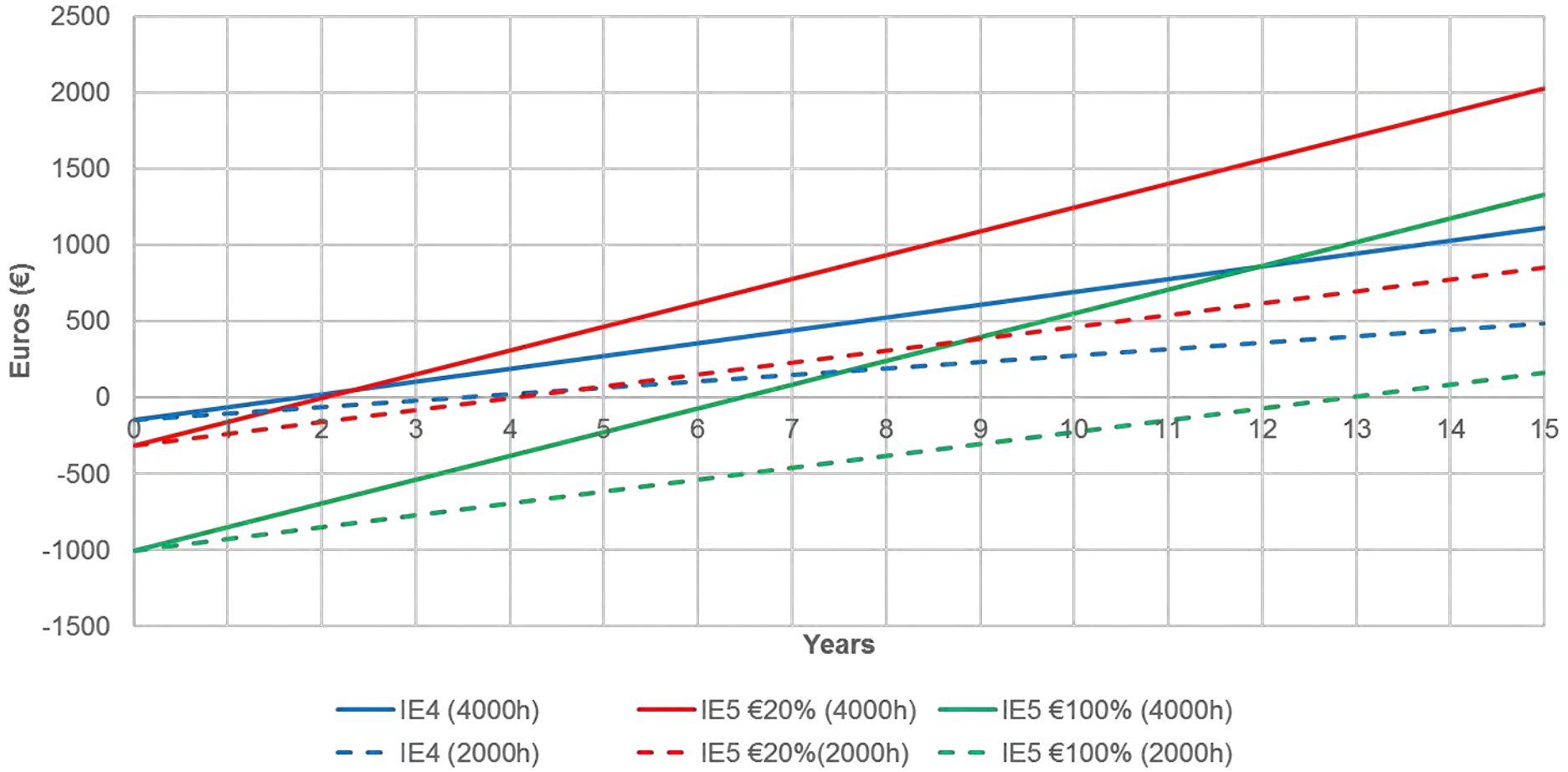
11 kW motor
15 years lifetime
EU average Electricity Price 2015: 0.119 €/kWh







