Energy Saving by Power Electronics in Household and Automotive Applications

Werner Weber, Infineon

Never stop thinking

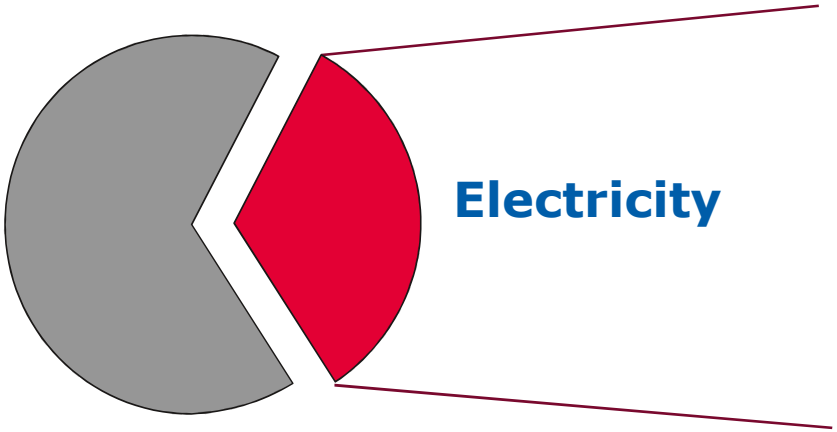
Agenda

- Introduction: global and regional energy consumption, its environmental consequences and ways to alleviate its effects
- The SmartPM Project
  - Motivation
  - organizational figures
  - Technologies & Demonstrators
- Examples of power saving by advanced power electronics
  - Household
  - Cars
- Brief comparison of different power devices

One third of the global energy use is based on electricity !

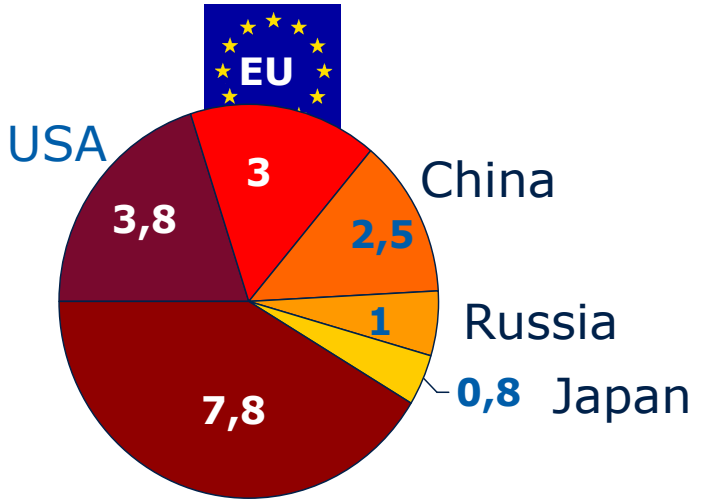
While debate continues over the environmental impact of different means of electricity production, its final form is relatively clean & it is one of the easiest means of transporting energy over long distances !

Global energy consumption 2006



Global electricity consumption 2006

16.4 million GWh



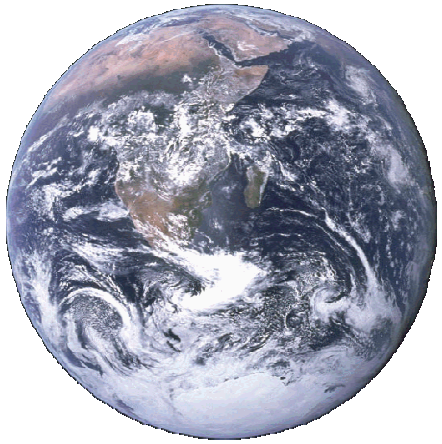
~1/3 of **global energy consumption** is electricity

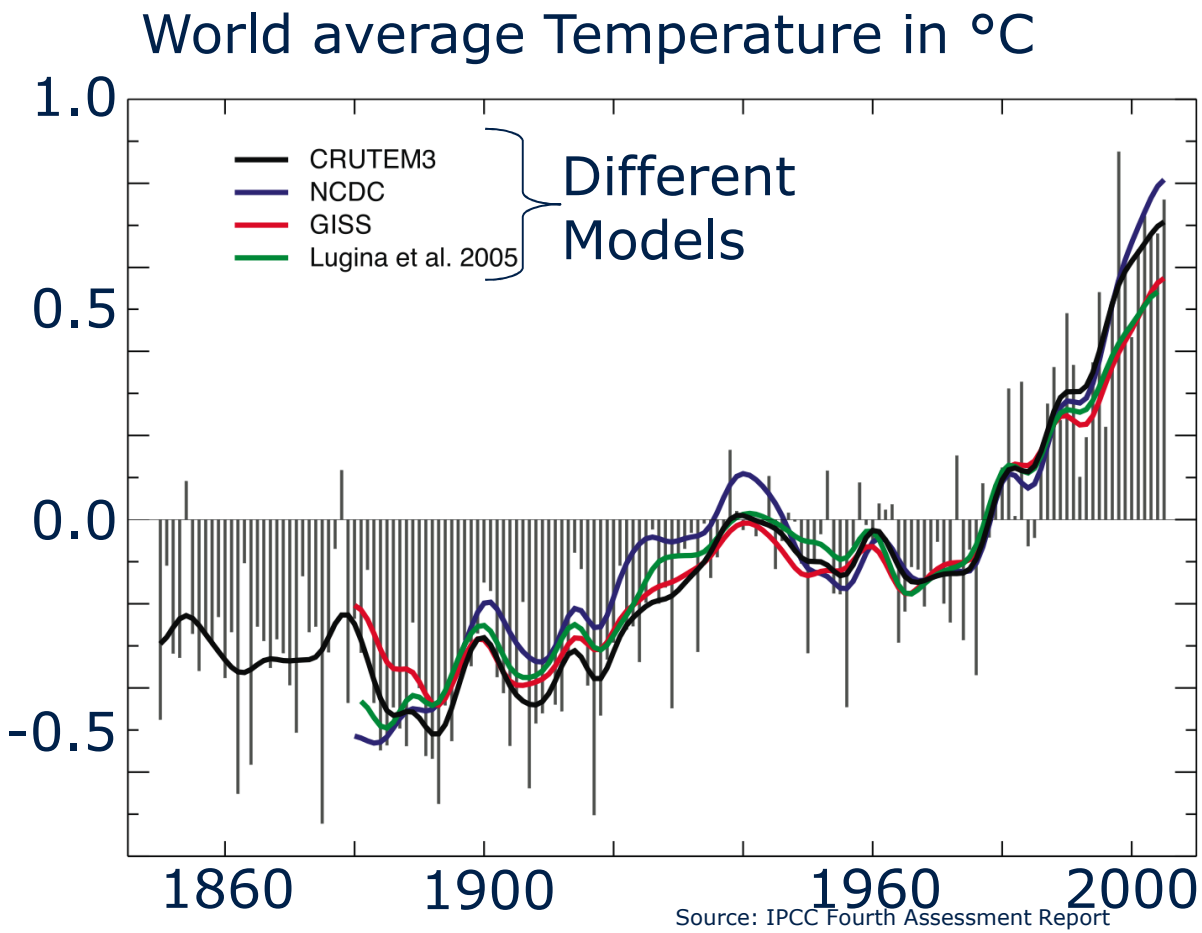
USA and the EU are the **largest consumers of electricity**

Sources: BP World Energy report; Energy Information Administration (EIA) – International Energy Annual 2006, Dec 2008
EU includes all 27 member states of the EU (http://europa.eu/abc/european_countries/index_en.htm)

Why Energy Efficiency?

