PPP Implementation for
Road Transport Electrification

Vision of Electromobility:

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Ovidiu Vermesan SINTEF, Norway

The Research Council of Norway

Federal Ministry of Education and Research

SEVENTH FRAMEWORK PROGRAMME

Joint EC / European Green Cars Initiative Clustering Event 2012

July 11-12, 2012 Brussels

Synergize and leverage project output

1.

E^{3}CAR

Energy Efficient

Electrical CAR

2.

CASTOR

CAr multi propul**S**ion

integra**T**ed p**O**wer t**R**ain

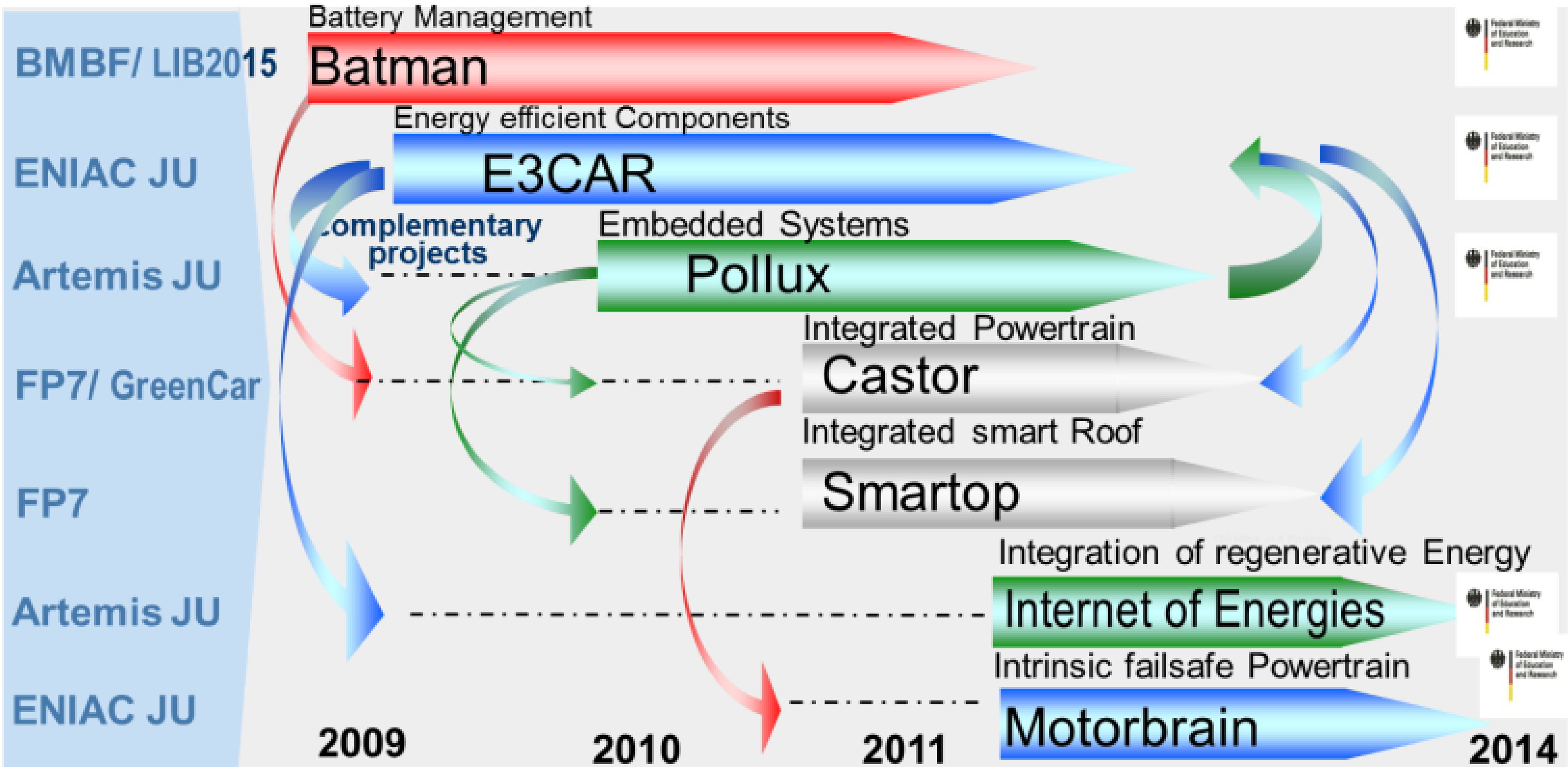
3.

MotorBrain

The Next Step in the EV-Powertrain

- Reach the critical mass in research

Convergence of Electrical Vehicle (EV) Projects



Synergize and Leverage

- Accelerate innovation, maximize output, address market hurdles
- Combine European variety and strength for excellence

Research → **Semiconductor** → **Tier1** → **OEM**

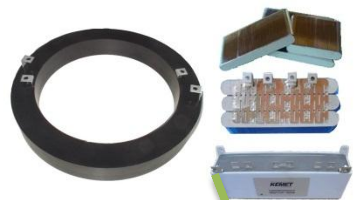
Synergize and leverage project output

- 12. July 2012 Clustering event
- Session 3 E-Drive train technologies

	Energy Efficient Electrical CAR	Process Oriented Electrical Control Units for Electrical Vehicles	Generation CAr multi propulSion integraTed pOwer tRain	highly integrated Powertrain	Battery Management
Project name	**E3Car**	**Pollux**	**Castor**	**MotorBrain**	**BATMAN**
Generation	1	2	2+	2+	1
Target	Efficient modules eff technologies subsystems	Embedded systems	multiphase motor Integration Efficieny	Intrinsic failsafe Powertrain	Flexibility, Efficiency, Reliability
Research area					
System Architecture	X	X	-	-	-
Control Architecture	-	X	X	X	X
Circuit Topology	X	-	X	X	X
Machine topology	-	X	X	-	-
Powertrain Structure	X	X	X	X	-
Device technology	X	-	-	X	-
Circuit Efficiency	X	-	X	-	-
Unit Funct. Integration	-	X	X	-	-
Modul Standardisation	-	-	-	-	-
Battery Management	X	-	-	-	X
Battery Integration	-	-	X	X	-
Reliability	X	-	-	-	X
Dynamic Integration	X	X	-	X	-
	Twin Project -> complementary				
		Generation project			
	Generation project				

MotorBrain Adressing Key Components

Passive Components



Source: KEMET

Switching Elements

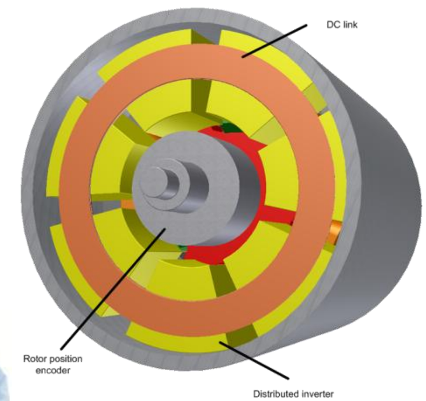
Source: Infineon

Control Elements

Source: Infineon

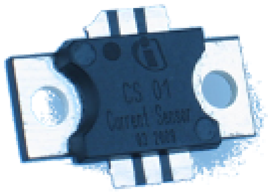
Drive System

Electric Motor



Source: Siemens

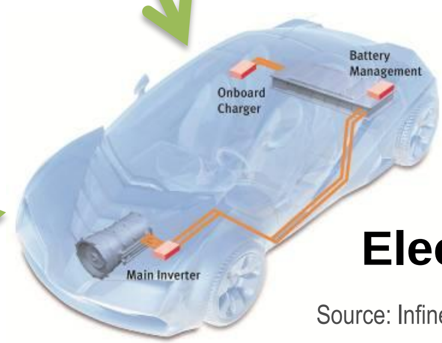
Sensors



Linear Hall coreless (planned)

Storage

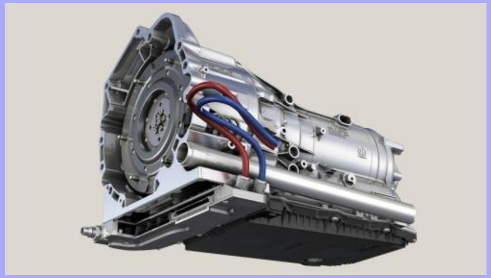
Source: QinetiQ



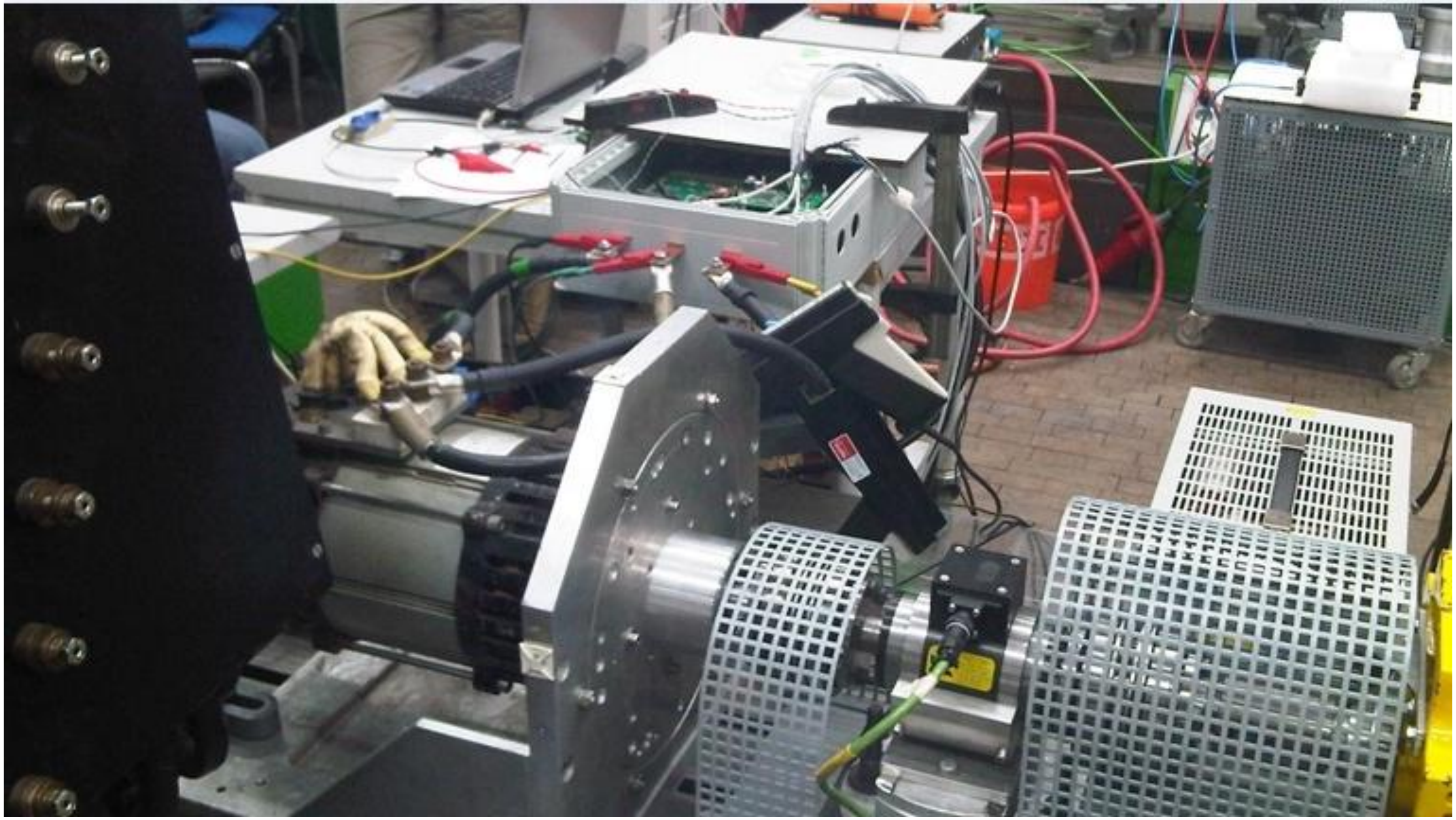
Electric Car

Source: Infineon

How to make the power train cheap, safe and efficient?

Integration of power electronics and motor	Separate  Source: Bosch	Built-On  Source: EfA, ZF	Fully Integrated  Source: electronicdesign.com
Cost	O	++	+
Size, Weight	-	+	++
Availability	+	+	O
Maintenance	++	+	-

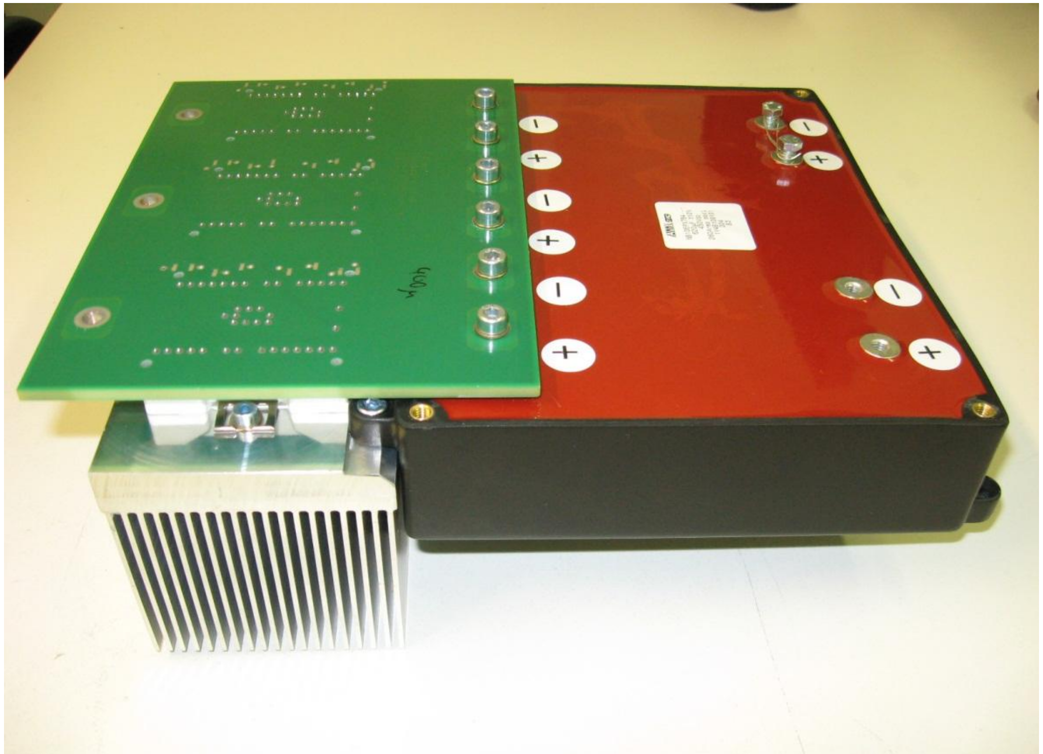
Power electronics: on the test bench



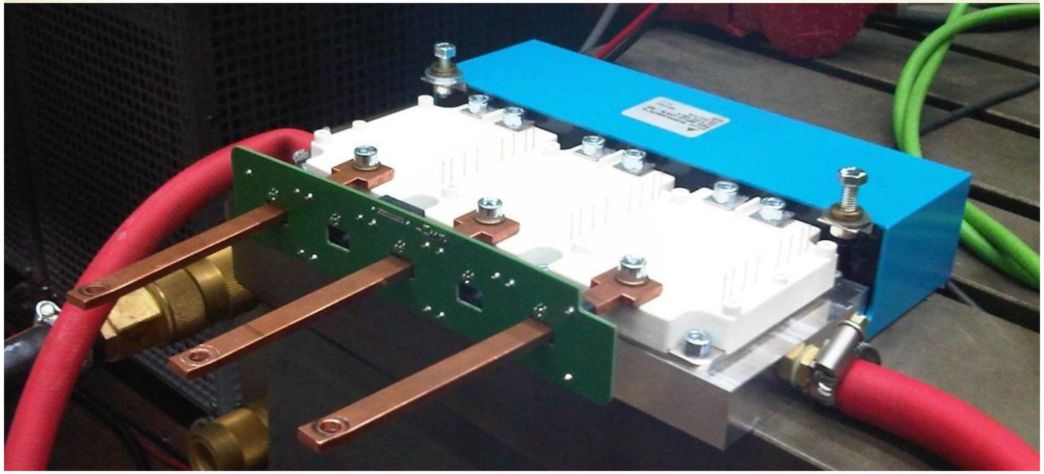
Missing electrical efficiency requires mechanical engineering