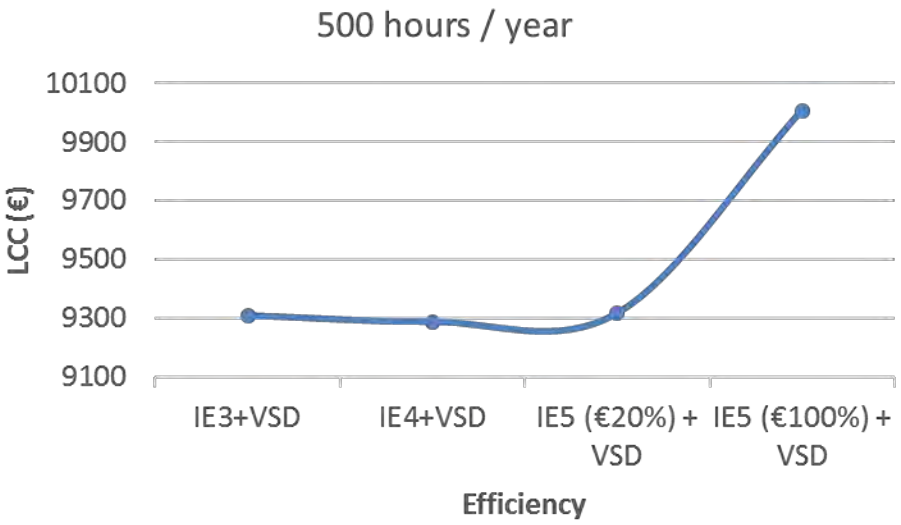
Investment Overview

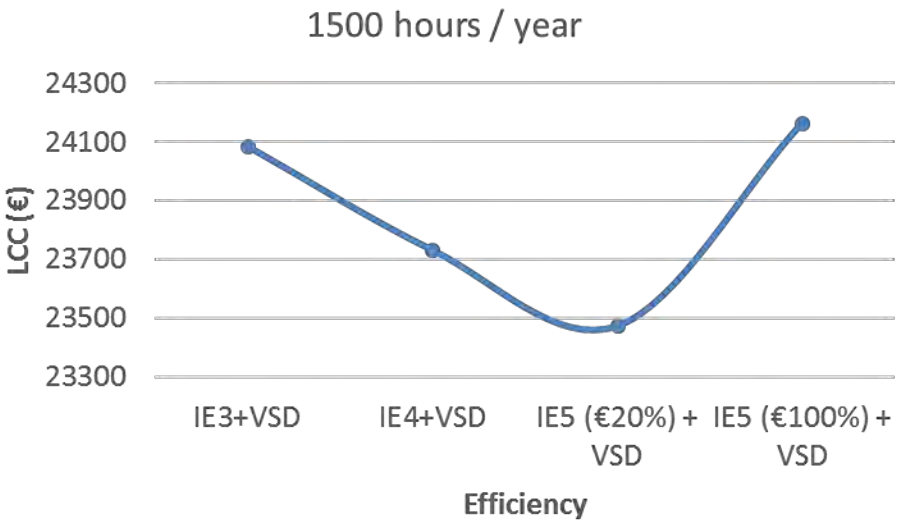


11 kW induction motor
EU average Electricity Price 2015: 0.119 €/kWh
2000 and 4000 operating hours per year