Climate Change





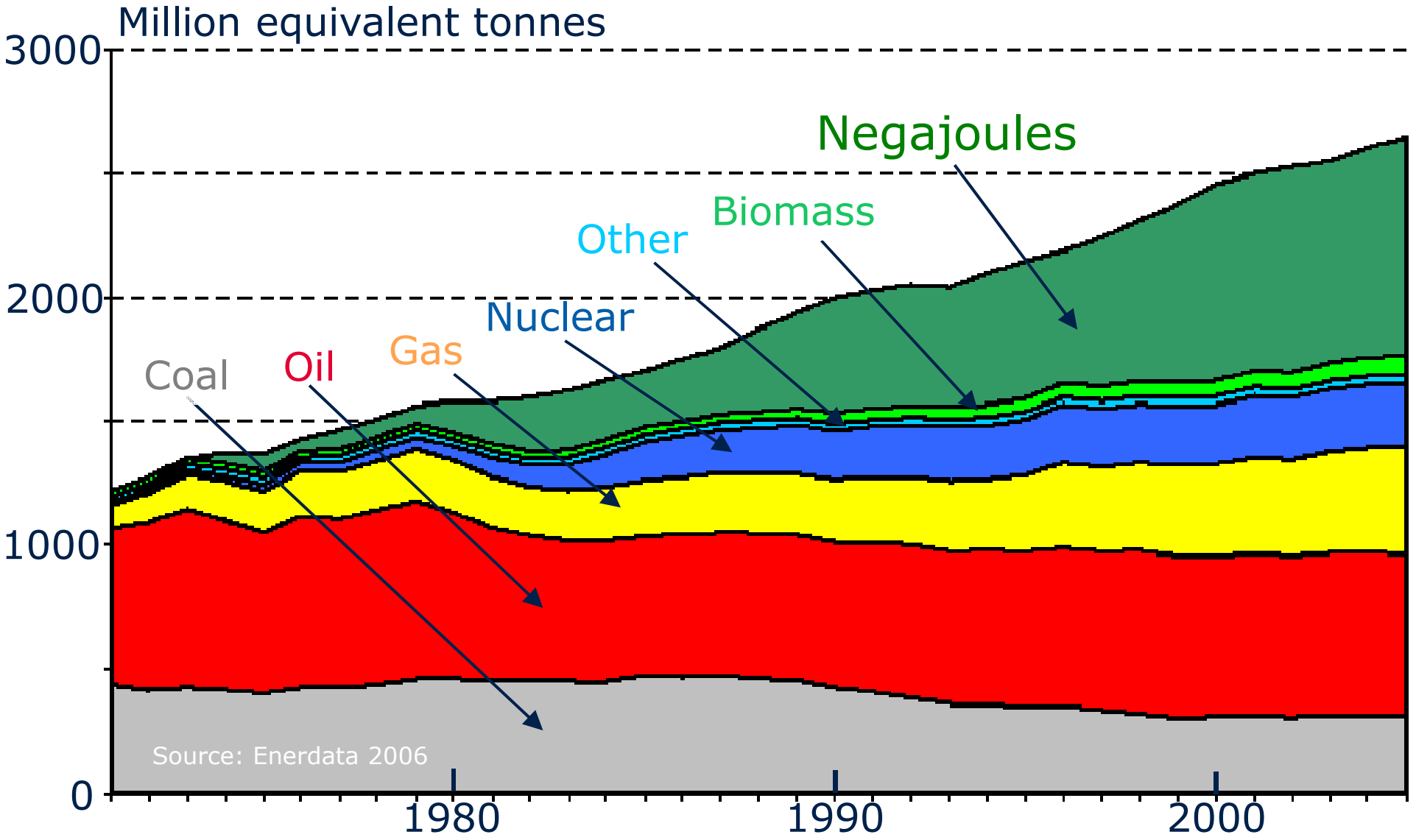
Source: IPCC Fourth Assessment Report

EU has actively adopted an integrated energy and climate change policy with clear targets

- **cutting greenhouse gases** by at least 20% of 1990 levels (30% if other developed countries commit to comparable cuts)
- **increasing use of renewables** (wind, solar, biomass, etc) **to 20% of total energy production** (currently ± 8.5%)
- **cutting energy consumption** by 20% of projected 2020 levels by improving **energy efficiency**

Source: http://ec.europa.eu/climateaction/eu_action/index_en.htm; December 2008

Energy Efficieny became the largest Energy Source in the EU

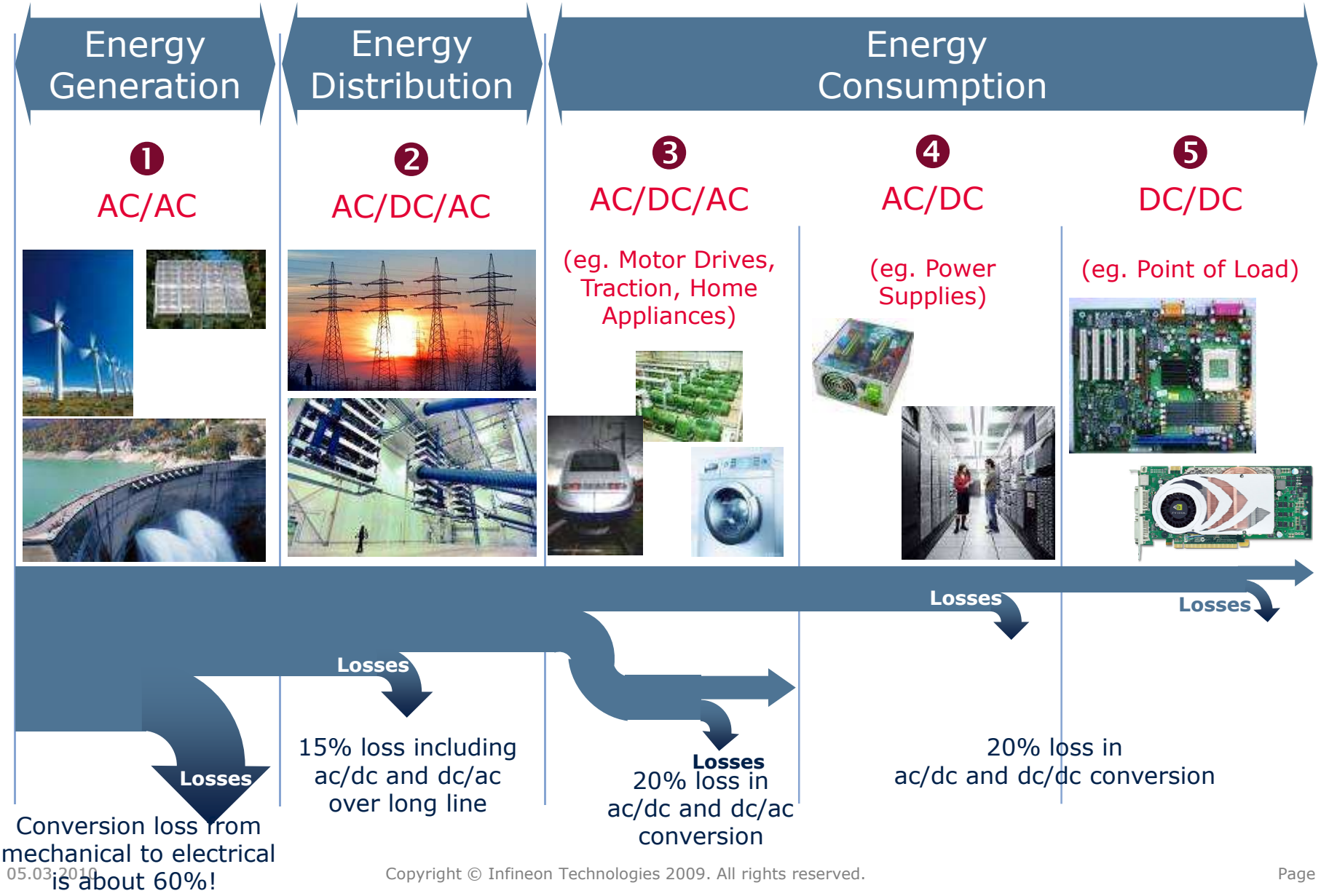


Standard Setting Powers

- European Minimum Standards related to ICT:

Stand-by and off-mode losses	Adopted
Simple set-top boxes	Adopted
External power supplies	Pending
Televisions	Adopted
Computers	Pending
Imaging equipment	Pending
Complex set-top boxes	Pending

A big portion of the energy consumed is LOST as heat, along the complete supply chain



Significant saving potentials using microelectronics are possible today !