Air cooled
15KW Inverter
Based on IGBT 400V
400A devices
(intrinsically
highest efficiency)

Used for 72V DC-Link
Needs > 300A due to cos Phi



water cooled
100 KW Inverter
Based on IGBT 650V
Used for 400V DC-Link
250A



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Renewable Mobility: The global challenge

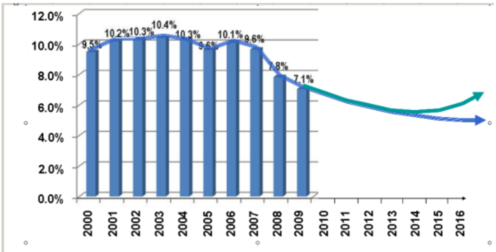
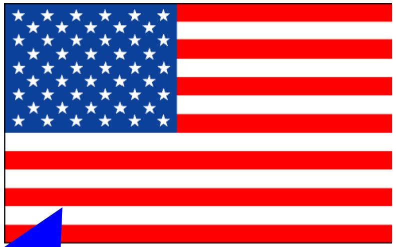
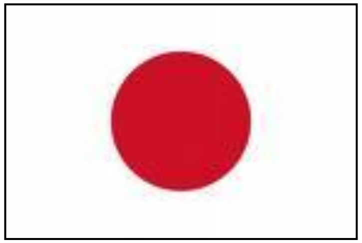


Figure 31: Loss of sales of European semiconductor industry (reference: world market 300 billion €)





Our Chance for
The European
Semiconductor
Industry

Global competitors

Urbanisation and Infrastructure
Standardisation
Batteries
Power electronics

Europe and the Global competition:

Team Blue

Standardization:

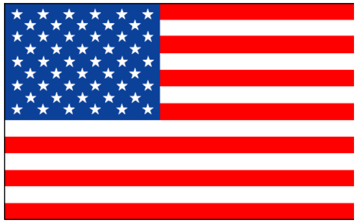
Grid, Car, Tax, rules, Infrastructure, networking among the national clusters and among the automotive manufacturer

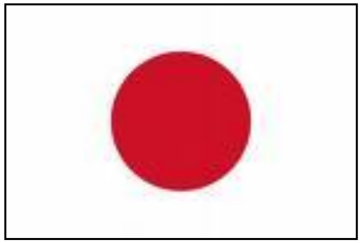
Drive Train Technologies

Diverse Trends, light weight, DC-LNK up to 400V, cooperations for Storage, cost

Infrastructure:

Fast charging station





Team Red

Standardization -> Market size, volume

China practise since 3000y
US, J are one country, cultural based early adoption of standards

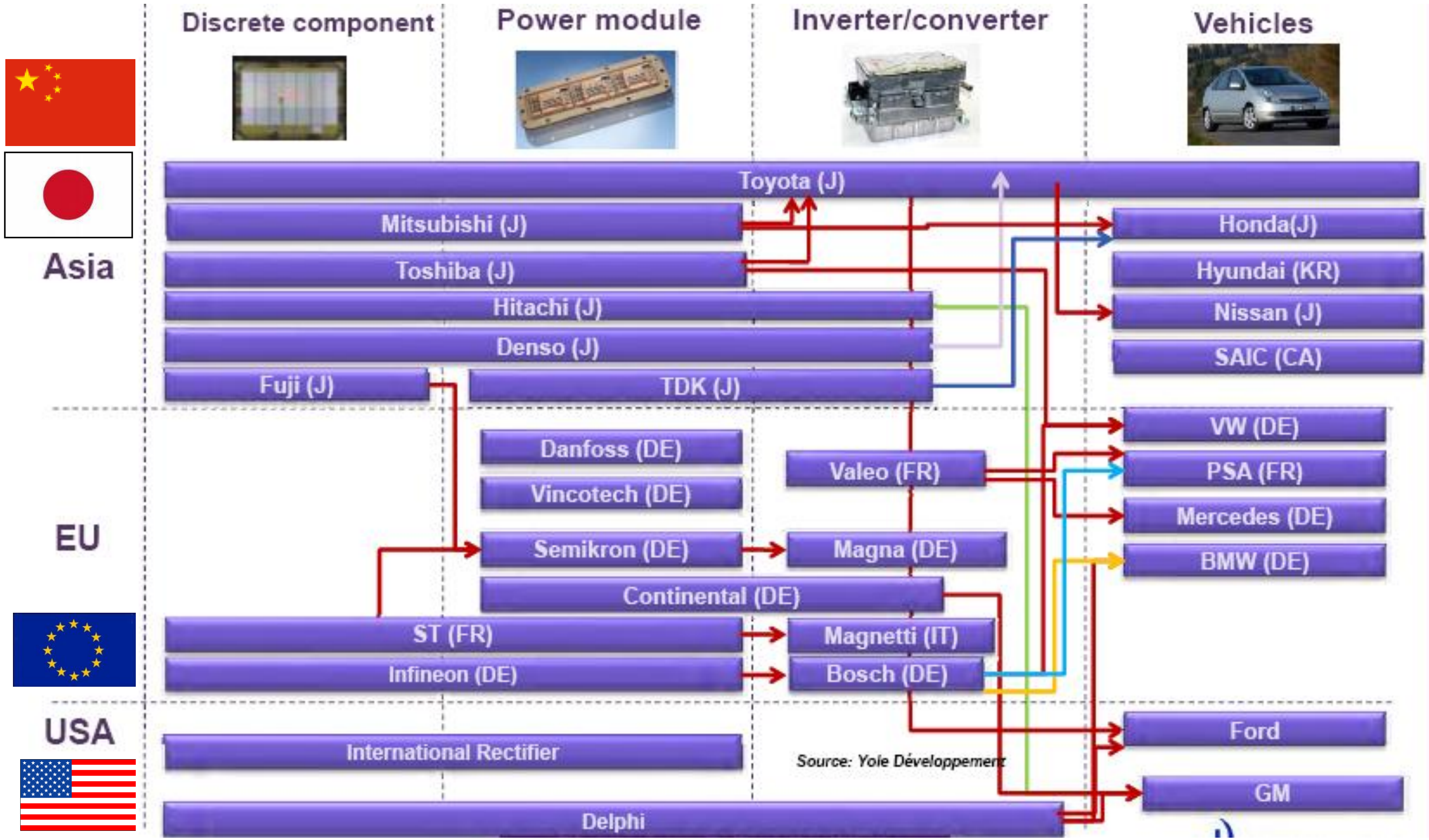
Drive Train Technologies

J: High voltage (> 700V) drive train
US, C: driving battery cost

Market trends, Infrastructure

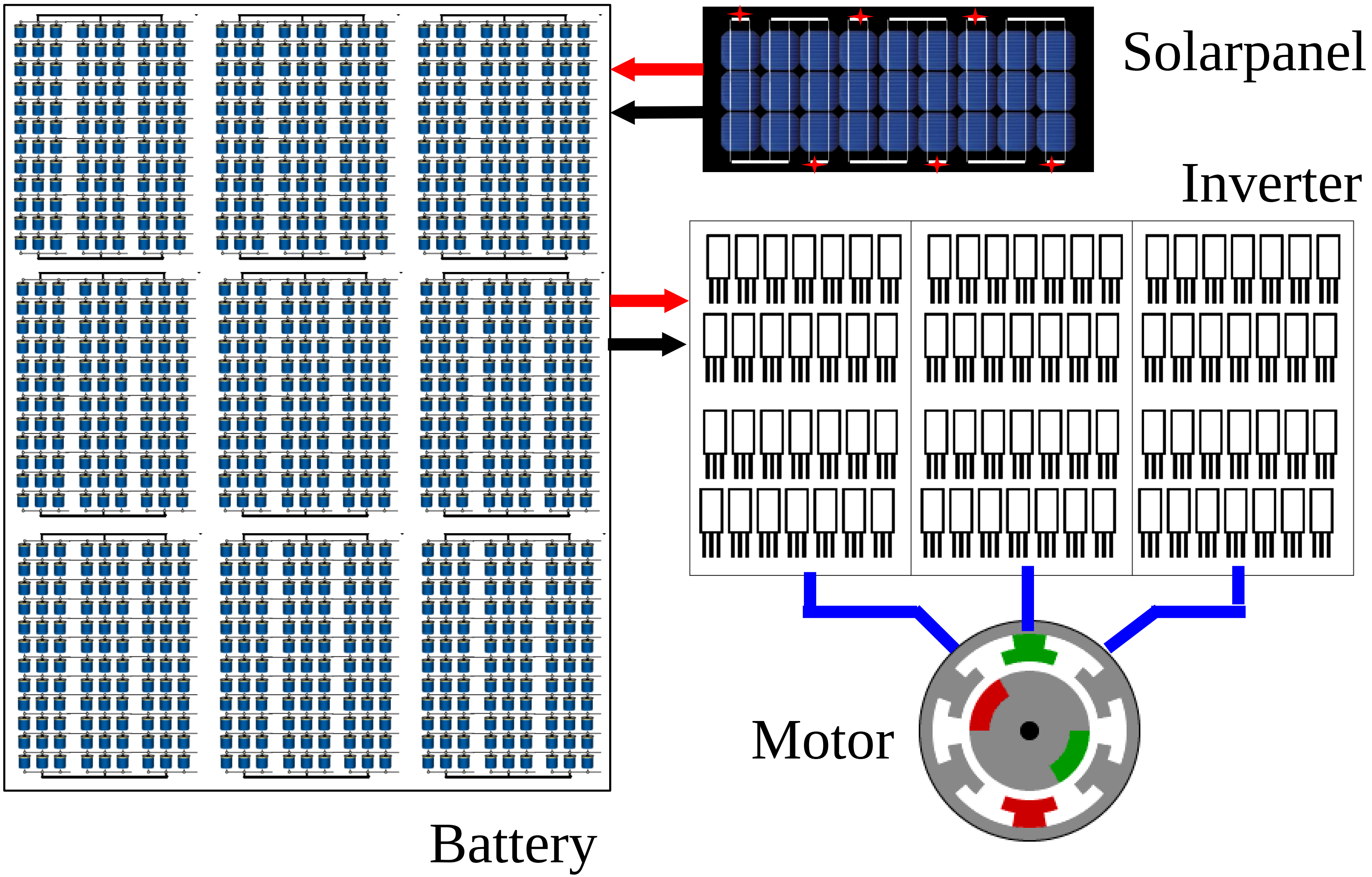
- ✓ US -> electrification of ICE, hybridisation
- ✓ C -> Automotive industry developes FEV
  J -> highly advanced ICE, Hybrid, FEV
- ✓ Standardization,rigid legislation
- ✓ Early Mass market

Semiconductor suppliers to EV power electronics



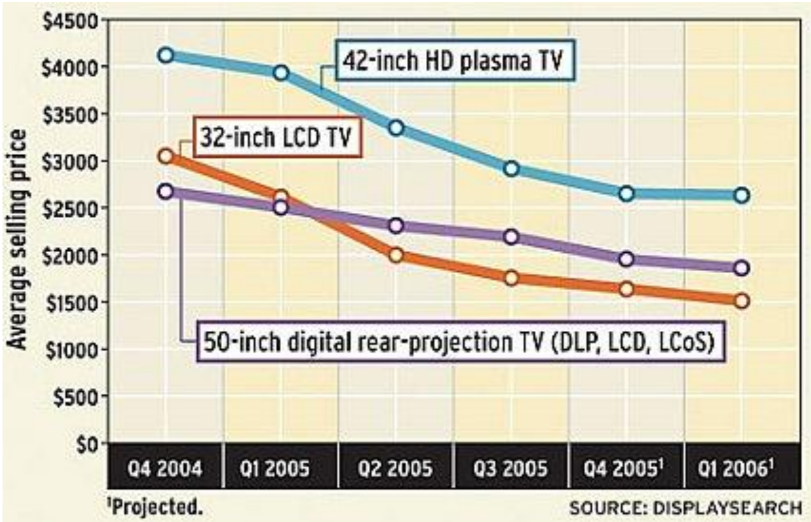
Balanced supply chaines

Regular Topologies favor standard components ?

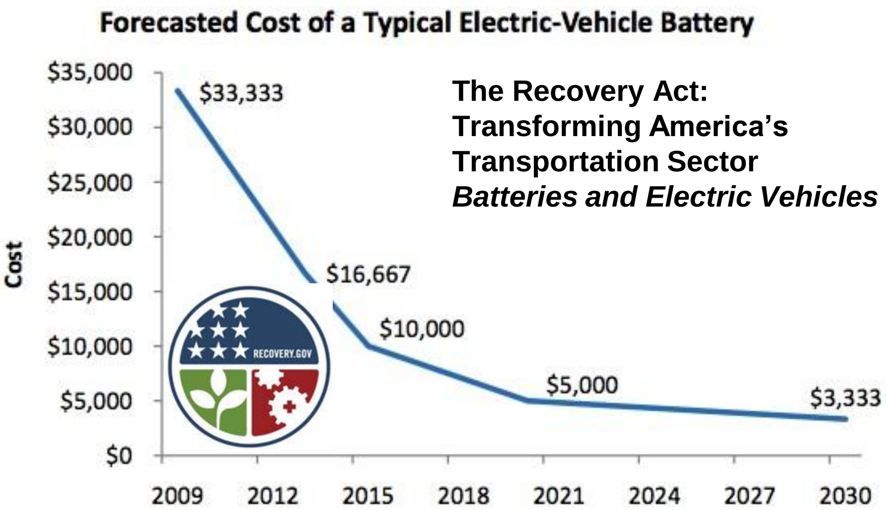


Regular topologies drive economy of scale

Flat screen



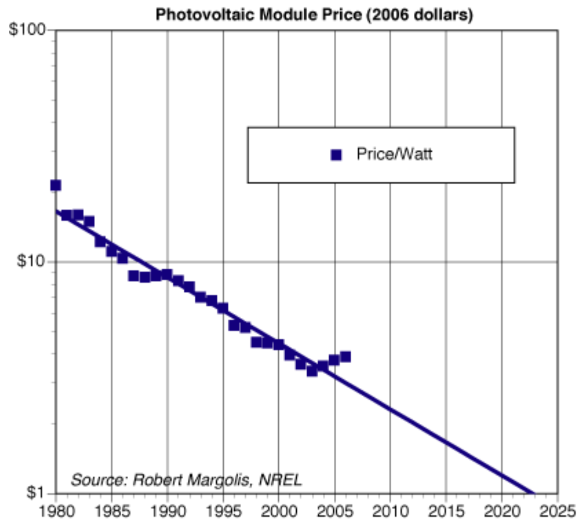
Batteries



3 miles per kilowatt hour and 100-mile range.