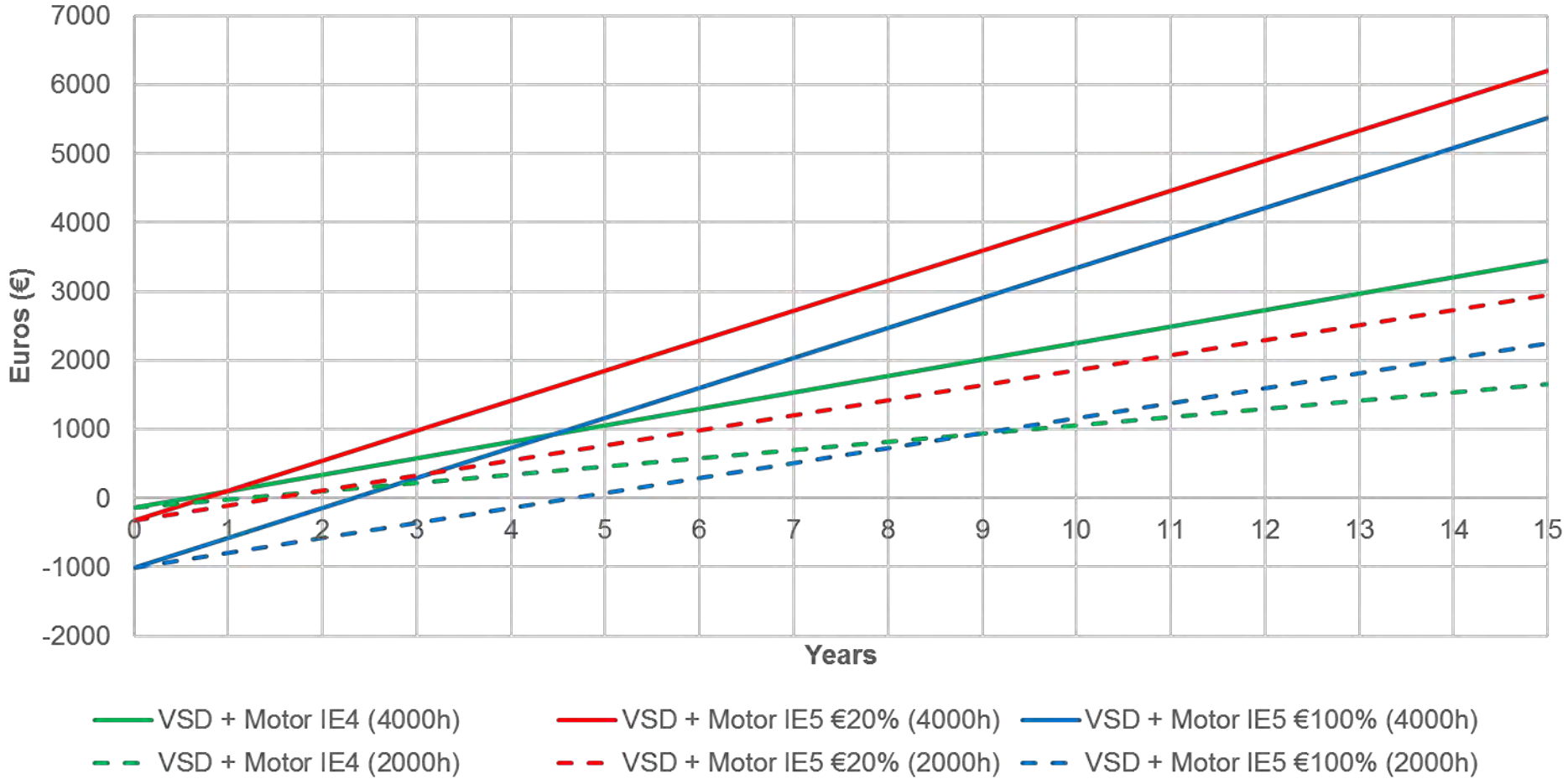
Motor + VSD Total Life-Cycle Cost

11 kW motor + VSD
15 years lifetime
EU average Electricity Price 2015: 0.119 €/kWh