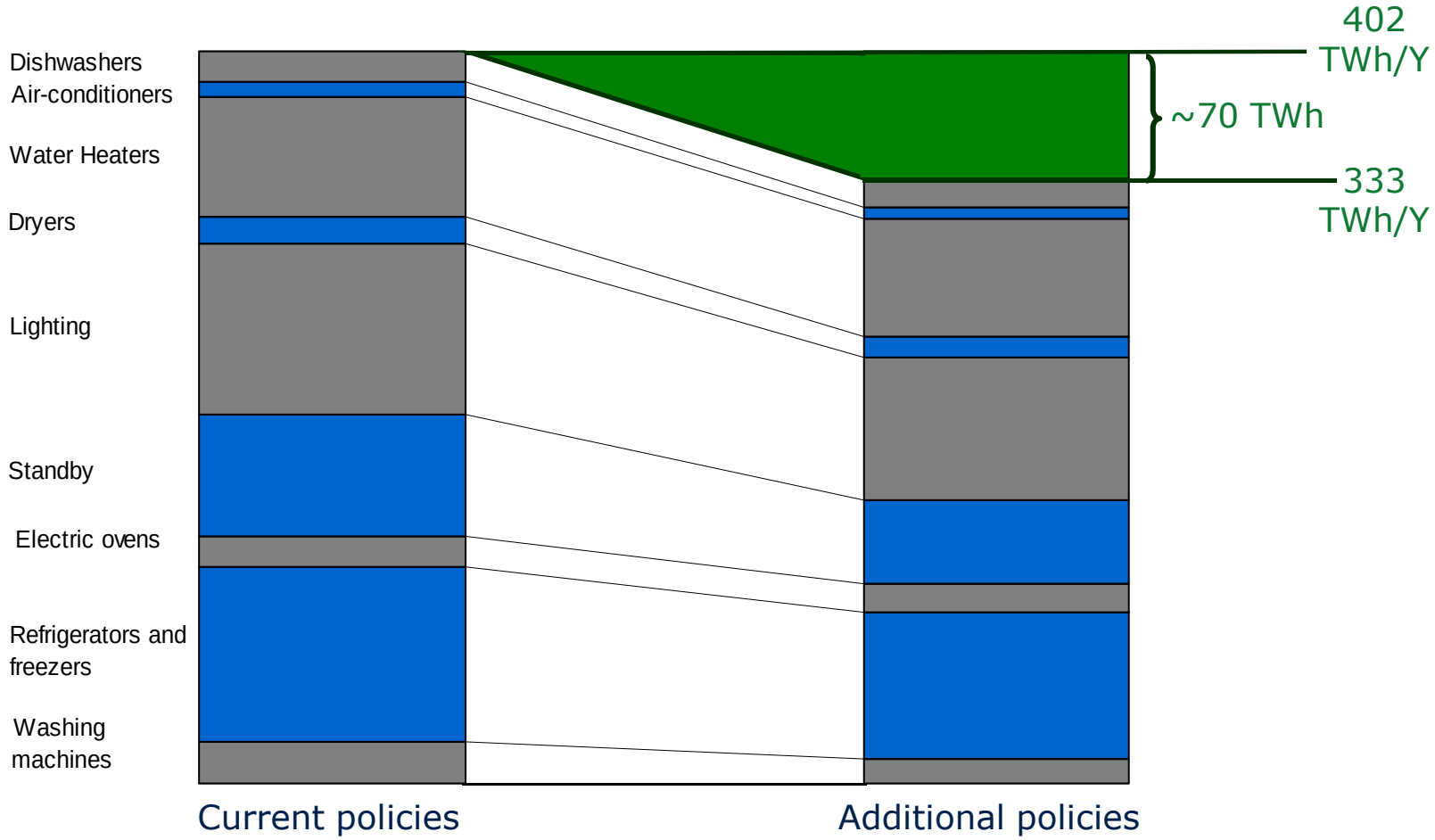
Consumers electrical energy (Europe)

	Electricity consumption		Saving potential	Key technology
Consumer power supply: - stand-by, - active mode, …	**Others 18%**	- stand-by - active	**>90%** **>>1%**	CoolMOS™, SiC Smart control ICs CoolSET™
Computing power supply, - stand-by, active mode, …	**Information & Comm. 12%**	80+ / 90+	**>>1%**	CoolMOS™, SiC, Smart control ICs, Low cost µC
EC-Ballast Daylight dimming HID, LED, …	**Lighting 15%**	Electronic control	**>25%**	CoolMOS™ Smart ballast ICs Low cost µC
Factory automation, Process engineering, Heavy industry, Light industry, …	**Motors 55%**	Variable Speed Drive (VSD)	**25% … >40%**	IGBTs Modules CoolMOS™ Optimized µC 8 bit / 16 bit / 32 bit
Transportation: Train, bus, car, …		VSD + Bi-directional energy flow		
Home appliance: Fridge, washing machine, Air conditioning, …		VSD		

Sources: ZVEI, Infineon, 2008

Saving Potential per Segment in Europe

- About 70 TWh per year can be saved in European households
  - With additional policies
  - With current available technologies



Sources: Wai 2004, Kem 2004; Joint Research Center IES, Status report 2004

Motivation
Smart Power Management in Home and Health

- Energy consumption is predicted to double in the coming 20 years, as so will the CO_2 emissions
- The political, social and technical challenge of the next decade is, to achieve efficient use of energy and reduce energy consumption by at least 30%
- The political goal is, to reduce Europe's dependence on energy suppliers and increase economic competitiveness by creating new market sectors.

⇨ The target of the project Smart**PM** is, to develop application-specific, efficiency-optimized semiconductor power technologies enabling the deployment of intelligent systems, that can save up to **25 %** of electrical energy consumption without losing performance, comfort and safety

The research leading to these results has received funding from the ENIAC Joint Undertaking under grant agreement n° 120008 and from national programs/funding authorities German Federal Ministry of Education and Research (BMBF); the Belgian IWT; the French Ministère de l'Economie, des Finances et de l'Industrie; Secrétariat d'Etat à l'Industrie (STSI); Enterprise Ireland; the Italian Ministero Istruzione Università Ricerca; APRE Agenzia per la Promozione della Ricerca Europea; the Dutch SenterNovem; the Research Council of Norway; the Spanish DGI-Ministerio de Educación y Ciencia; and the Swedish Vinnova.

SmartPM Consortium

18 partners under the leadership of Infineon

Press release

News Release of the European Technology Cooperation “SmartPM”

News Release/Presseinformation

European Technology Cooperation “SmartPM” for Energy Savings in Home Appliances, Healthcare and Medical Equipment Aims at Reduction of Electricity Wastage to a Minimum; Under Infineon Project Coordination

Neubiberg, Germany – September 8, 2009 – As awareness increases about climate change, stringent emission controls, dwindling energy resources and a rising demand for energy, it is more important than ever that the available electrical energy is consumed efficiently. Supporting this approach, together with 17 European partner companies Infineon Technologies (FSE: IFX / OTCQX: IFNNY) has formed the technology cooperation SmartPM (Smart Power Management in Home and Health) to bring down electrical waste to a minimum in home appliances, power supplies and in healthcare and medical equipment. Under the project coordination of Infineon, the companies are collaborating to significantly increase energy efficiency savings in

organizational data

- Start of Project by EU: Feb. 2009
- End of Project: Jan. 2012
- Total Project budget: € 19.8 Mio
- Total funding (partly national, partly EU): € 10.3 Mio
- 18 partners from 9 European countries including Belgium, France, Germany, Ireland, Italy, the Netherlands, Norway, Spain and Sweden

Scope of work
Smart Power Management in Home and Health

- Smart**PM**'s research fields are innovative system architectures and circuits, new components, efficient power electronic technologies and innovative module, interconnect and assembly technologies
- Technologies investigated are Si, SOI, and SiC
- Voltage ranges include
  - <100V (low voltage)
  - 120 – 400 V (net voltage)
  - > 1000V (high voltage)
- Various demonstrators are to be implemented in Smart**PM** as discussed below