DEPARTMENT OF ENERGY

Solar cells



<u>European strenght:</u>

Highly integrated smart devices based on innovations with European pilot and production facilities to synergize and leverage European designs.

EV: harsh conditions for SMEs in the market

- SME facing severe market conditions, severe hurdles from research to manufacturing and selling the E-car in the market
- 4 x SME in 3 projects (Think, Elbil, AGV, Clean Mobile) went bankrupt and/or are bought by new investor
- Epyon taken over by ABB
- EV Market introduction from prototyp to production needs huge efforts: (Tesla manufacturing supported by Toyota, Daimler)

Big companies adapt there strategies ….mixed …market…:

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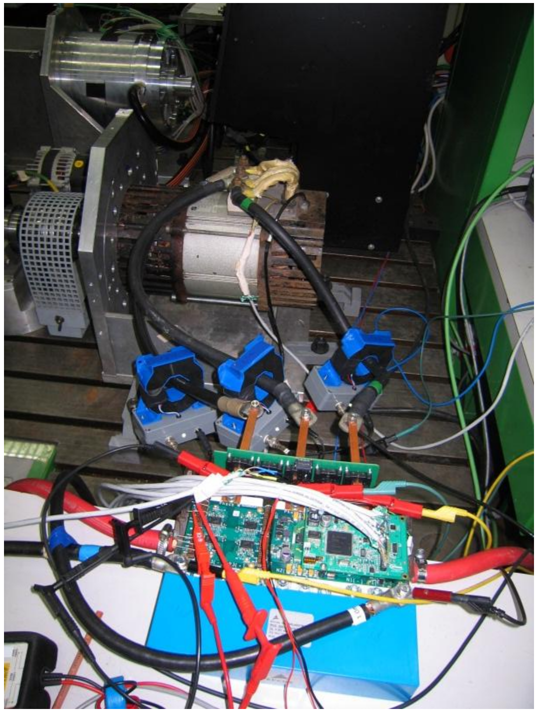
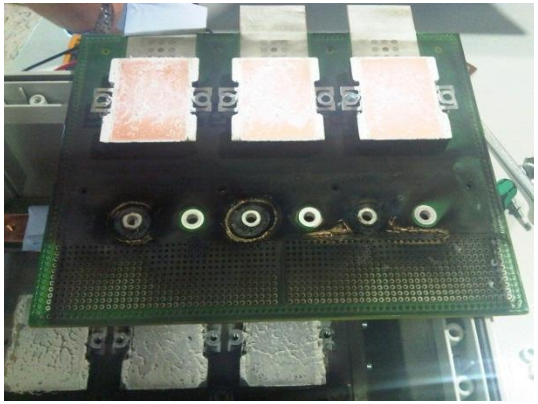
E^{3}CAR is …….action





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E³Car: Achievements in 4 Application areas

Top targets for energy savings by:

- Converter efficiency (9% potential)
- Mileage of battery set (11% potential)
- Weight by integration (10% potential)
- Power distribution net (5% potential)

Overall target: 35% Energy savings

1. Efficiency
2. Mileage

3. Temperature
4. Flexibility
5. Functionality
6. Harsh Environment electronics
6. Sensors

Integration

Power Distribution network +3 - 5%, 10%	▪ Power switches for high current on/off under load ▪ Safety/ fail mode switches ▪ High current sensor with low insertion loss ▪ smart sensor for power network functionalities **Solar panel**
Power Conversion +9%	▪ AC/DC DC/DC converter ▪ High Power Modules **400V IGBT inverter** **650V IGBT inverter**
Power Management +15%	▪ Power switches for high current on/off under load ▪ Safety/fail mode switches ▪ High current sensor with low insertion loss smart sensor for power network functionalities **Starter battery**
Smart Dynamic Monitoring	▪ Integrated smart control units, ▪ Integrated smart sensor and distributed sensor networks ▪ Electronic interfaces for ISM and DSN ▪ SiP solutions to reduce the costs of sensors ▪ High temperature interconnection technologies ▪ EMC, ESD functionalities **Current-Sensor**

Energy efficiency and range of operation

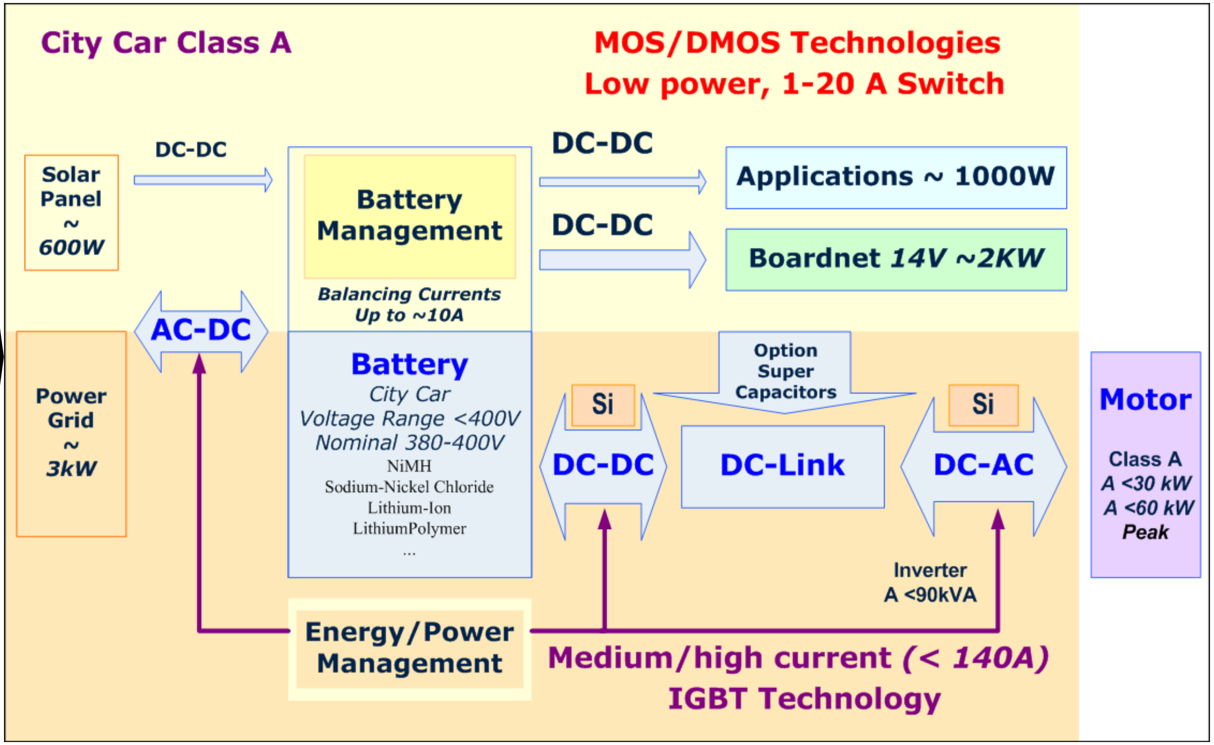
E³Car: Match of HV technologies and EV

- Build **a solid Nano electronics technology base** for Europe.
- Establish **standard designs and platforms** for electrical vehicles.
- Develop efficient **semiconductor components** for the **first industrial generation** of **electrical** vehicles.

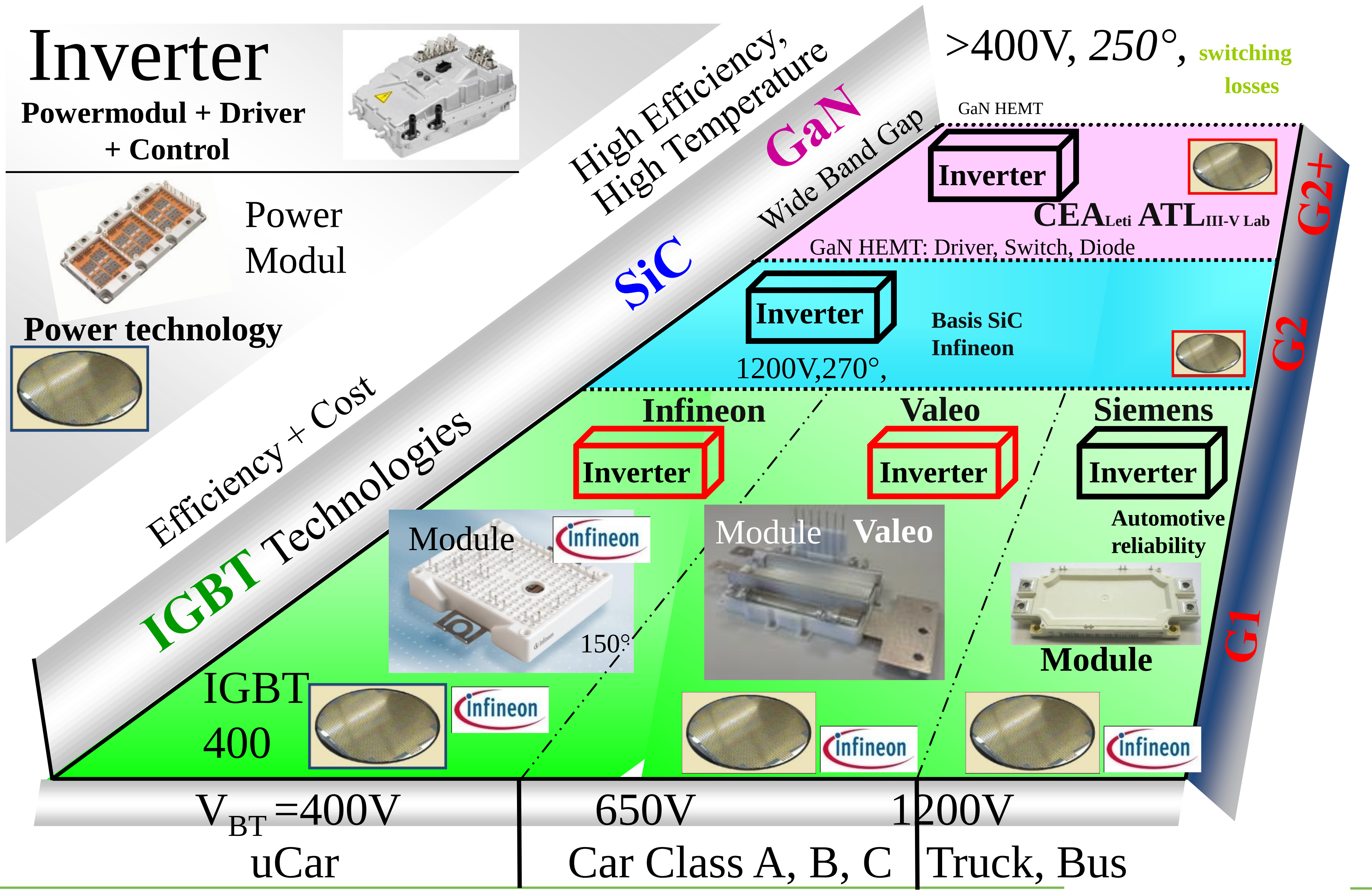
1. **IGBT400V devices based on**
2. **40mm thin technology**

Nano electronics Technology mapped to EV functional units

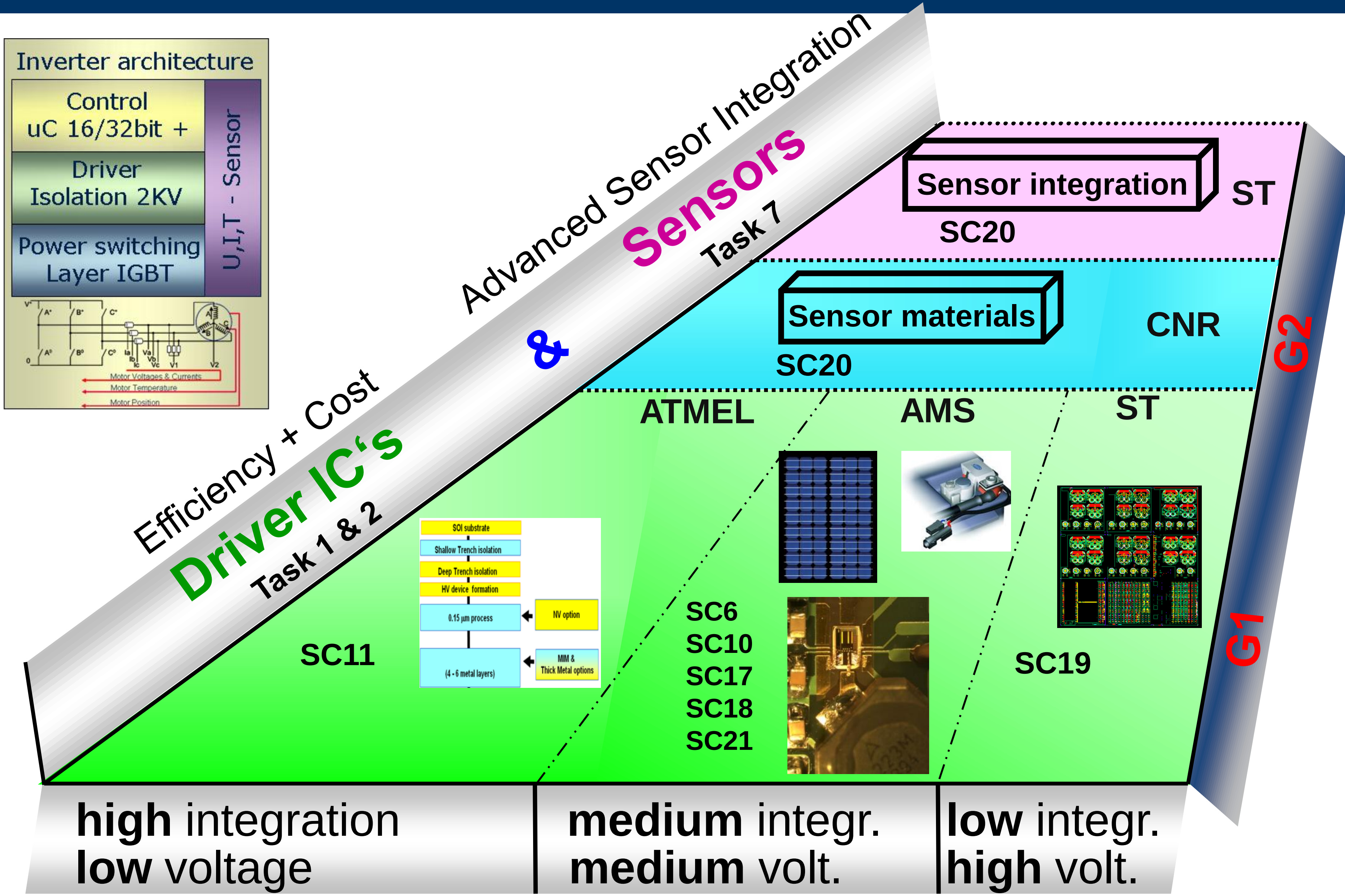
Match strengths and limitations of
High Voltage (HV) technologies
High Voltage CMOS (< 700V)
IGBT (**400V**, 650V, 1200V)
BCD (Bipolar/CMOS/DMOS)
SOI (Silicon on Insulator)
SiC (Silicon Carbide)
GaN (Gallium Nitride)
Package technologies
for high temperature devices
Submicron lithography
needed to combine complex
logic with high voltage driver
devices