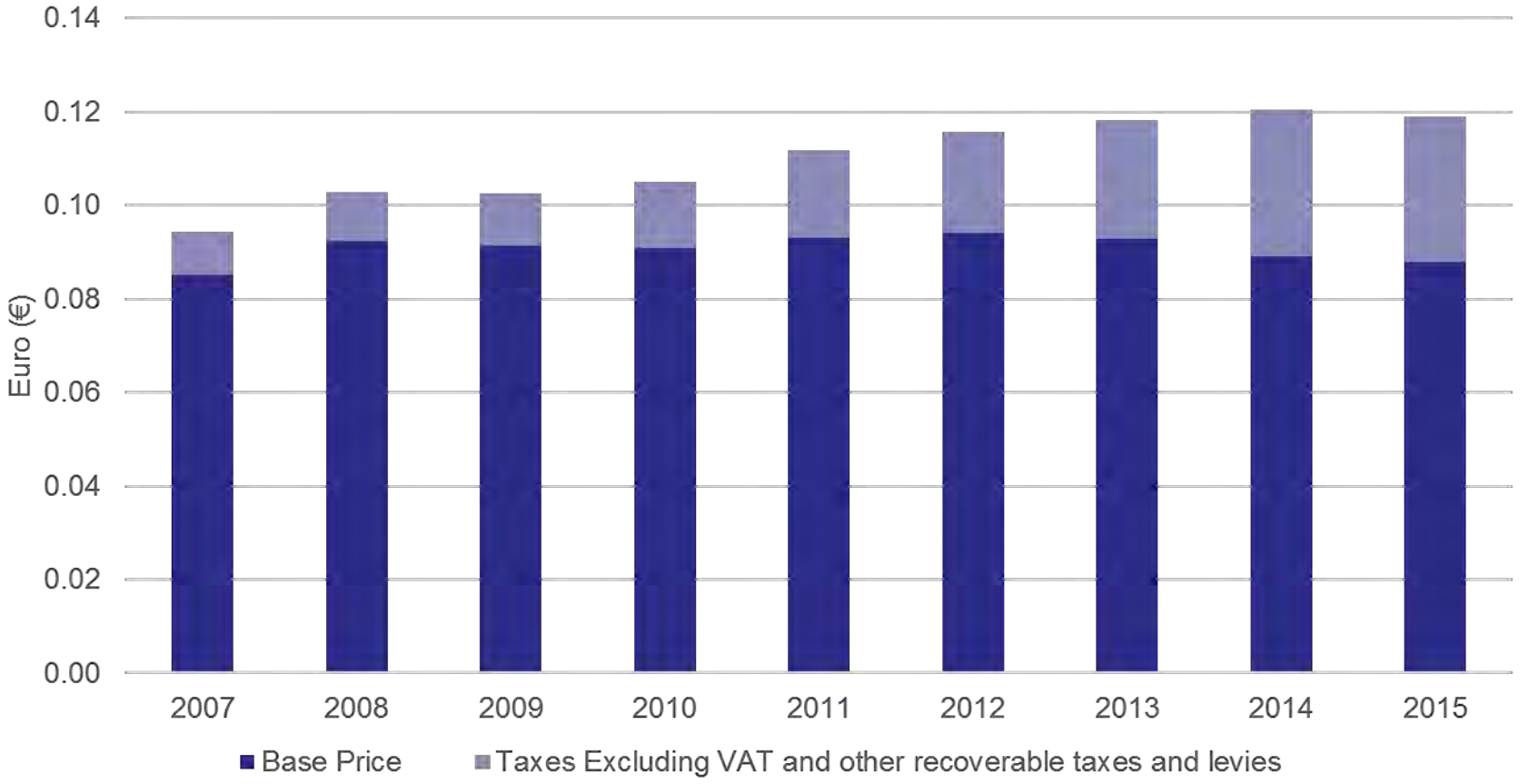


Investment Overview



11 kW induction motor + VSD
EU avg Electricity Price 2015: 0.119 €/kWh
1000 and 3000 operating hours per year