Demonstrators

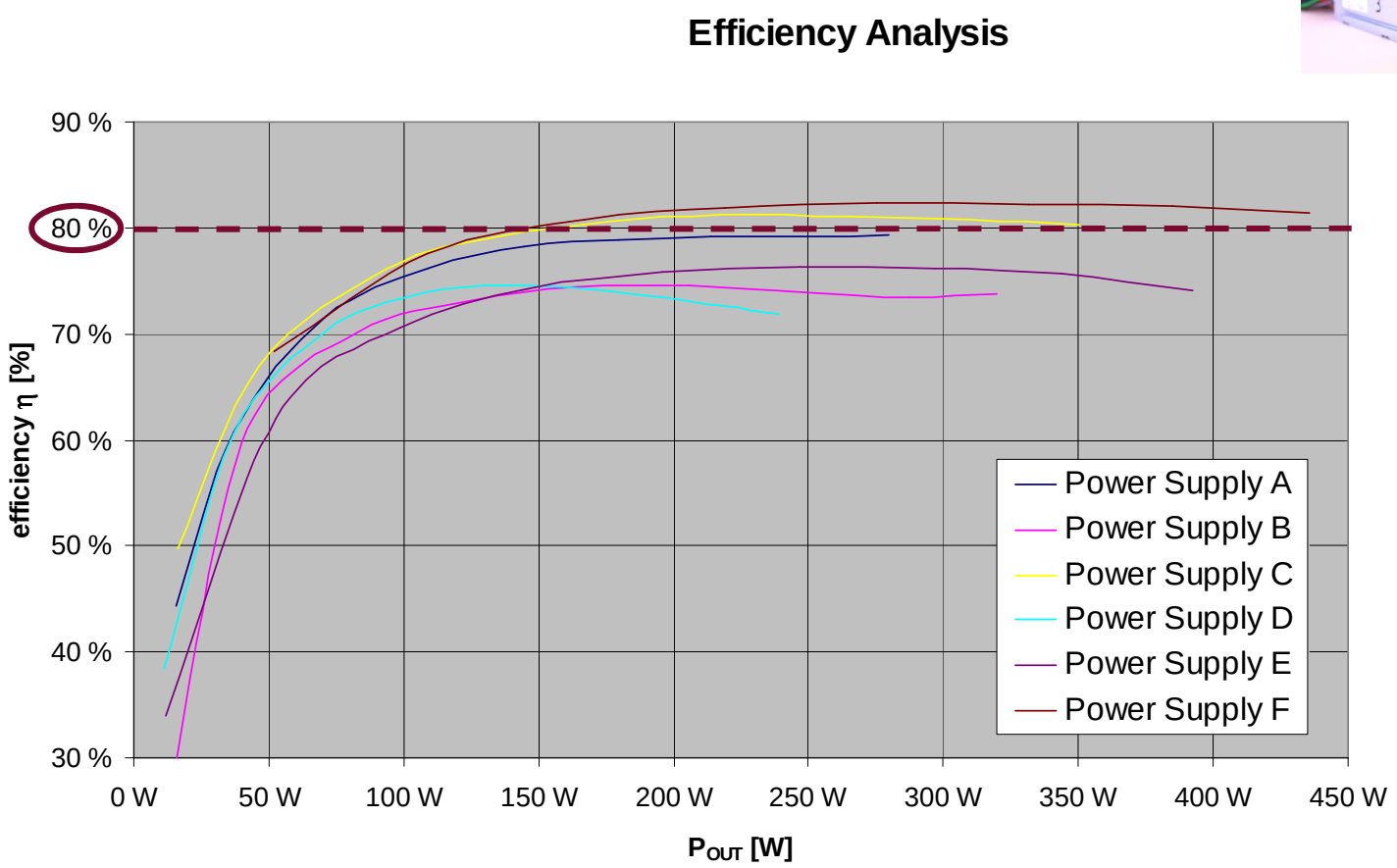
- 1. Power saving in TV by novel circuits and control (Philips NL)
- 2. Pulse Width Modulator for Power Applications (Telefunken)
- 3. Highly integrated intelligent power module for Motor Drives (HI2PM) (Infineon)
- 4. High voltage rectifier for X-Ray imaging (Philips D)
- 5. High voltage Grid switch for X-Ray tubes (Philips D)
- 6. AC/DC Power supply for embedded PC's (Kontron)
- 7. Ultrasound Transceiver, component level (GEVU)

Examples for energy savings

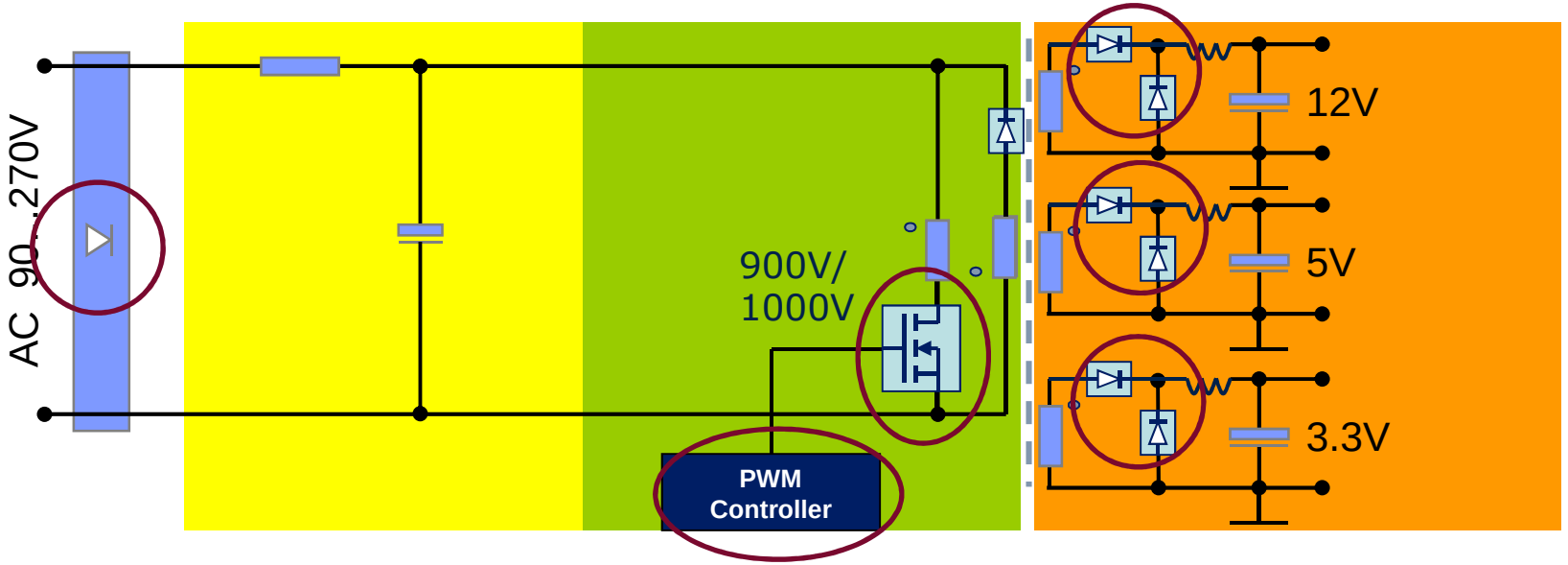
- reducing standby losses,
- On-current in data centers and PCs
- AC/AC, AC/DC and DC/AC conversion for energy generation and distribution
- Power saving in automotive applications

Let's take the example of PC power supplies…

Conventional power supplies achieve efficiency of around 70%-80%



They typically use single transistor forward topology with one power MOSFET & some diodes



Passive PFC stage

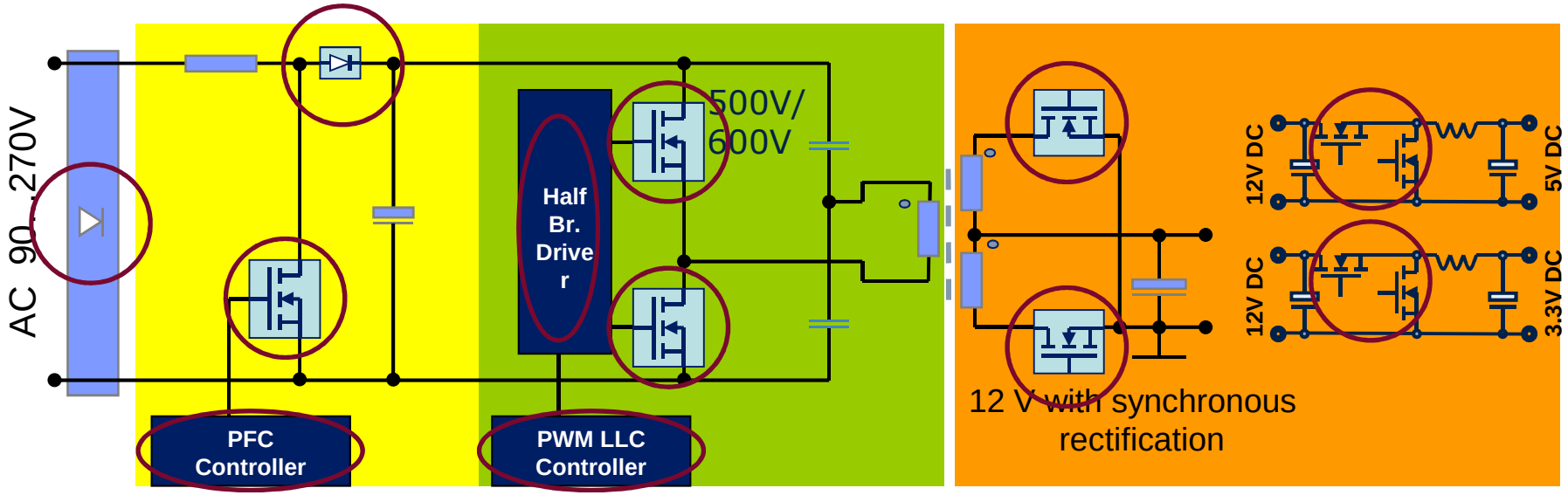
PWM stage
- Galvanic insulation
- PWM-IC
- 900V/1000V MOSFET