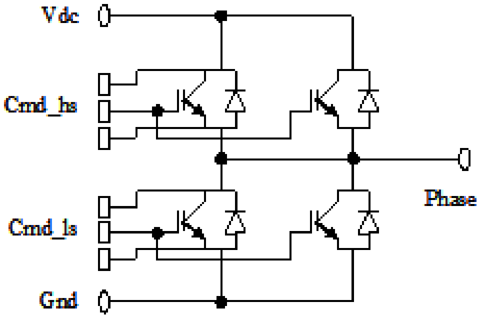
E³Car Inverter Roadmap: Power Conversion



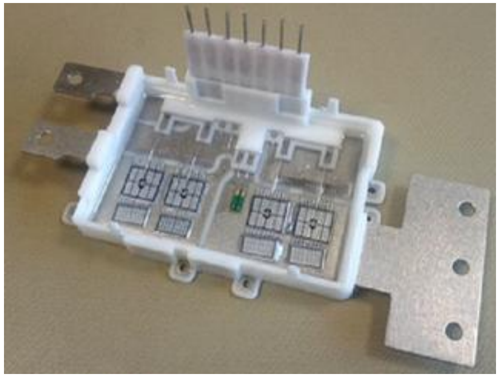
E³Car Roadmap of Driver IC-Technologies

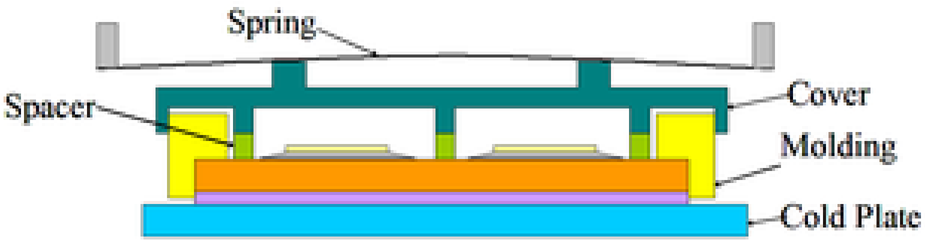


E³Car: 650V IGBT IML module technology



- Half Bridge topology:
  - 2 IGBT & 2 Diodes per switch
  - 650V IGBT Diodes from IFX
- IML technology (Valeo)
  - Large copper traces
  - Dices mounted on these copper traces for good thermal performances
  - All materials available in high quantities and at low cost
- Mounted onto the water cold plate using spring to compensate for creep effects





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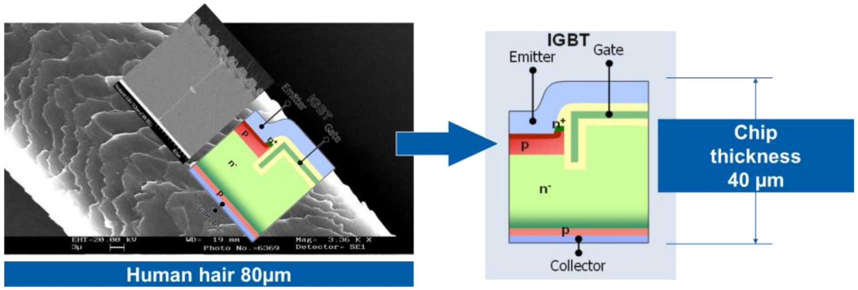
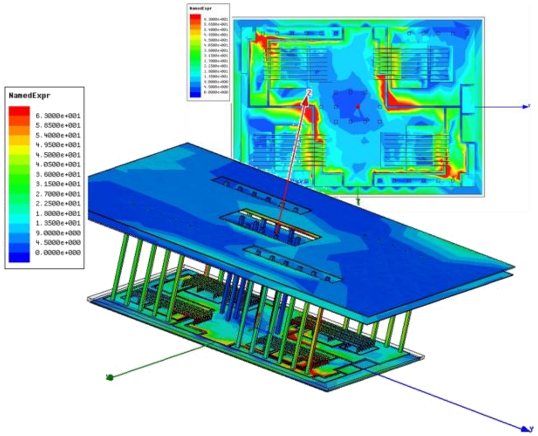
Motor controller module using 400V hybrid HV Bipolar IGBTs

- Development of low inductance 400V IGBT power module:
  - Low inductance Easy 2B module to utilise fully the performance of Infineon's new fast switching 40µm IGBT/diode chipset
  - Use of low cost easy automotive package
  - Connection to low inductance power PCB by PressFit connections



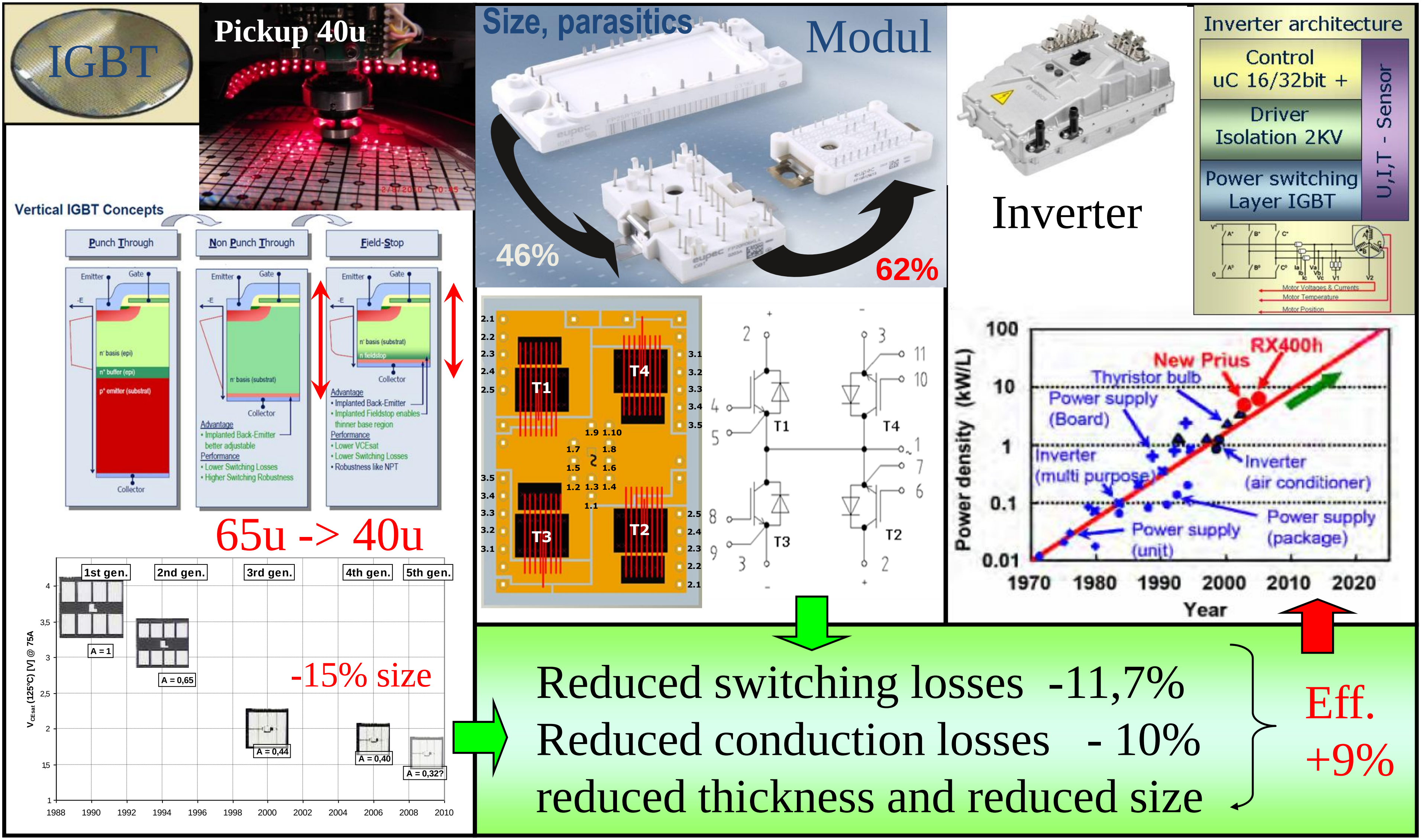


ultra thin 400V IGBT/diode chipset ⟹ **low inductance IGBT power module**

- 40µm thin 400V IGBT/diode chipset
  - significant reduction of conduction/switching losses
  - very fast switching characteristic, i.e. very high di/dt
  - high demands on the module package concerning internal stray inductance

- Stray inductance
  - Simulation: $L\sigma$=11,2nH including PCB
  - Measurement: $L\sigma$=8,8nH including PCB

E³Car: IGBT 400V Inverter



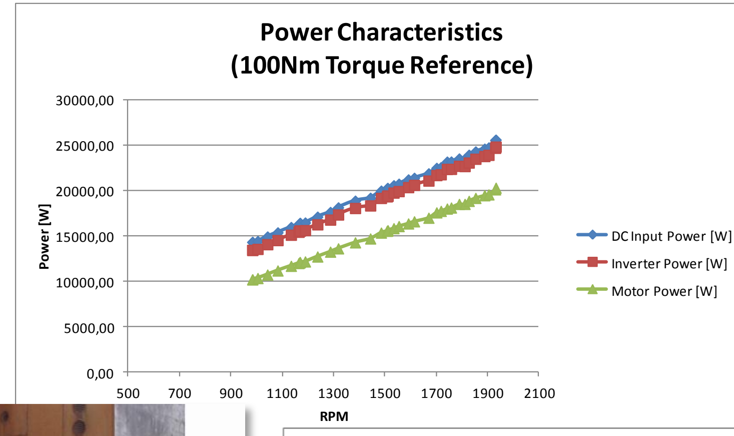
Reduced switching losses -11,7%
Reduced conduction losses - 10%
reduced thickness and reduced size

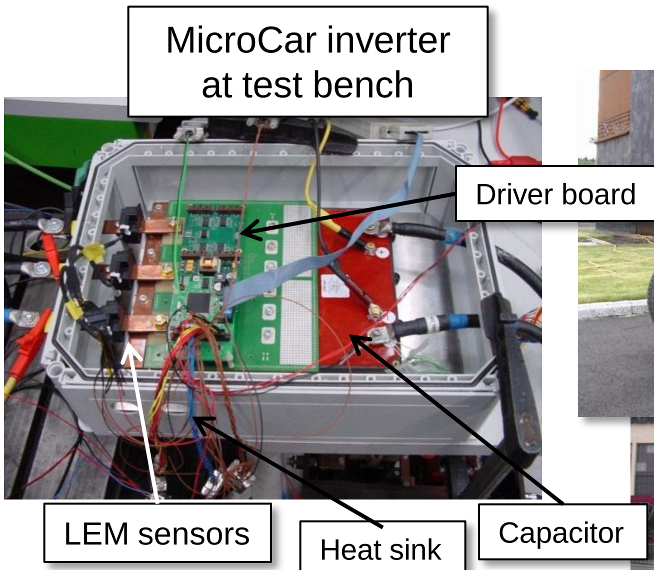
Eff. +9%

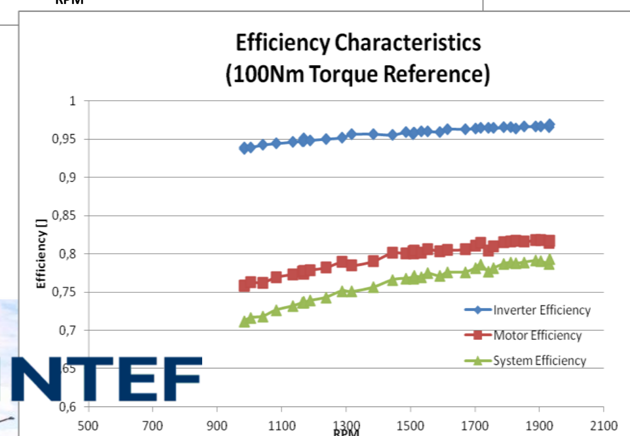
Costs, performance, power density improved

Evaluation of 400V inverter on the City motion eCar

- Inverter test bench results:
  - Max. mechanical power of 20 kW
  - Continuous phase current of 250A max
  - Inverter efficiency of up to 97%
  - System efficiency of up to 87%







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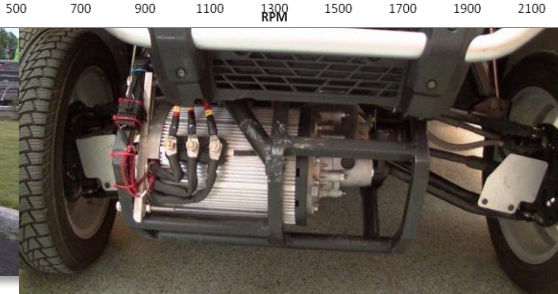