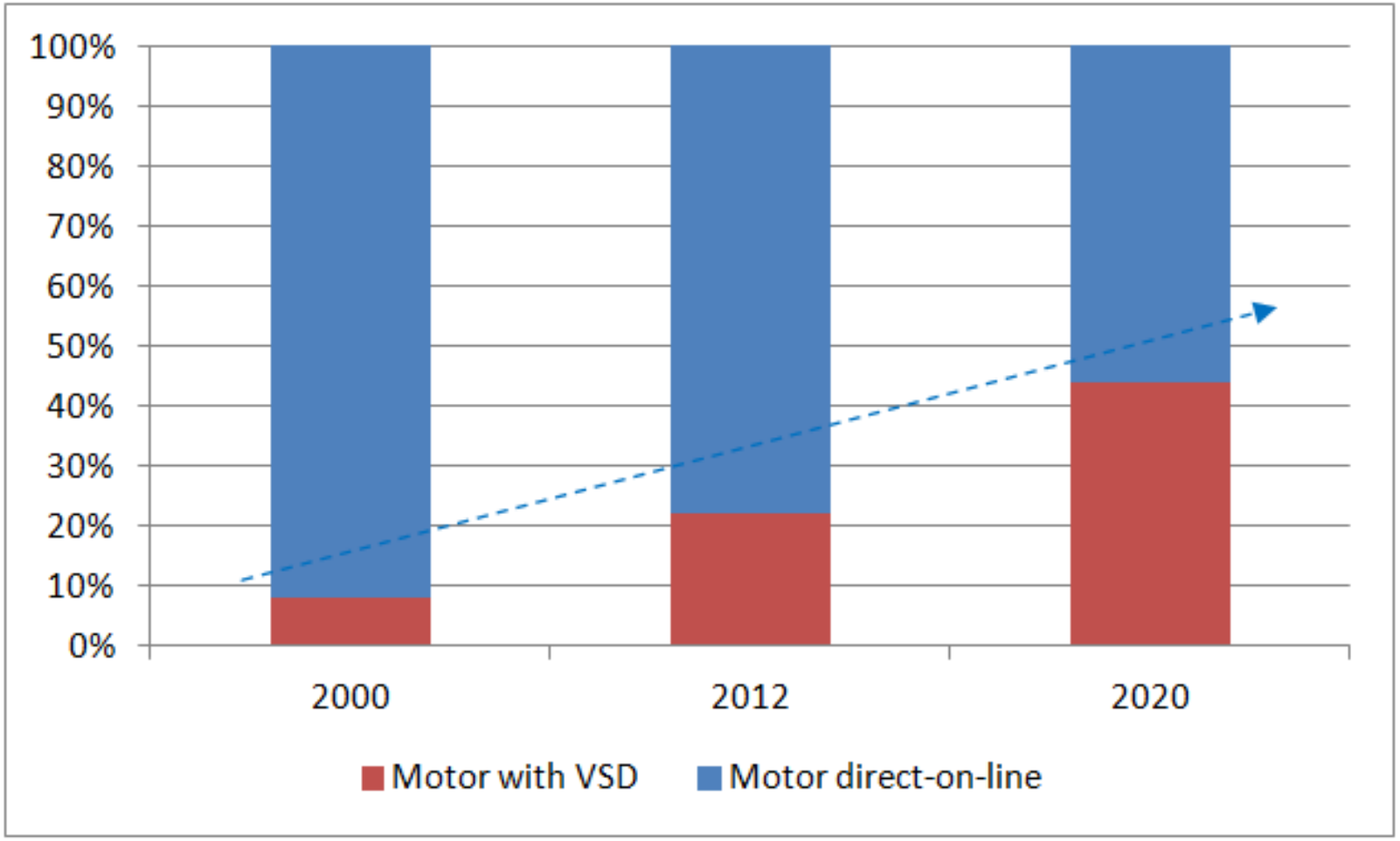
Electricity Prices in the EU28



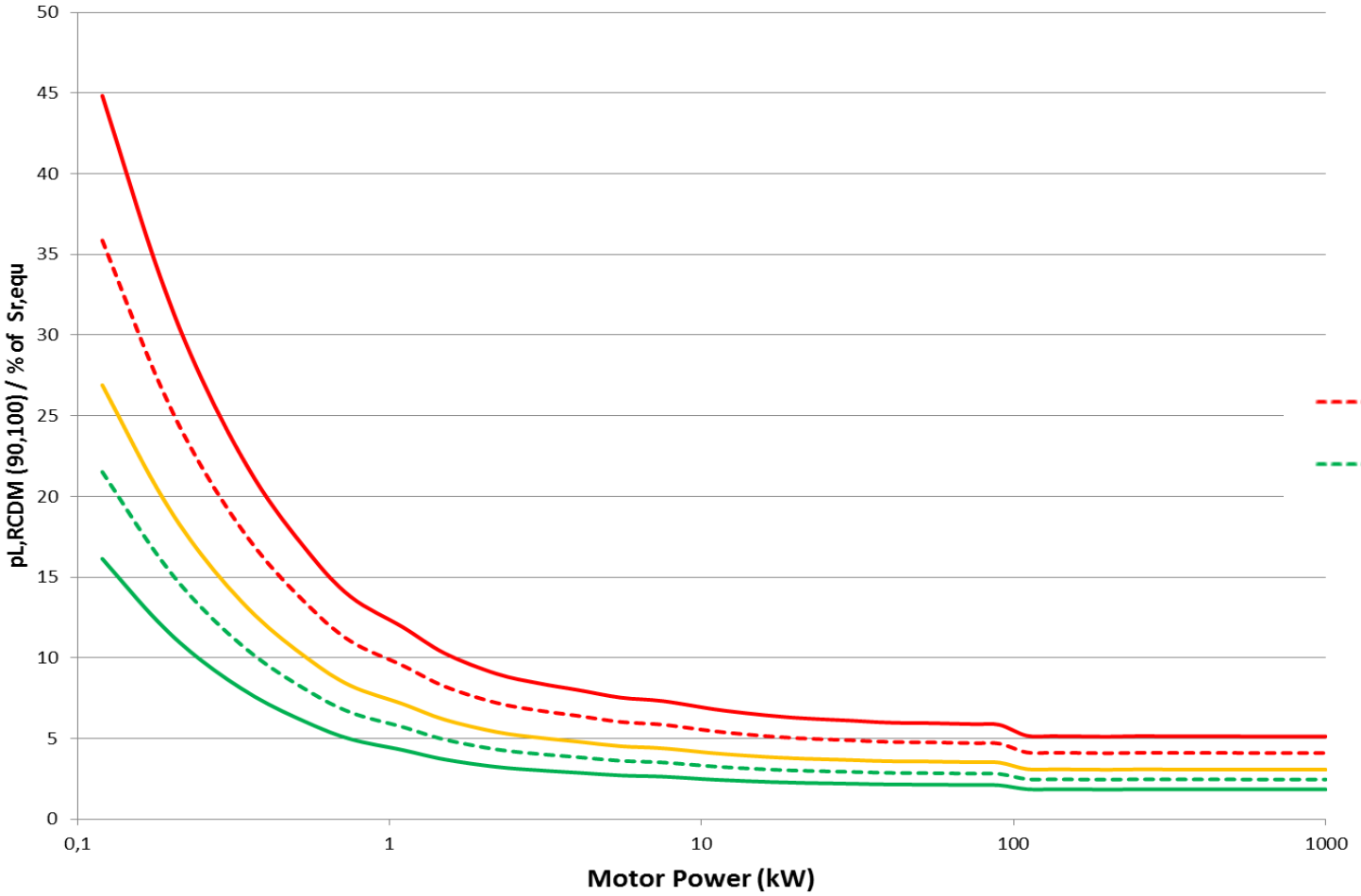
EU average Electricity Price 2015: 0.119 €/kWh
Band IC: 500 MWh < Consumption < 2 000 MWh

VSD market penetration forecast for 2020

(source: CEMEP)