Three **secondary side** windings on one transformer
- Diodes 12V, 5V, 3.3V

PFC=Power Factor Correction PWM=Pulse Width Modulation

Indicates Power Semiconductor content

However, with the use of new topologies on primary and secondary side …



PFC stage

- ensures current to follow voltage sine wave, PF=1
- hard switching, 64..100 kHz
- CoolMOS 500V/600 V, 199 mOhm
- SiC Schottky diode 600V

PWM stage

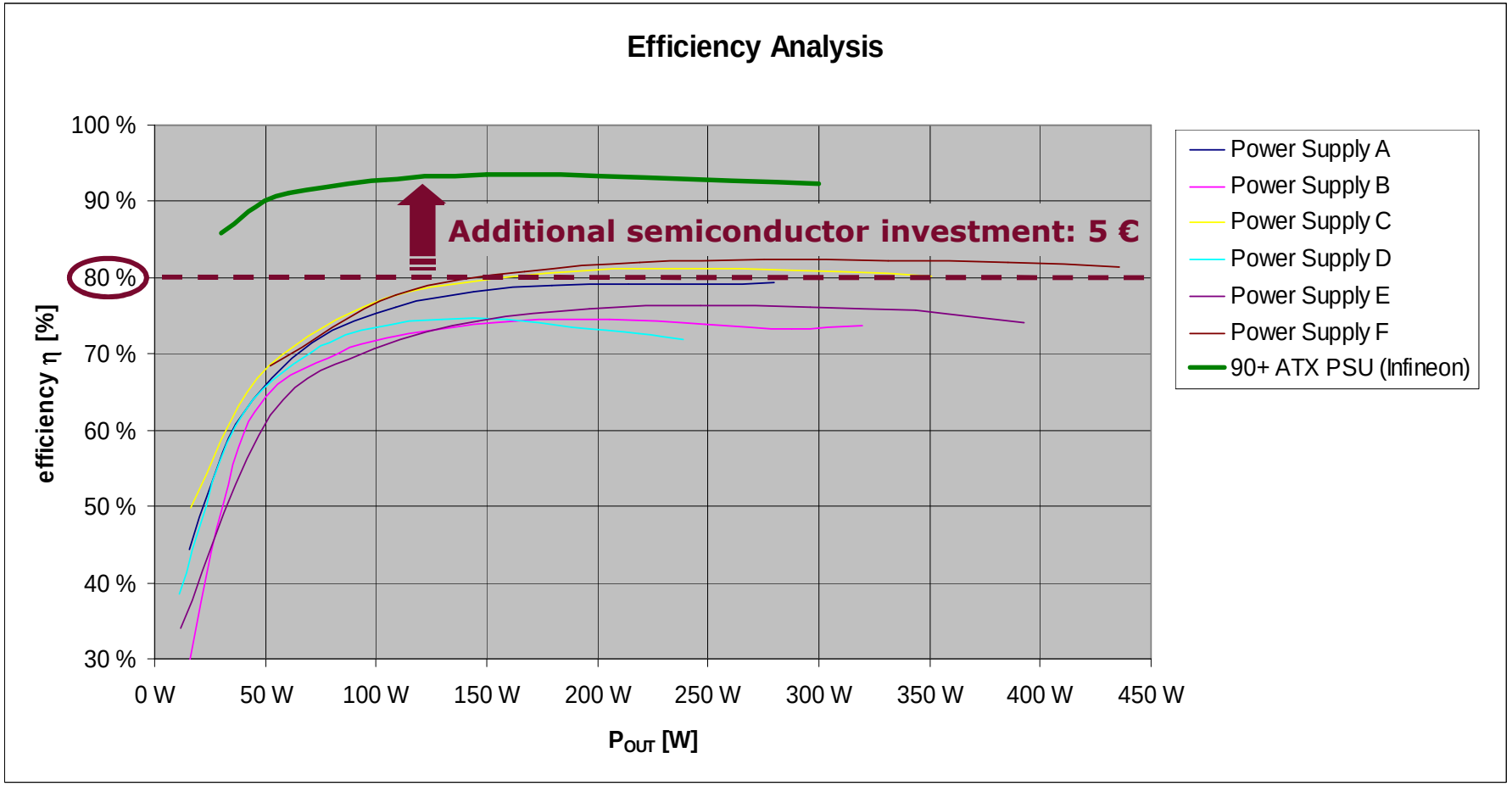
- Galvanic insulation
- hard or resonant sw., 100..200 kHz
- CoolMOS 500V/600 V, 199 mOhm C6
- PWM IC and Half Bridge Driver

Secondary rectification

- synchronous rectification for 12V
- hard commutation, 100..200 kHz
- OptiMOS 60..100 V, 5..10 mOhm
- Buck Stages for 3.3V and 5V

Indicates Power Semiconductor content

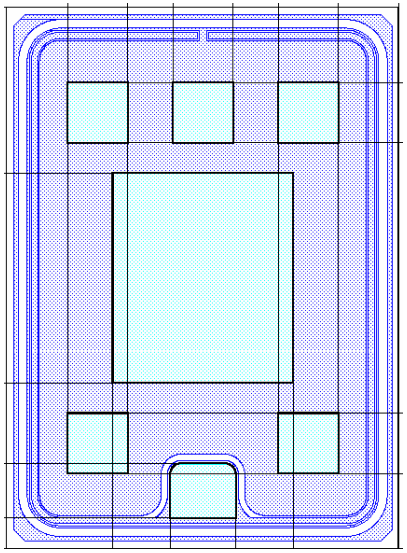
… we can achieve up to 10% increase in efficiency with an extra expense of upto €5 per system*



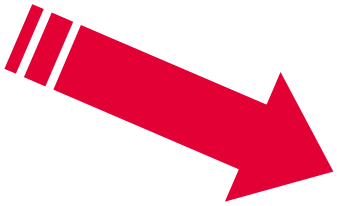
* Infineon Estimation at System level for a 300W power supply

Further potential exists with new devices like SiC to increase efficiency & power density !

CoolMOS
1000V / 1.2Ω

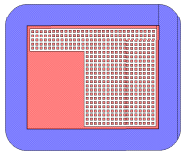


Status today :



>9x size reduction !!!

SiC JFET
1000V / 1.2Ω
1500V / 1.7Ω



SiC JFET benefits:

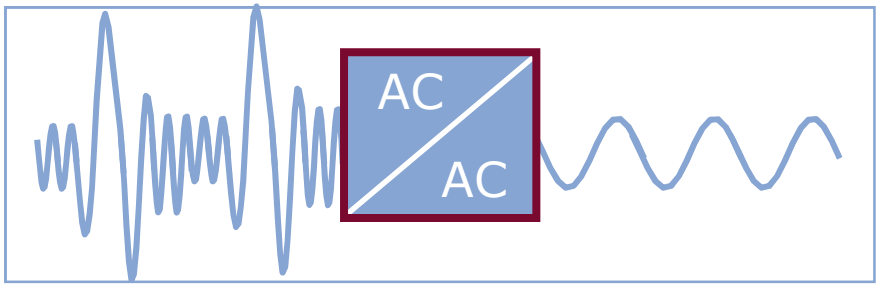
- **Higher power density & lower capacitive losses**
- **Ruggedness via gate oxide absence**
- **Excellent build in body diode**
- **High T (>> 200℃) capability**

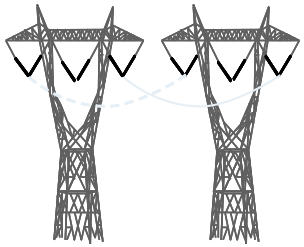
→ SiC switch is already cost competitive with Si MOSFET technology for 1200V and above !

→ Within the next 2-3 years, SiC switches should be competitive down to the 600V level!