- Successfully test of the MircoCar inverter in the CityMotion car

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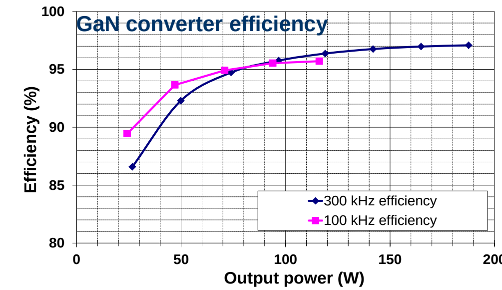
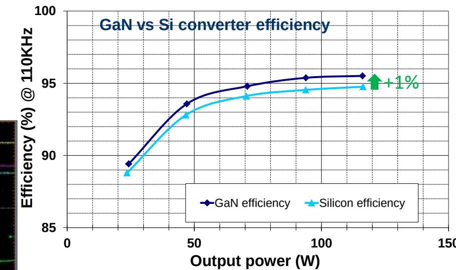
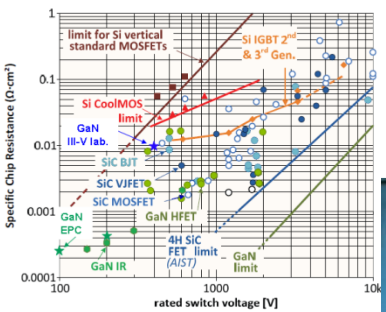
City motion

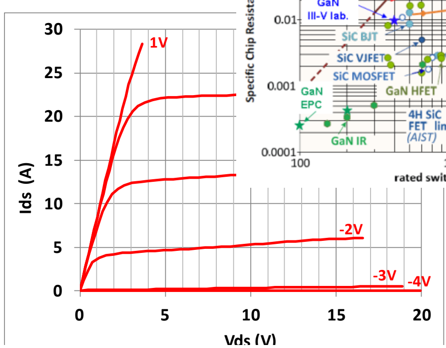
DC-DC step-up converter

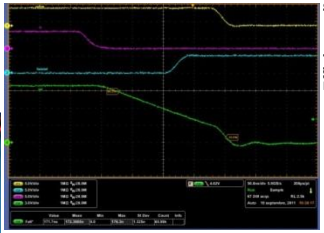
From GaN device to module

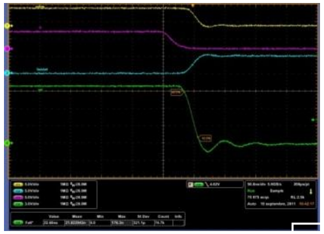


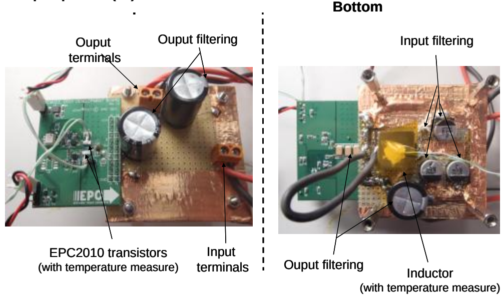


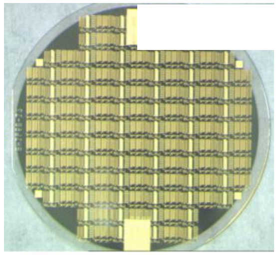


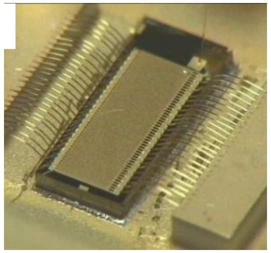


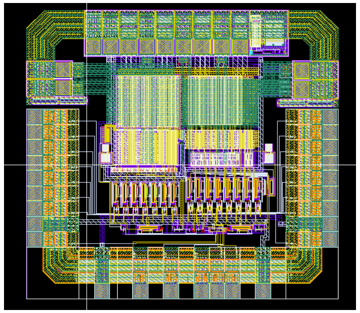


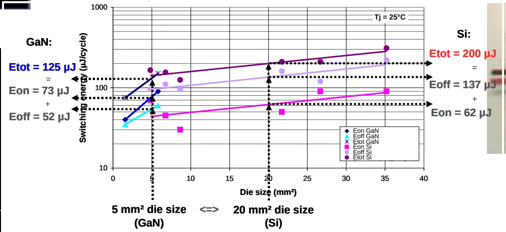












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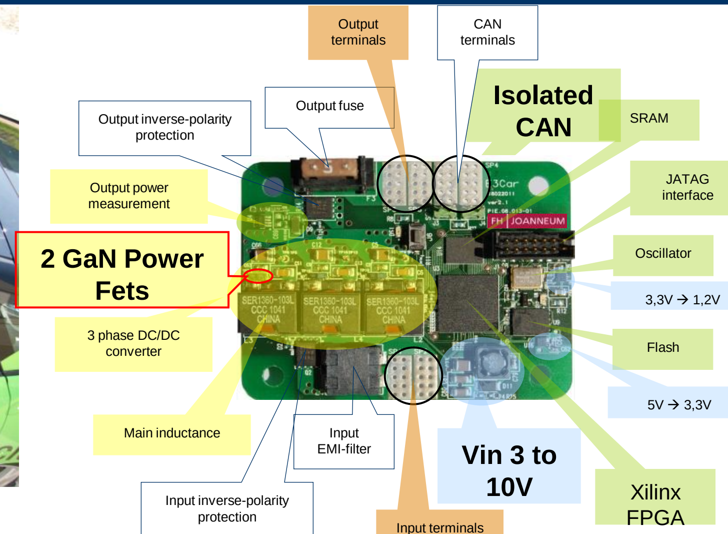
E³Car Highlight: Smart control Solar Panel

Mileage increase with Solar	MAX driving range, **6m²** solar area
Graz, Austria	**3419 km/yr**
Madrid, Spain	**4813 km/yr**
Oslo, Norway	**2469 km/yr**

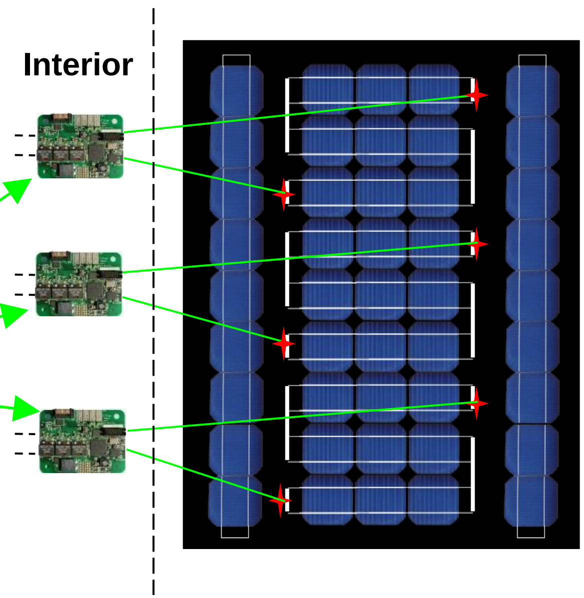


Assumptions:

- No shade
- → shading footprint **- 30%**
- No curvature
- → Module curvature **-16%**
- Grid operation

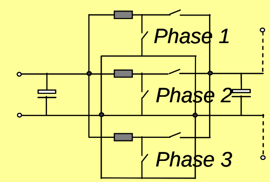
The solution:

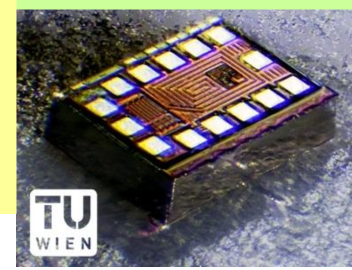
MPPT on cell level to increase *module* efficiency

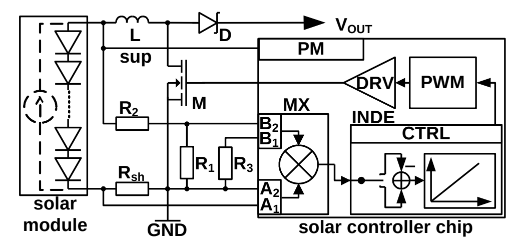


Peripherals	Power Supply
	Controller

DC/DC power stage







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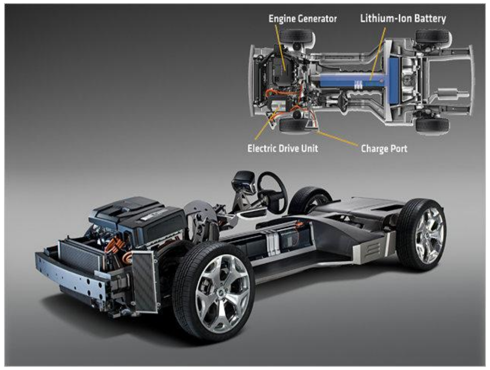


SEVENTH FRAMEWORK PROGRAMME

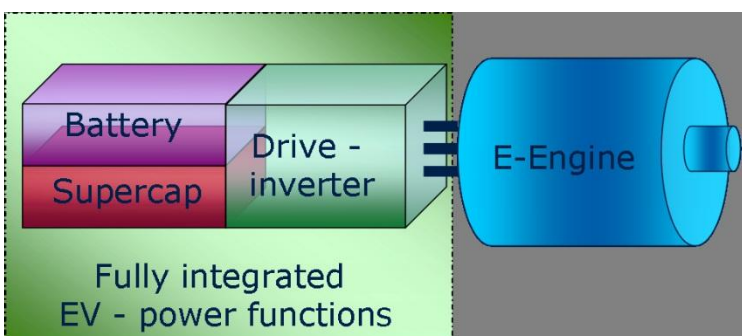
CASTOR
Car Multi Propulsion Integrated Power Train

CASTOR

CAr multi propulSion integraTed pOwer tRain

Integration of Multi propulsion power train

Reiner John, Infineon Technologies AG, Germany
Jiabin Wang, UoS, UK
Ovidiu Vermesan, Sintef, Norway



Green Car initiative 10.3

Volkswagen, CRF, Infineon, Ficosa, Magnomatics, SINTEF, University of Sheffield,

Castor : highly integrated propulsion system

Illustrated Examples for
integrated power train applications

Light Vehicle

Quadri-cycle

Personal propulsion

Application	Inverter class	DC Link Voltage	DC-Link current	No of Li-Ion cells	Battery weight [kg] (1h full power use)	full propulsion unit weight	switch Devices
light Car, vehicle	8 - 16 KW	typ. > 100V	80 - 160 A	min 29	48 - 96 Kg	80 - 180 kg	IGBT, MOSFET
Quadricycle	4 - 7.5 KW	< 65V *1	60 - 115 A	max 18	24 - 45 kg	40 - 80 kg	MOSFET, IGBT
personal propulsion	1 - 3.5 KW	< 65V *1	15 - 54 A	max 18	6 -21 kg	10 - 38 kg	MOSFET

7 Partners cover the whole Supply Chain

Research & SME → Semiconductor → Tier1 → OEM

The University Of Sheffield.

infineon

FICOSA

SINTEF

Magnomatics

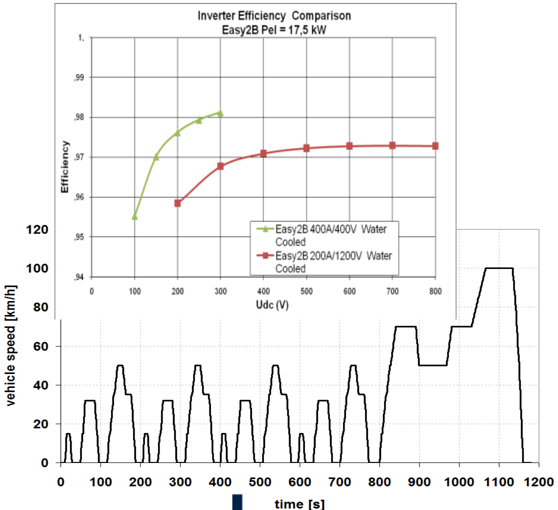
CENTRO RICERCHE FIAT

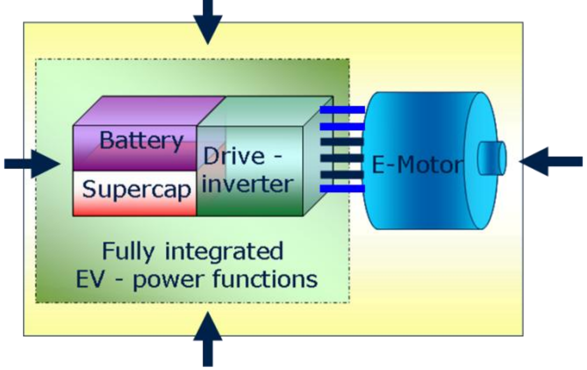
Germany	Italy	Spain	Norway	United Kingdom

Supply Chain in detail: Tasks and partner

Components	Motors	UoS-/ Magnomatics (UK)
	Inverter, Moduls	Infineon (D) – CRF(I)
	Accumulator	Ficosa (ES)
Silicon		Infineon (D)
System Integration and Packaging		Ficosa (ES), Sintef (NO)
power train application		CRF-FPT (I), VW (D)
On-board integration	 	CRF (IT)

Integration strategies for propulsion and energy storage



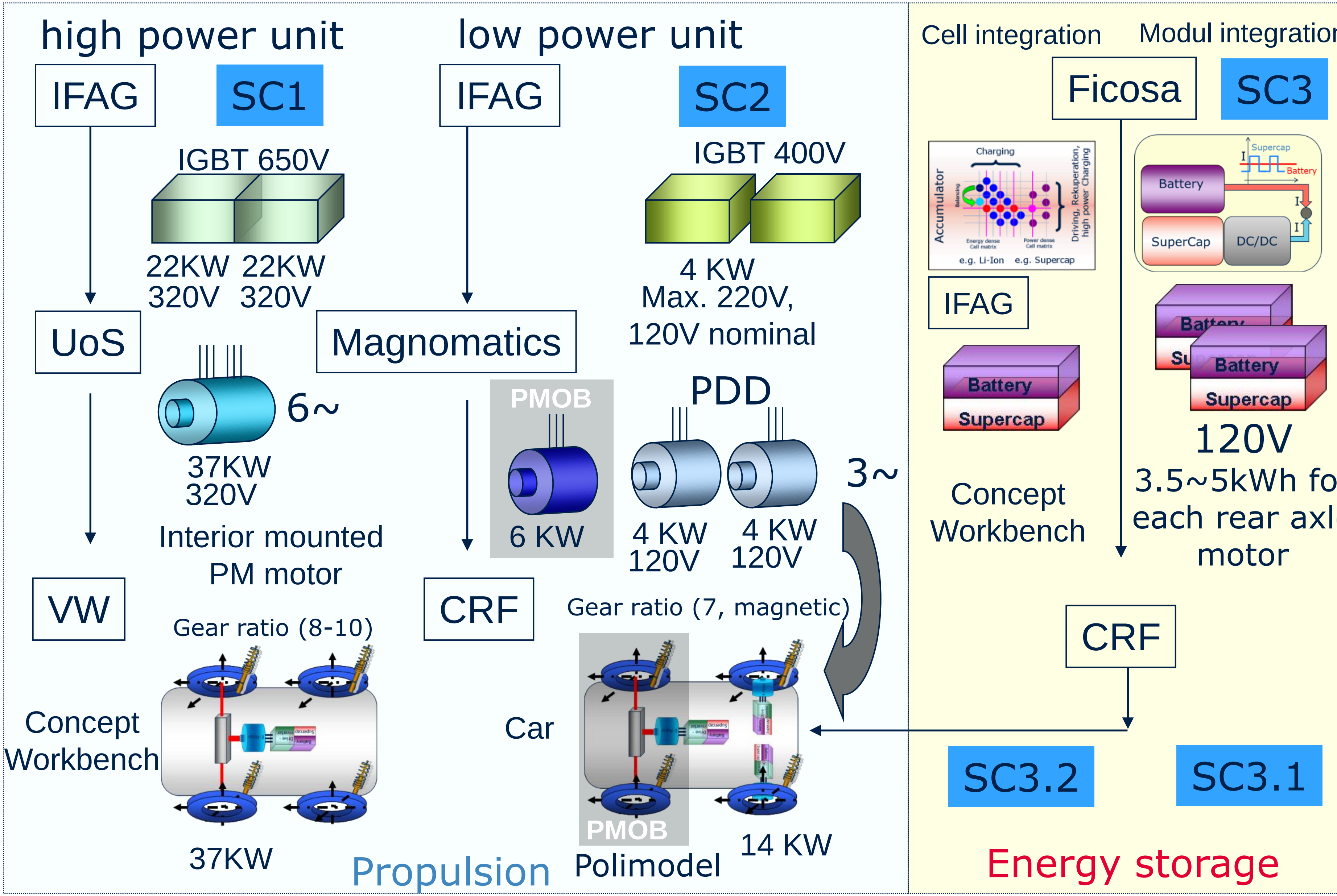


	Propulsion		Energy storage	
domain	high power train	Low power train	Modul integration	Cell integration
Car class	Class A	uCar		
Propulsion	central	Distributed		Li-Ion/ Supercap
Energy	Li-Ion Battery	HPSC ⟷	Li-Ion/ Supercap	
DC-Link voltage	360V	120V ⟷	DC/DC 120A	Fully integrated Design
Motor	Multiphase 6~ 37KW	PDD 3~ 7KW		
Power switch	650V IGBT	400V IGBT		
Thermal cooling	liquid	airflow		