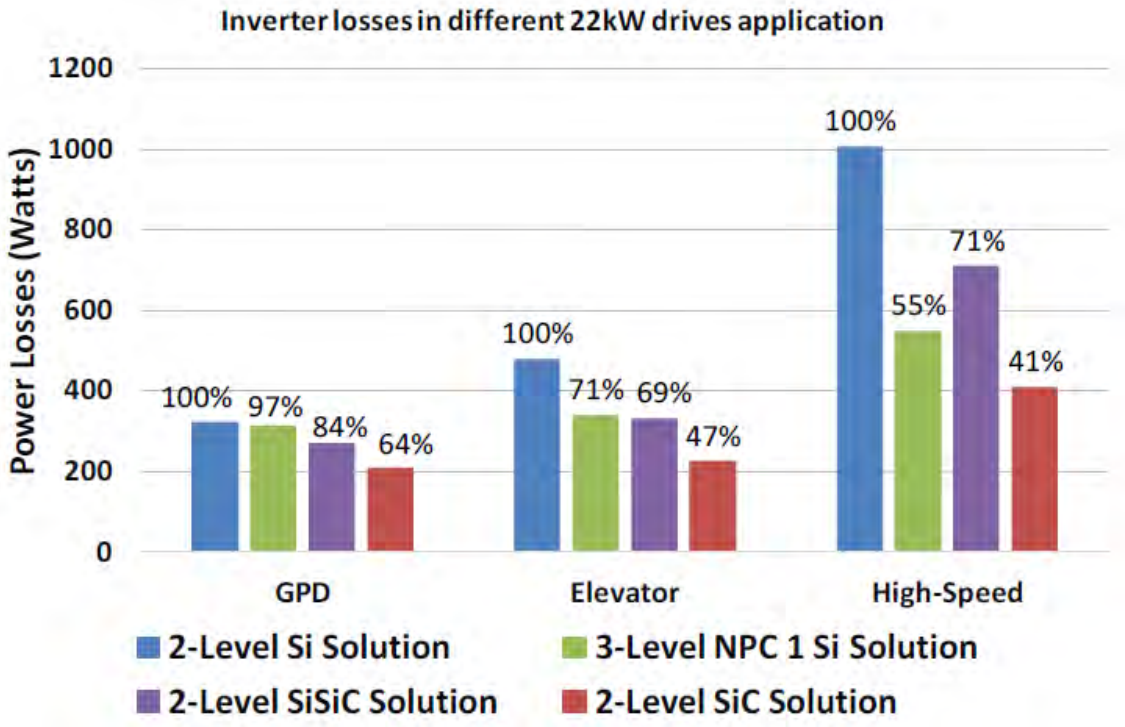


VSD Efficiency Classification
EN50598-2



Efficiency is defined by reference value +/- 25%

Inverter losses in different applications
22kW drive



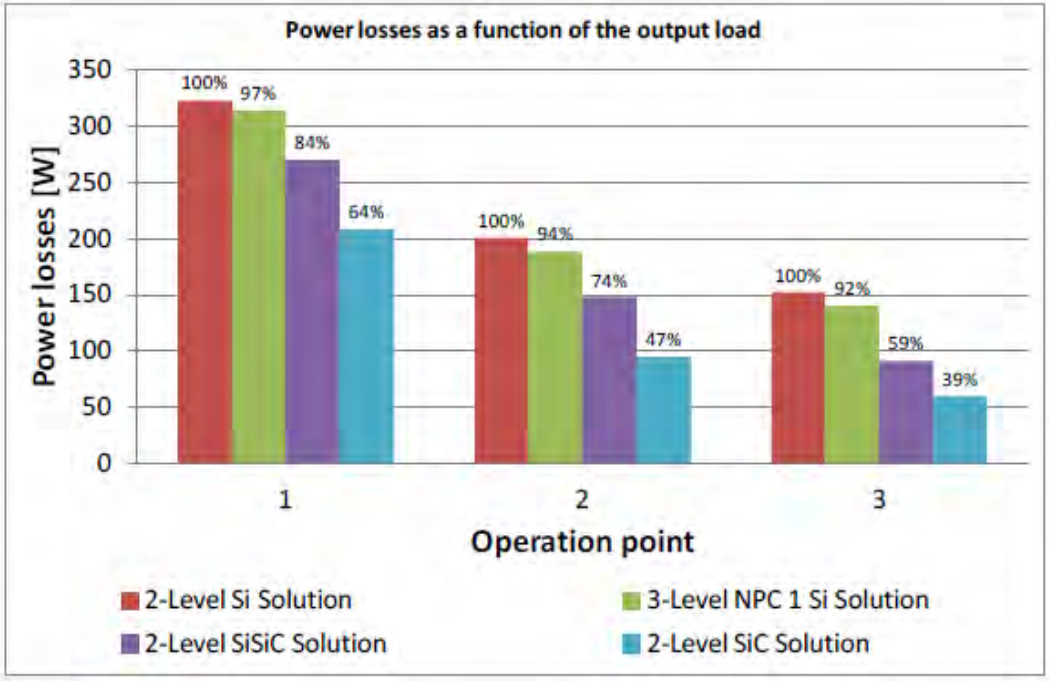
Typical power switching losses of 22 kW VSDs, 2-Level Si Solution as 100% reference GPD (fSW=5 kHz), Elevator (fSW=10 kHz) and high-speed (fSW=16 kHz).