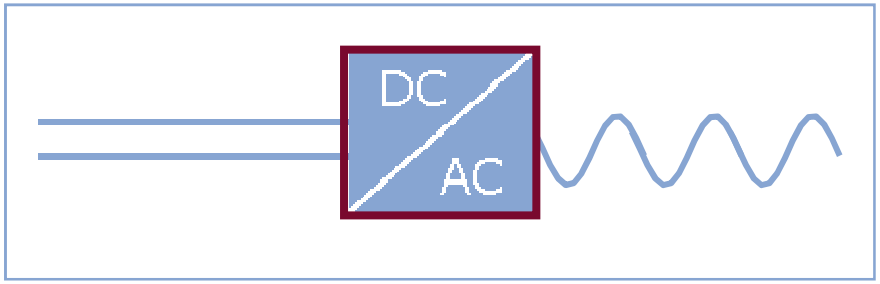
Converters driven by microelectronic components enable excellent grid coupling

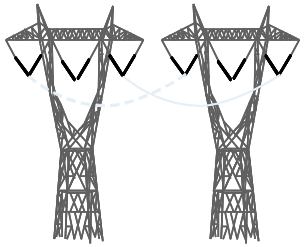
Wind Power: High efficiency coupling to grid



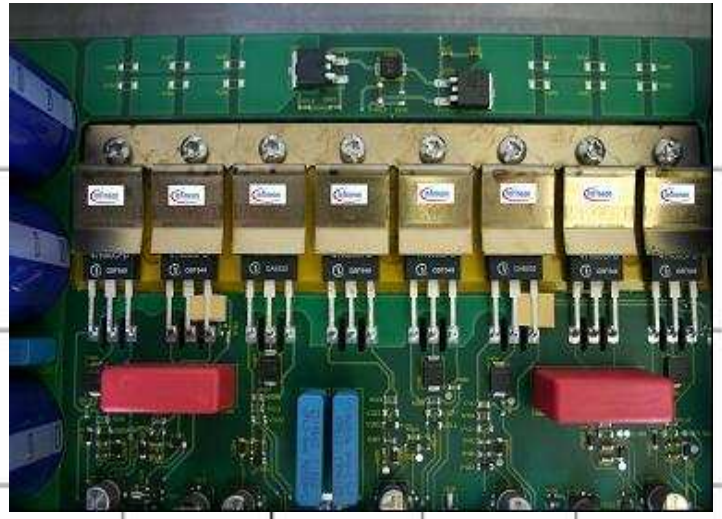


Solar Power: Direct current is delivered by solar panels





Use of latest generation of SJ devices results in highest efficiency in photovoltaic converters !



6 kW converter,
98.1% efficient

1% efficiency gain is worth 600 € more pay back in 20 years life time,
Inverter cost is 5% of panel cost only, semiconductor cost even less!

Source: SMA test report

Global CO_2 Targets

CAFE May 2nd 2008
Cars + LD: 35 mpg by 2020

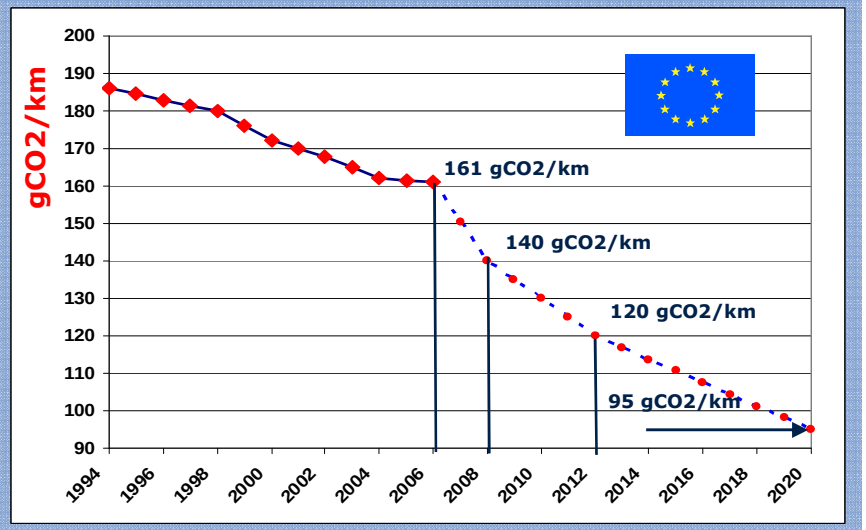
EU Dec. 17th 2008
Cars: 95gCO_2/km by 2020

Overall tax: Car, Fuel and CO2
-On the Fuel (≈90€ per gCO2/km)
-On the Car (≈30€ per gCO2/km)
-On the OEM (≈95€ per gCO2/km)
-On the CO2 (≈20€ per tone CO2)

Car running 10 years
16.000 km/y or 10.000 miles/y

Conversion table for regular gasoline engine

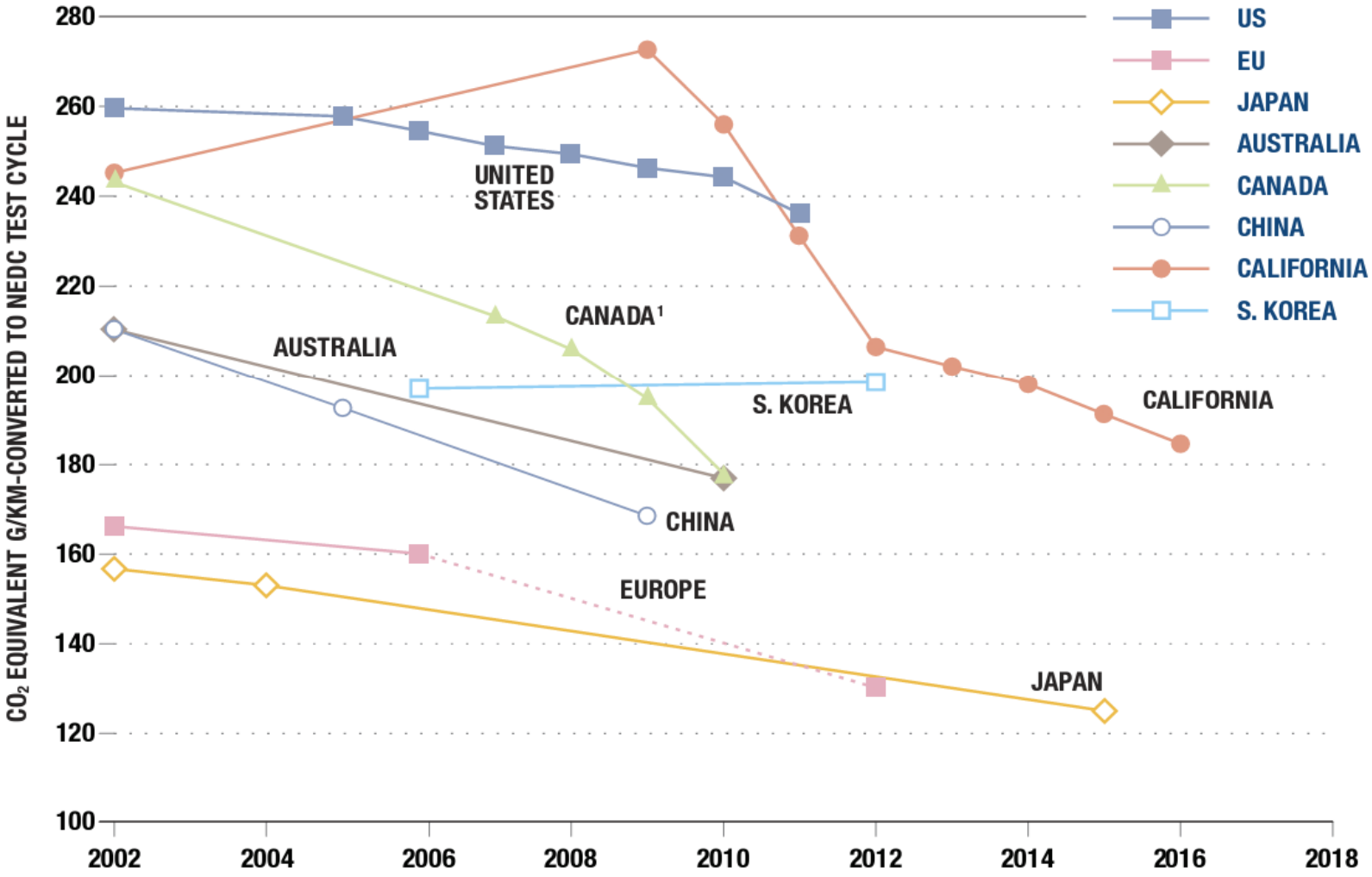
gCO2/km	155	140	130	120	110	100	95
L / 100km	6.72	6.08	5.65	5.21	4.78	4.34	4,13
MPG	35.0	38.7	41.7	45.1	49.2	54.2	57.0