HPSC = High Power Supercap Battery

Step1: Evaluation and simulation of the system components
Step2: Definition and selection of storage, motor, power switch

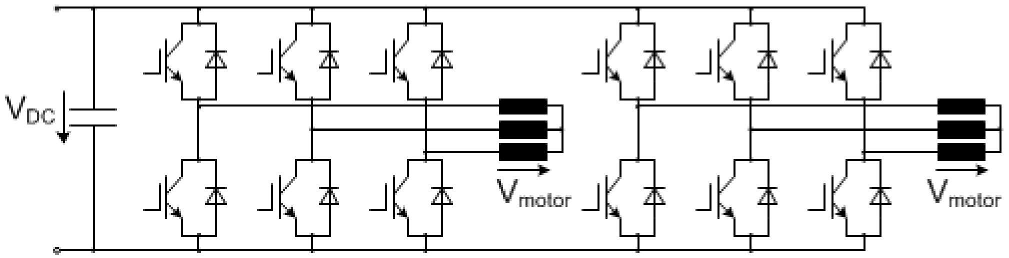
Supply Chains: Propulsion and Energy storage

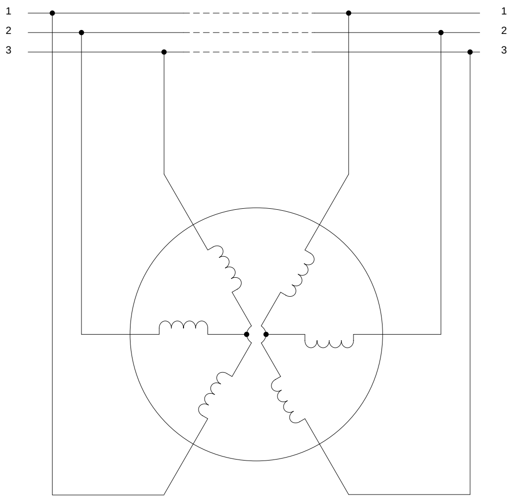


Benefits of Multiphase Motors

- Multiphase Motors enable simple integration (smaller power modules, less current)
- Multiphase motors enable limp home (independent motors)

➔ Multiphase motors reduce cost and add functionality

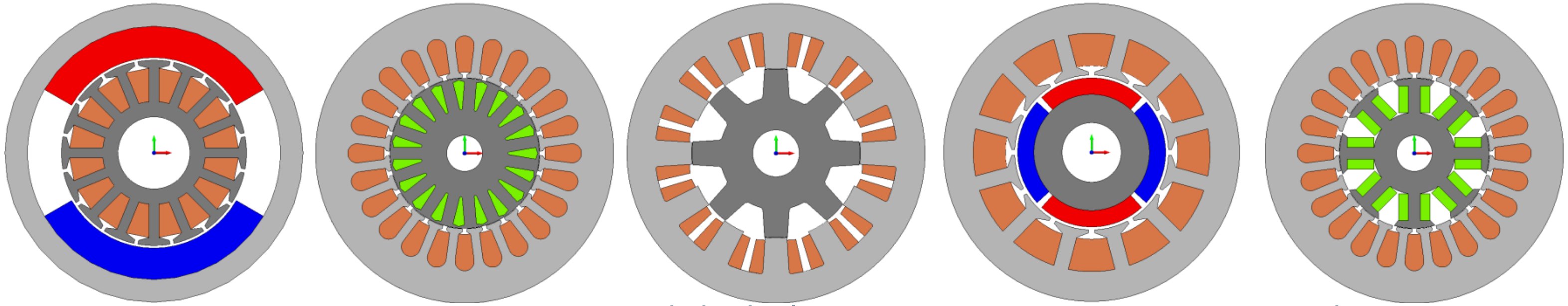




Example 6 phase motor with two star points

Motor types comparison : technologies

- Comparative studies of electrical machine technologies and topologies (D4.1)
  - Conventional machine technologies for EV traction

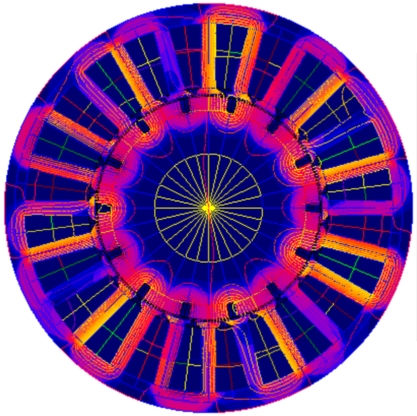


DC machine | Induction machine | Switched reluctance Machine | Permanent magnet machine | Synchronous machine

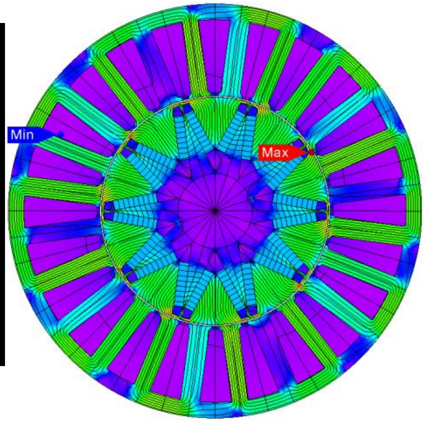
	DC Motor	Induction Motor	SR Motor	PM Motor	Sync Motor
Torque/Power density	5	7	7	10	8
Torque ripple	10	9	4	8	7
Efficiency	6	7	8	10	7
Controllability	10	7	7	8	8
Reliability	5	10	10	8	9
Maturity	10	10	8	8	10
Cost	7	10	7	6	8
Manufacturability	8	9	10	7	8
High speed operability	7	8	10	7	7
Fault tolerance	6	6	10	8	7
Figure of merits	**79**	**90**	**88**	**90**	**87**

Castor: Main achievements & highlights

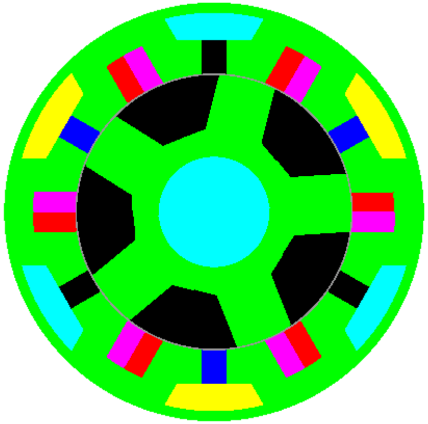
- Comparative studies of electrical machine technologies and topologies (D4.1)
  - Advanced machine technologies for preliminary studies
    - **Fractional slots per pole winding topology for 3-ø and 6-ø:**
    - **Permanent magnet variable-flux switching motor**
    - **Synchronous reluctance motor**



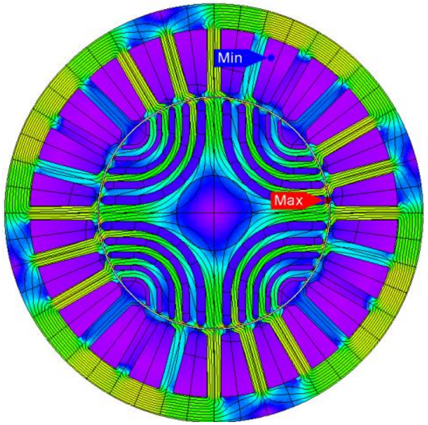
Fractional Slot SPM (24 slots, 14 poles) (5^{th} harmonic eliminated)



Fractional Slot IPM (24 slots, 10 poles) (7^{th} harmonic eliminated)



Variable flux switching (6 slots, 5 poles)



Syn. Reluctance (24 slots, 4poles)

Castor: Comparision motor concepts

- Comparative studies of electrical machine technologies and topologies (D4.1)
  - Results of preliminary studies on advanced technologies

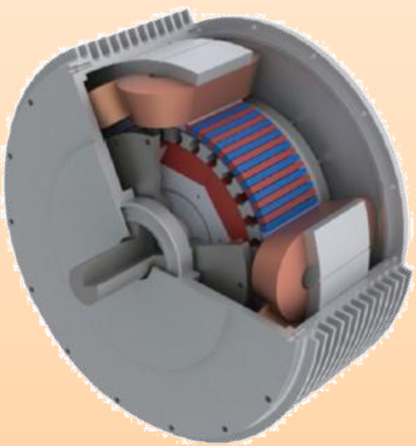
	SPM 12s/14p	IPM 36s/6p	Fractional slot SPM 24s/14p	Fractional slot IPM 24s/14p	Flux switch PM m/c	Syn. rel. m/c
Torque (Nm)	35.0	35.0	35.0	35.0	35.0	35.0
Current (A)	85	58	85	73	85	100
Torque/Ampere	0.41	0.60	0.41	0.48	0.40	0.35
Speed (rpm)	1350	1350	1350	1350	1350	1350
Efficiency (%)	94.7	94.2	94.4	95.2	87.5	89.5
Torque ripple(%)	1.2	1.5	1.0	1.5	20%	1.5

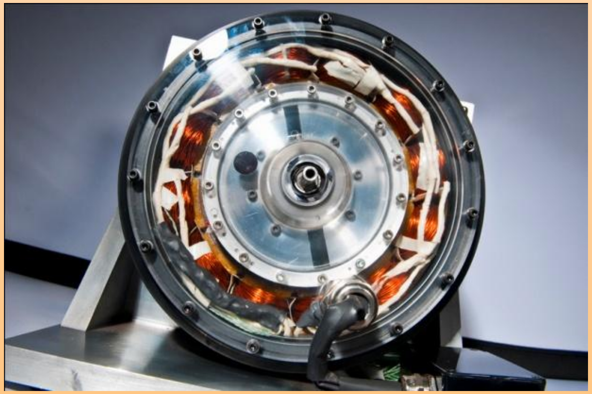
Need to be further optimised

WP4 PDD ® – magnetically geared motors

4kW PDD® for Aerospace Actuator

- 95Nm continuous torque
- OD=185mm L=45mm
- Naturally cooled

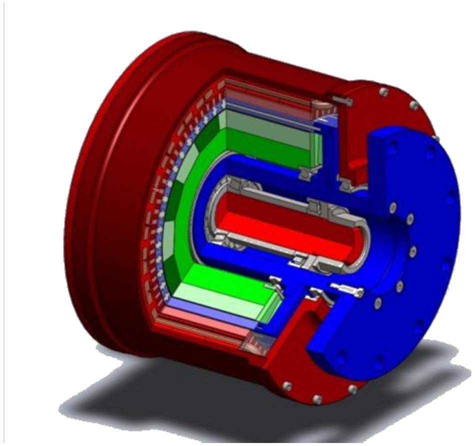


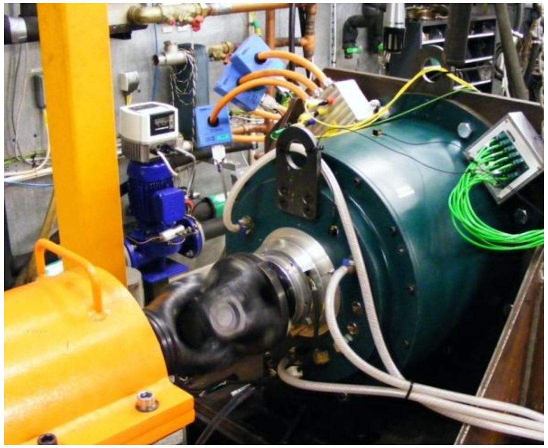


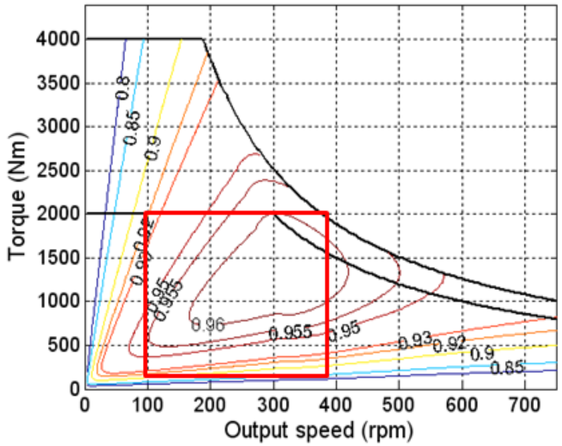
Volvo 65kW - PDD® for City Bus Application

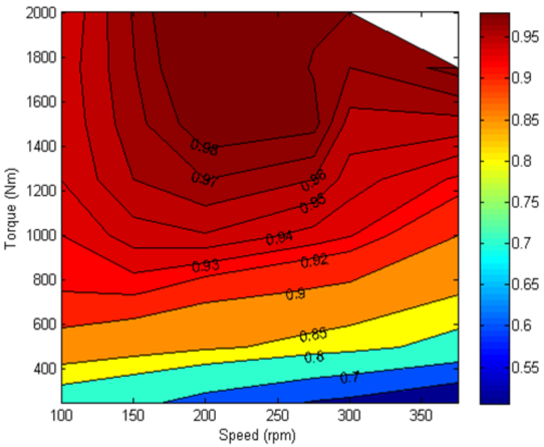
Fits in 22” wheel rim (485mm OD)