Klaus Vogel, Adalberto Jose Rossa, Improving Efficiency in AC drives: Comparison of Topologies and Device Technologies, PCIM Europe 2014, 20 – 22 May 2014, Nuremberg, Germany

Inverter losses in different applications
22kW drive

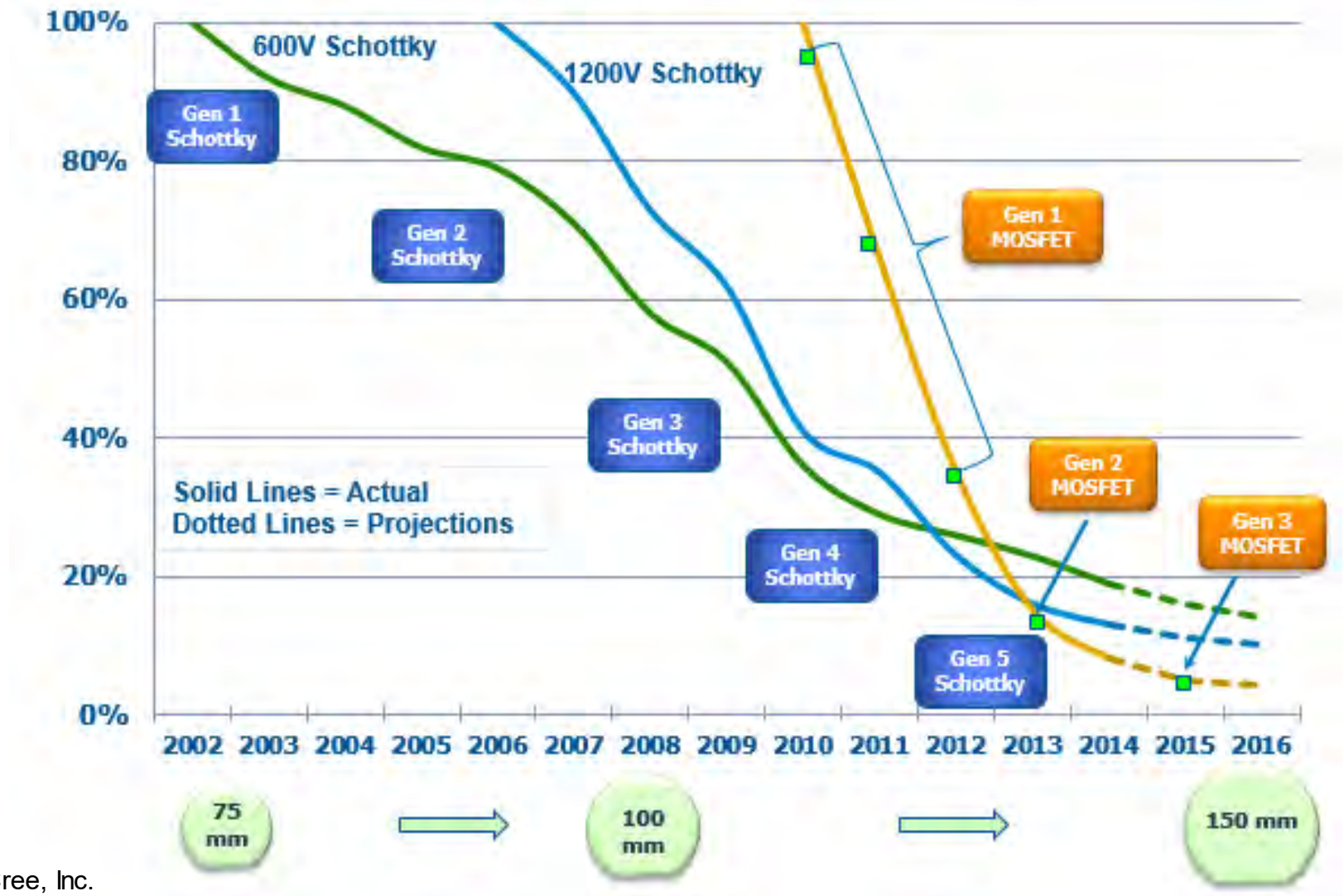
Operation conditions considered

Operation point	1	2	3
Motor speed (100%= rated motor speed) [%]	100	75	50
Motor Torque (100%= rated motor torque) [%]	100	56	25
Inverter Fundamental Frequency [Hz]	50	37,5	25
Inverter Output Voltage Uout [V]	400	300	200
Inverter Modulation index (m)	0,91	0,75	0,5
Motor Current Iout [Arms]	40,5	27	21
Motor Power Factor Cos(φ)	0,85	0,8	0,51