Barrel Price from June 2008 to June 2009

http://www.wtrg.com/daily/crudeoilprice.html

Planned CO_2 Reduction Measures



Semiconductor Contributes to Sustainable Mobility

Engine

- More precise injection and more efficient throttle control lead to less petrol consumption

Transmission

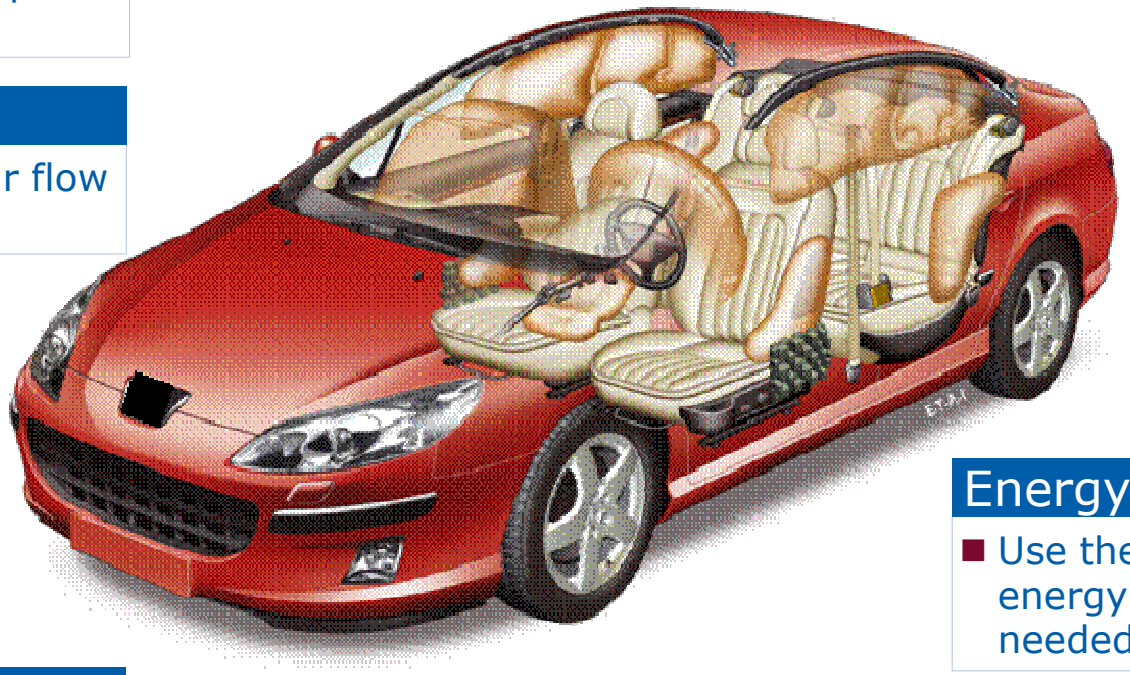
- Aim is to minimize energy losses when changing gears

Hybridization

- Efficiently use electricity to power the car

Air Drag

- Improvement of air flow



Energy Management

- Use the right quantity of energy only when it is needed

Friction Reduction

- Tire pressure control reduces friction thereby reducing consumption

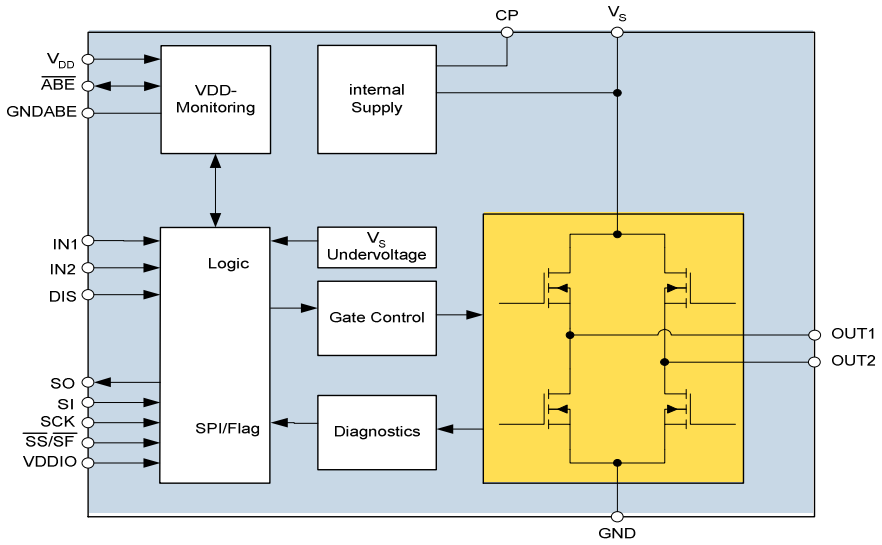
Energy Efficiency

- Use minimum energy for a certain function

WEIGHT

- Light weight System approach

High Current H-bridges for DC-Motor Control in Powertrain Applications



Features:

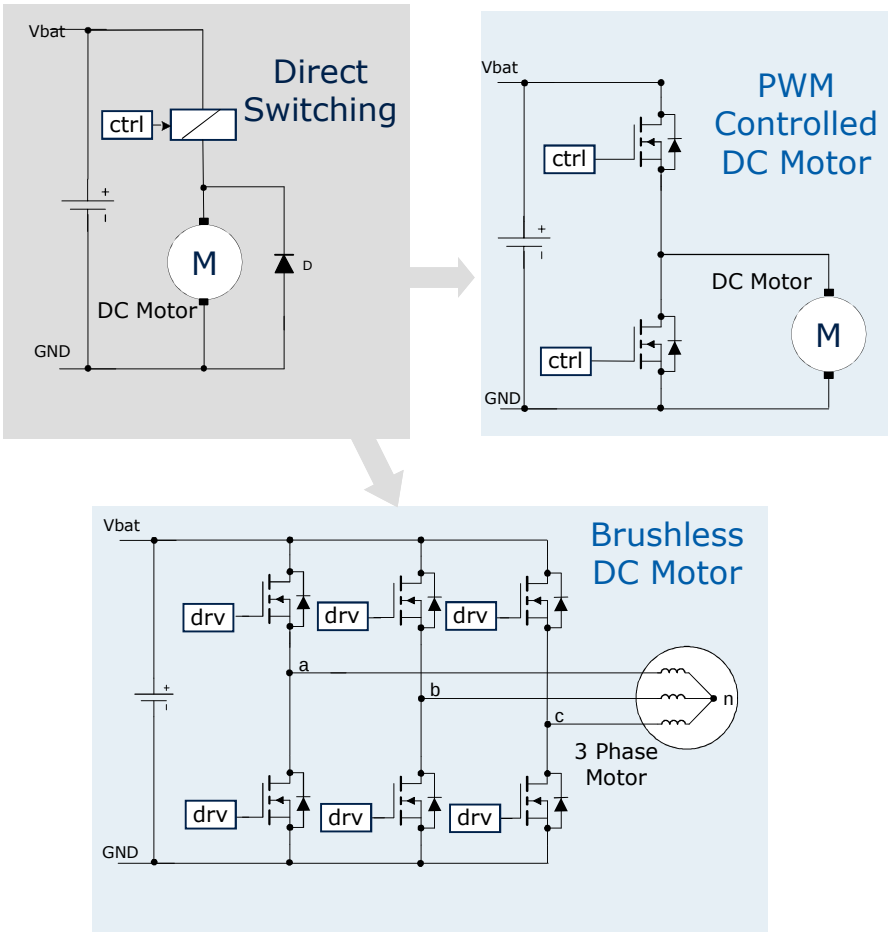
- Power Stages up to 300 mΩ
- Slow rate & current limitation program module
- Control in Dual Half Bridge Mode
- 8bit SPI Register
- …

Applications examples:

- Electronic Throttle Control (ETC)
- Exhaust Gas Recirculation (EGR)
- Turbo Charger Waste Gate
- Variable Turbo Geometry (VTG)
- Swirl and Tumble Flaps
- Variable Intake Manifold
- …