2kNm/4kNm cont/peak torque

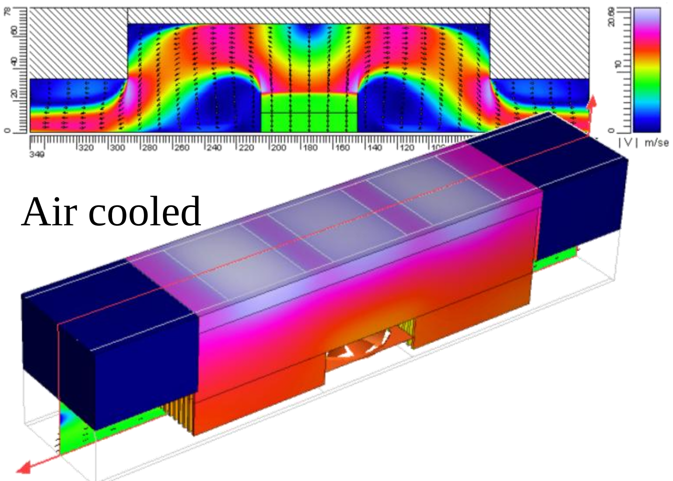


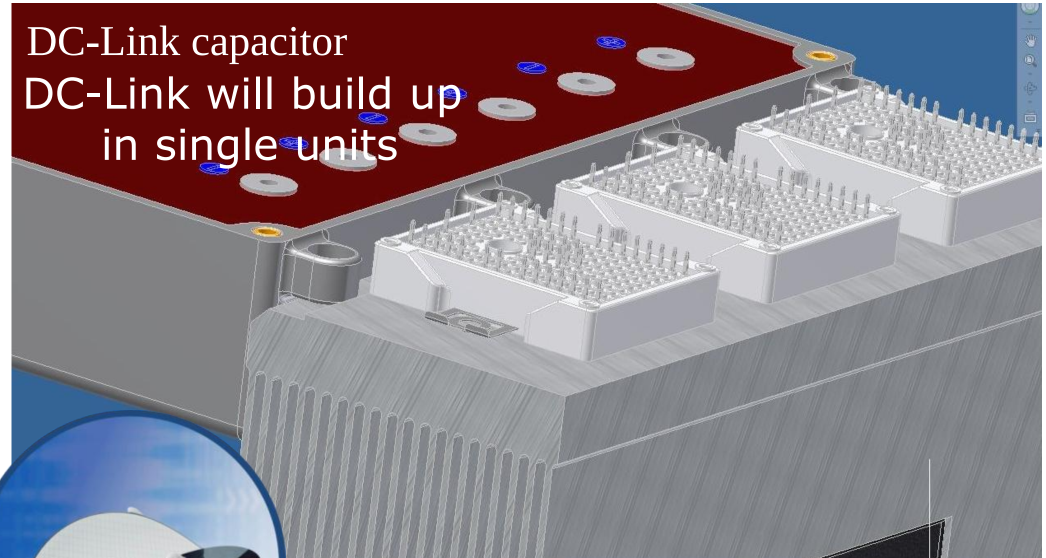


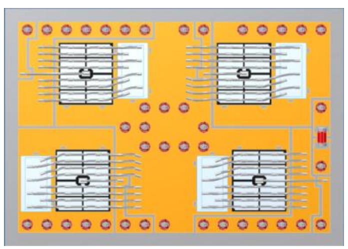


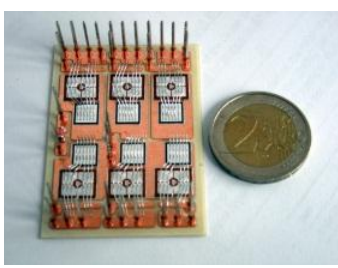


Aircooled 3~ Inverter (draft concept) 400V IGBT





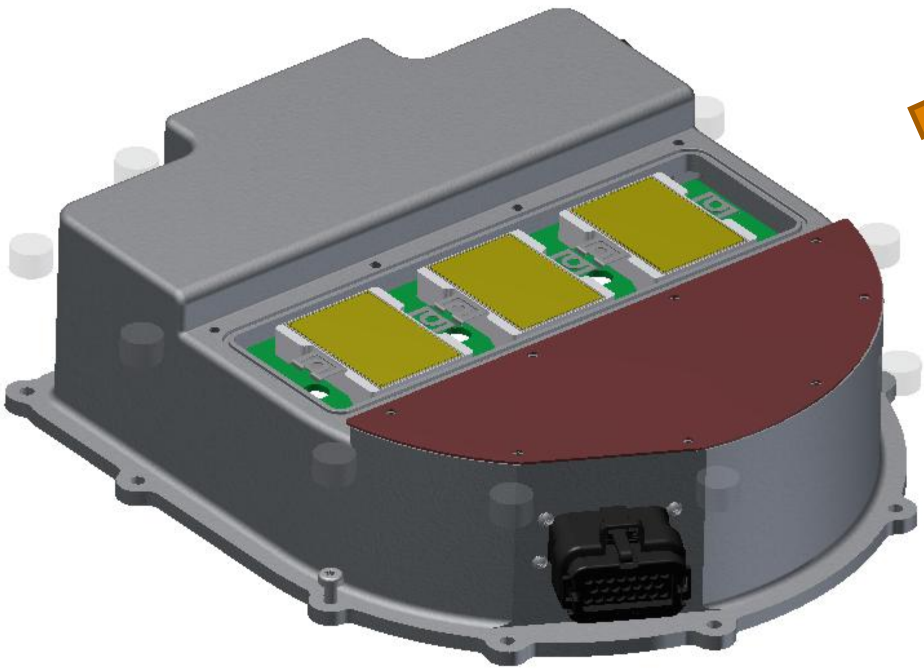


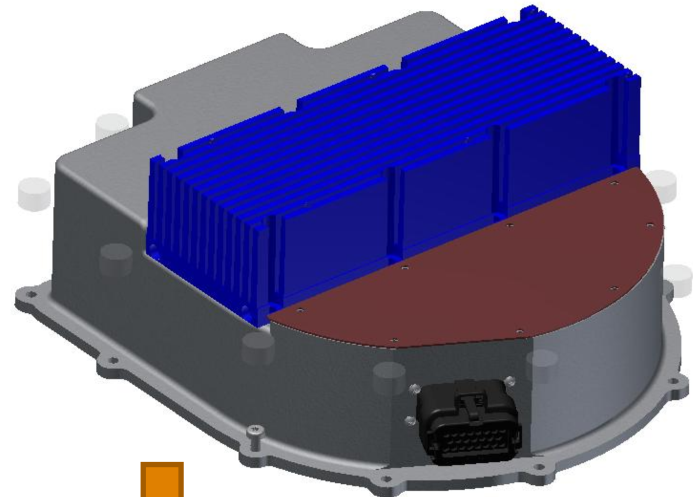


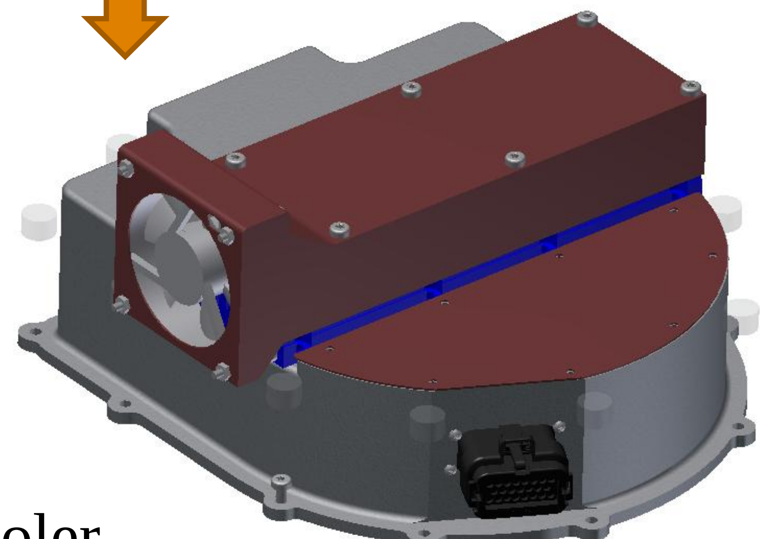
Moduls + Driver + interconnection

Aircooled 3~ 10KW Inverter 400V IGBT (final)

Highest efficieny IGBT technology
Power modules ~ f(DC-Link)



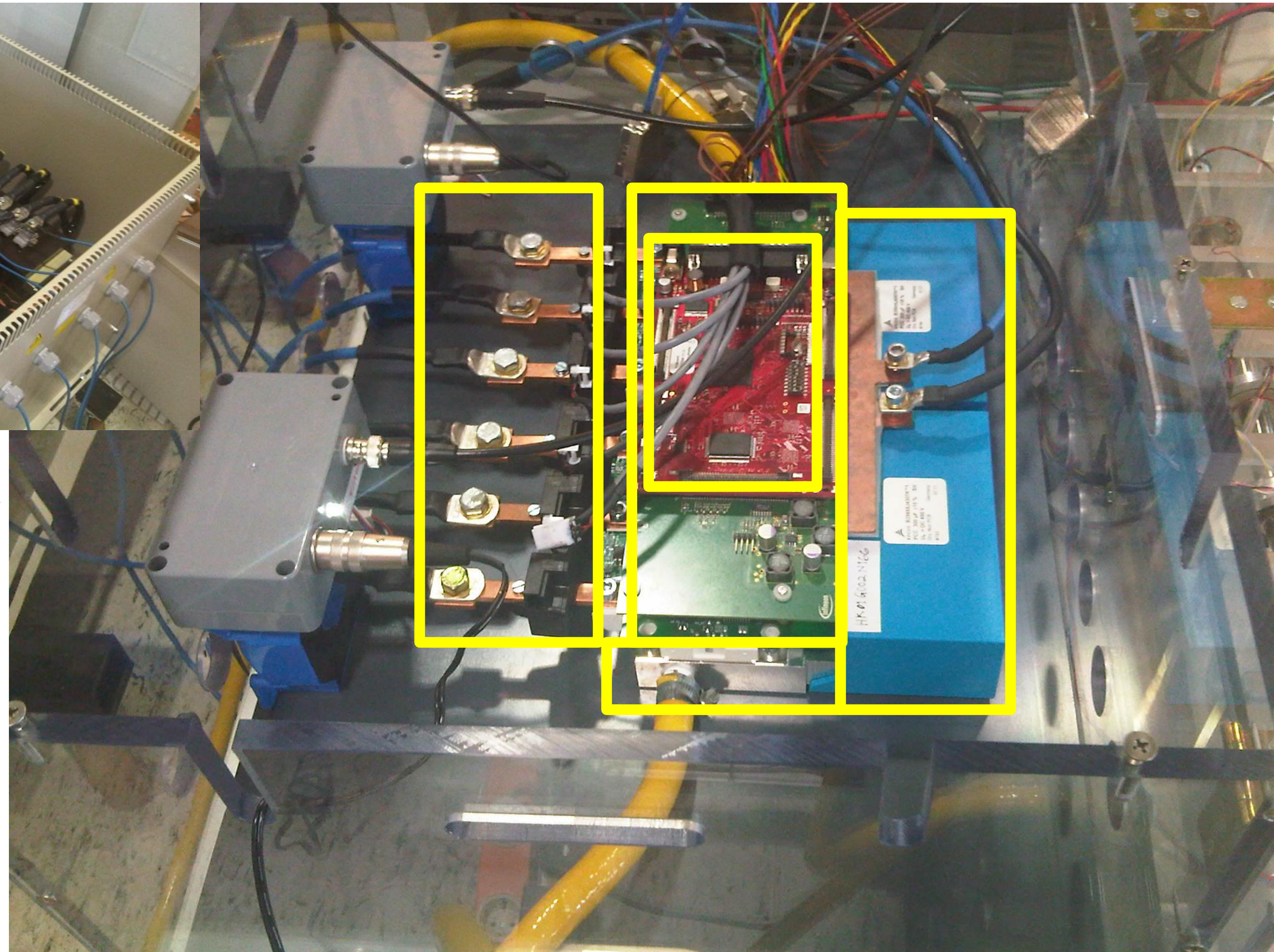




Encabsulated Aircooler

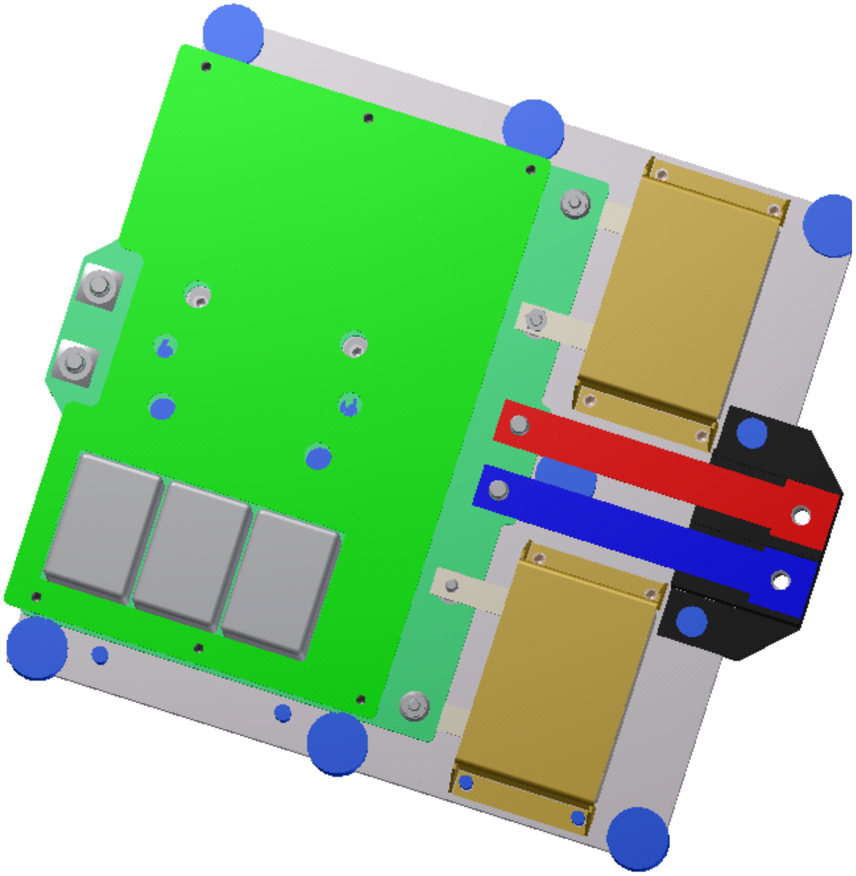
Watercooled 6~ Inverter (concept) 650V IGBT

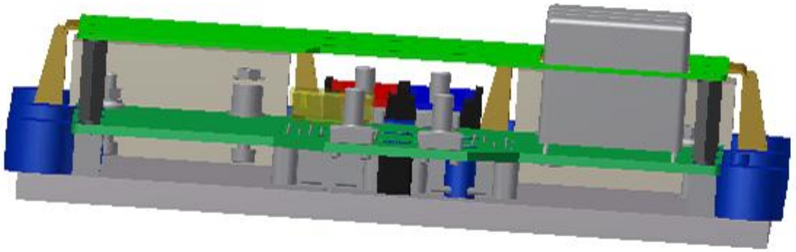
6~ Motor model

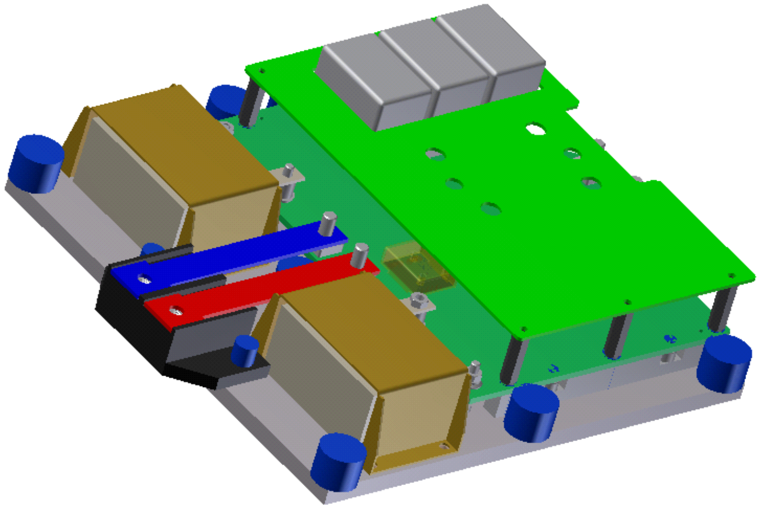


6~ Inverter

DCDC (draft initial concept) 400V IGBT







EVs - A Way of Life - A New Lifestyle

Enjoy Life!