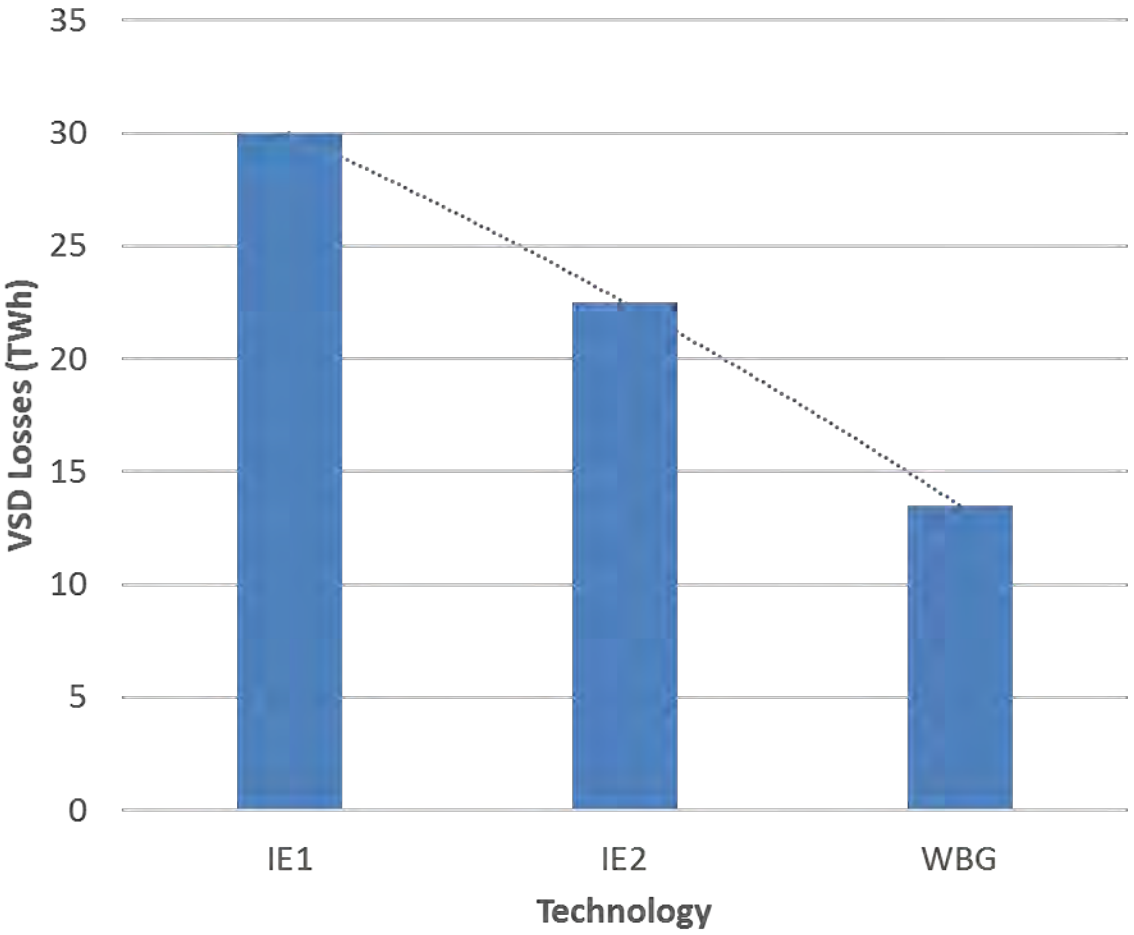
Klaus Vogel, Adalberto Jose Rossa, Improving Efficiency in AC drives: Comparison of Topologies and Device Technologies, PCIM Europe 2014, 20 – 22 May 2014, Nuremberg, Germany

Decline of Device Cost for SiC Products



Source: Cree, Inc.

VSD Savings in the EU
(0,75 – 375 kW)



- 45% penetration (2020)
- average efficiency 94.5%
- WideBand Gap potential to reduce VSD losses by 55%

Opportunities

Comparative experimental analysis (efficiency, starting performance, thermal, vibration) of different Super Premium motor technologies:

1 -Induction motor with copper rotor

2- Induction motor with aluminium rotor

3-Permanent magnet synchronous motor

4-Line start permanent magnet

5-Synchronous Reluctance

Opportunities

TYPES OF EXPERIMENTAL TESTS

- under different load profiles ($T = f(\omega)$)
- under different power quality conditions

  (voltage magnitude & unbalance, harmonics)
- Interaction of motor technologies with VSDs (efficiency of power drive system, motor and VSD)
- Future avenues for motor efficiency policy – moving from a components approach to a systems approach.

Opportunities

- Ecodesign assessment of super-efficient power drive system technologies