Power on Demand
PWM Regulated Fuel Pump

- Demand controlled by PWM
- Reduced Average Power Consumption up to 40 %
- Technologies available



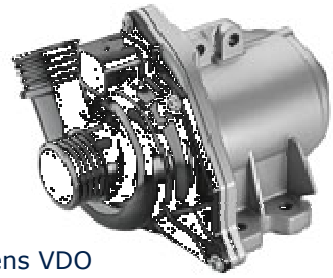
Total Power Saving ~ 80 W

CO_2-reduction ~ 1.9 g/km

Energy Management: Electric Water Pump

Uncontrolled	PWM controlled
Water pump directly driven from engine	EC-motor drives water pump (8 bit µC / B6-bridge / package / PWM interface)

- Main benefit: Improved thermal control of engine + better efficiency of pump
- Feasibility: available technology, complexity: low



Source : Siemens VDO

- CO_2 Benefits:

Benefit equivalent	~ 300W el.
Estimated additional costs	~ 55€
Reduced fuel consumption	~ 0.3l / 100km
CO_2-reduction	~ 7.1 g/km

Pays off after less than 12.000 km or 0.8 years

Engine Management
Alternator

Conventional

Rectification with diodes

Active rectified

Replacement of diodes by B6-MOSFET-bridge (16 bit µC / B6-bridge / package / LIN)

- Main benefit: Efficiency improvement of 10% by reduced diode losses, calculated with 1.0 kW continuous output power
- Feasibility: available technology, complexity: medium (very high currents)

Source : Valeo

- CO_2 Benefits:

Loss improvement	~ 100W el.
Estimated additional costs	~ 60€
Reduced fuel consumption	~ 0.1l / 100km
CO_2-reduction	~ 2.4 g/km

Pays off after 37.000 km or 2.5 year

Energy Management: Electric Power Steering

Uncontrolled	PWM controlled
Hydraulic power steering with overpressure valve	EC-motor with field oriented control (32 bit µC / B6-bridge / Π-Filter / package / connectors)

- Main benefit: Provides torque only when needed, power consumption reduced from 300 W to less then 50 W in average
- Feasibility: Available technology, complexity: medium (high currents)

Source : ZFLS

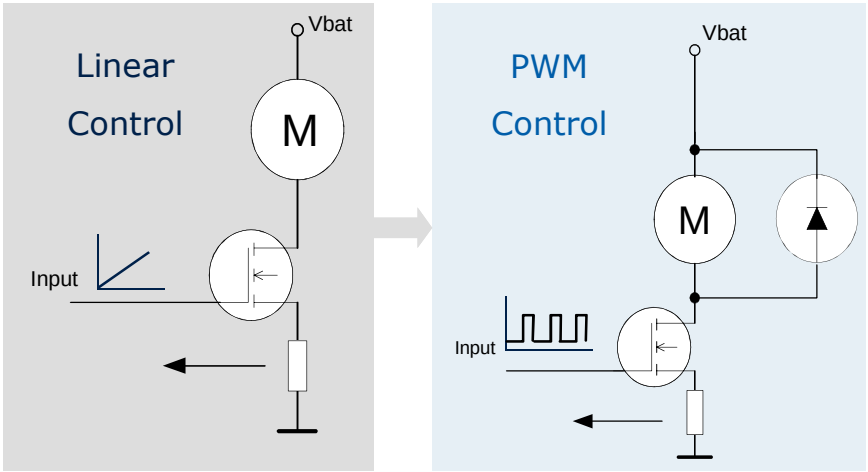
- CO_2 Benefits:

Loss improvement	~ 250W el.
Estimated additional costs	~ 60€
Reduced fuel consumption	~ 0.25l / 100km
CO_2-reduction	~ 5.9 g/km

Pays off after 15.000 km or 1 year

HVAC System Has Huge Saving Potential
PWM Controlled Blower Fan

- Blower Control via PWM
- Drastically Reduced Power Losses
- Technologies available



Total Power Saving ~ 80 W

Comparison against linear controlled motor with huge power losses

Source : Continental

CO_2-reduction ~ 1.9 g/km

Overview of CO_2-Reduction Examples

Application	CO_2-reduction [g CO_2 / km]
PWM for bulbs	0.8
Use of LED	1.2
Infotainment	1.2
Fuel pump	1.9
HVAC Fan	1.9
Alternator	2.4
EPS	5.9
Water pump	7.1
……**…**	**…**

- **Total electric power saving** **~1000 W**
- **Total improvement of CO_2-emission** **~23 g/km**
- **Total CO_2-saving per car lifetime** **~3.3 t**

Global CO_2 Targets

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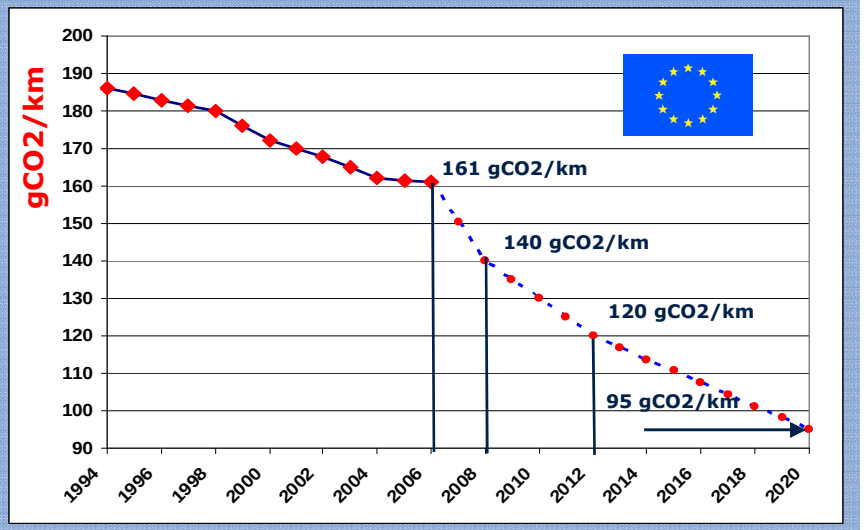

Overall tax: Car, Fuel and CO2
-On the Fuel (≈90€ per gCO2/km)
-On the Car (≈30€ per gCO2/km)
-On the OEM (≈95€ per gCO2/km)
-On the CO2 (≈20€ per tone CO2)

Car running 10 years
16.000 km/y or 10.000 miles/y

Conversion table for regular gasoline engine

gCO2/km	155	140	130	120	110	100	95
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MPG	35.0	38.7	41.7	45.1	49.2	54.2	57.0

Barrel Price from June 2008 to June 2009

http://www.wtrg.com/daily/crudeoilprice.html

Overview on device concepts

	MOSFET	IGBT	SiC-JFET	Comment
Voltage classes	20..900V	600..6500V	600..1700V	overlapping in 600..900V classes
@ Vgs=0V	normally off	normally off	normally on	
Conductivity	majority carriers only	bipolar conductivity	majority carriers only	
Forward mode	ohmic	knee voltage around 1V	ohmic	low voltage drop for MOSFET and JFET
Conduction losses	I^2xR_{DSon}	~ IxV_{CEsat}	I^2xR_{DSon}	MOSFET and JFET allow low losses
Switching losses	extremely low	medium	extremely low	dominated by bipolar plasma in IGBT
Capacitive losses	medium	low	ultra low	
Cost	medium	low	high	SiC presently introduced to market

Conclusion

CO_2 – Reducing Emissions is a worldwide obligation for the sake of our future

CO_2 – Reducing Emissions will be driven by many small steps in a variety of applications

Semiconductors are the enabler

⇨ Let us drive our future

The Color System

R: 230 G: 239 B: 245	R: 200 G: 216 B: 230	R: 135 G: 165 B: 210	R: 64 G: 134 B: 191	R: 227 G: 0 B: 52	R: 0 G: 93 B: 169	R: 0 G: 33 B: 74
R: 255 G: 255 B: 255	R: 221 G: 221 B: 221	R: 192 G: 192 B: 192	R: 150 G: 150 B: 150	R: 26 G: 24 B: 23		
R: 227 G: 0 B: 52	R: 183 G: 13 B: 40	R: 121 G: 9 B: 46				
R: 91 G: 235 B: 156	R: 24 G: 198 B: 99	R: 14 G: 120 B: 52				
R: 255 G: 163 B: 79	R: 250 G: 242 B: 88					

Primary Colors

Never stop thinking