Emissions -> **Electrical vehicle vs. combustion vehicle:**

CO: -99%, **HC**: -97%, **NOx**: -92%, **CO_2**: -50%

www.castor.eu

MotorBrain Research

The Next Step in the EV-Powertrain

Electromobility
Brussels July 12the 2012

Reiner John	Infineon
Philip Brockerhoff	Infineon,
Yves Burkhardt	Siemens,
Wolfgang Schön	ZF

MotorBrain – Key Facts

Lead

Reiner John - Infineon Technologies AG

Target

Raising today's EV efficiency up to 20%

36.000.000 €
Funding Budget

> 3.300
Person Months

31 Project Partners

- 2 OEM
- 4 Tier1 Suppliers
- 17 Tier2 Suppliers
- 8 Academic Partners

9 European Countries involved

8 Supply Chains deliver 8 Demonstrators

3 Years
Project Duration

But there is much more!

MotorBrain Consortium

MOTOR BRAIN

Research — Tier 2 — Tier 1 — OEM

TECHNISCHE UNIVERSITÄT DRESDEN

OFFIS

FH JOANNEUM
UNIVERSITY OF APPLIED SCIENCES

IMT

The University Of Sheffield.

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY

UNIVERSIDAD DE SEVILLA

HAW
Hochschule Amberg-Weiden
für angewandte Wissenschaften
University of Applied Sciences (FH)

POLITECNICO DI TORINO 1859 1906

TNO innovation for life

Fraunhofer IISB

NXP

ROBOX

SEUFFER

EGSTON

GreenPower tech

Höganäs

QinetiQ

Istituto P.M. s.r.l.

infineon

ZF

AVL

SIEMENS

ST

CRF CENTRO RICERCHE FIAT

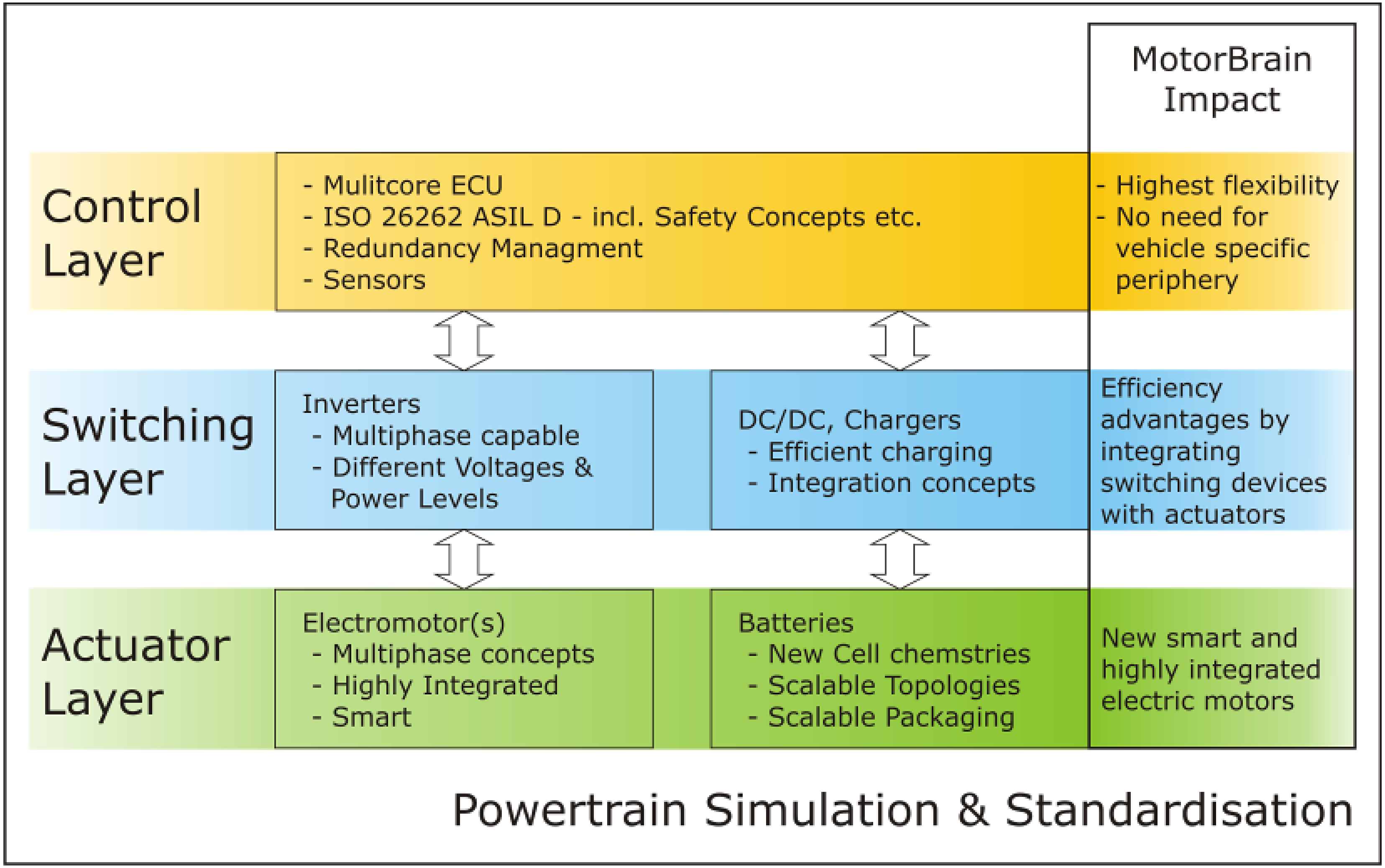
KEMET CHARGED.

MotorBrain – Organisation

WP 1	WP 2	WP 3	WP 4	WP 5	WP 6
Specification	Safety	Brain	Motor	Energy	Integration
CRF	OFFIS	STI	Siemens	QinetiQ	CRF

Subcontract	Topic
SC1 CRF	Distributed propulsion system, low power SMC motor
SC2 Siemens	High speed multiphase motor, sensor integrated, based on SMC
SC3 GP	Synchronous reluctance motor with multifunctional converter
SC4 QinetiQ	Li-Ion cell chemistry and battery pack design
SC5 tbd.	Scalable battery systems
SC6 IFRO	Torquesensors
SC7 IFAT	Current and angle sensors
SC8 IFAG	Multicore ECU

Development Overview – Complete Powertrain



Example Supply Chain 2: Smart integrated EV Powertrain Based on SMC Motor

Actuator Layer

Standard Li-Ion Battery
350 – 800 V

DC interface

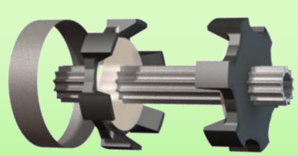
Controller Layer

Multicore ECU, Current, Angle and Torque Sensors
Infineon, NXP

Switching Layer

Inverter
IGBT
Infineon

Actuator Layer



SMC based Electric Motor
Siemens, TUD, ZF, Höganäs, Egston

Torque interface

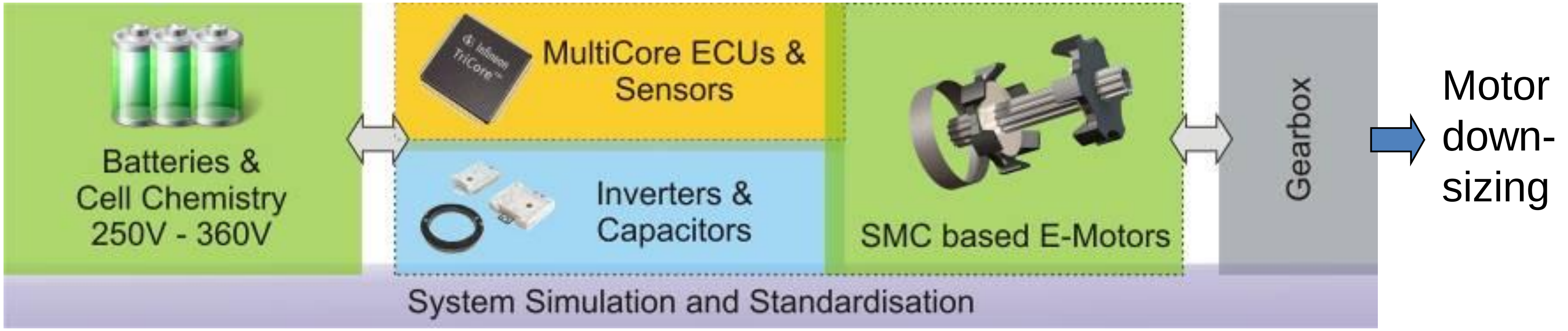
Highly Integrated SMC based Powertrain

> 6 Phases
Up to 60 kW
Up to 15.000 rpm
Gear ratio 9
Integrated sensors
Integrated inverters
Integrated gears
Integrated differential
Common cooling system

Source: digital-engineering-magazin

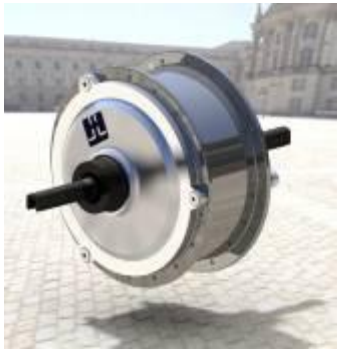
MotorBrain Adressing Key Components

MotorBrain



- Safe Powertrain, with SMC based Motors, MultiCore ECUs, integrated Sensors, Inverters and Capacitors
- No or less permanent magnet based SMC Motors with integrated Sensors, Inverters and Capacitors

Get independent from rare earth material
-> SMC Material Enables New Motor Design



Powders

Basis: Iron Powder of high purity and compressability

Component

Iron powder particles are typically distributed in insulating organic matrix. Recent SMC materials incorporate other filling material than organic matrix.

Machine

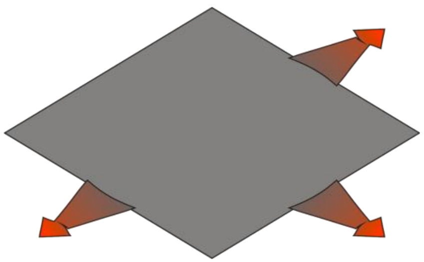
As a result, SMC properties are now suitable for electrical steel sheets and ferrites for a wide range of applications

Soft magnetic composites: high speed, low cost manufacturing and recycling Source Höganäs (Sweden)

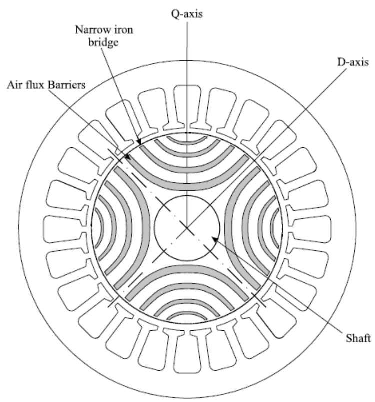
Using SMC, it becomes possible to define a magnetic field in three dimensions and create improved or even entirely new machine concepts

MOTOR BRAIN

Exploitation of novel 3D flux distribution through the use of soft-magnetic compounds (SMC)



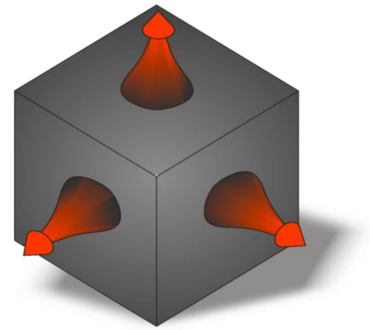
2D flux distribution as known from electric sheets

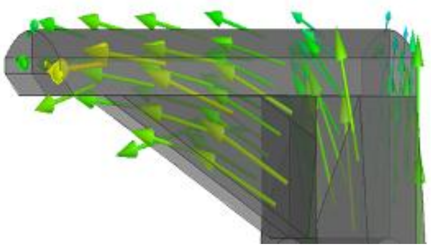


Cross section of a radially laminated Syncrel.

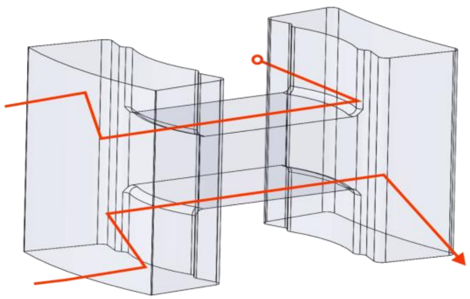
Source GreenPower, CRF

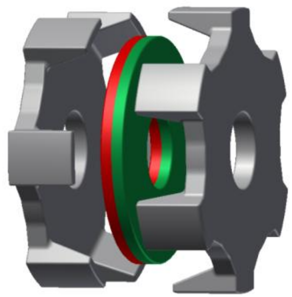
State of the Art





Possibilities of a 3D flux distribution by SMC





Source Höganäs, Siemens

Solutions in MotorBrain: Enter the 3rd dimension

Aeneas

eniac JOINT UNDERTAKING

Safety Revolution with Multicore ECU

Safety is key for the success of electromobility!

To achieve safety advanced diagnosis and control mechanisms are necessary.

The Brain in MotorBrain is advanced multicore control units with special sensors and safety functions!

Car Accident

Electro chock

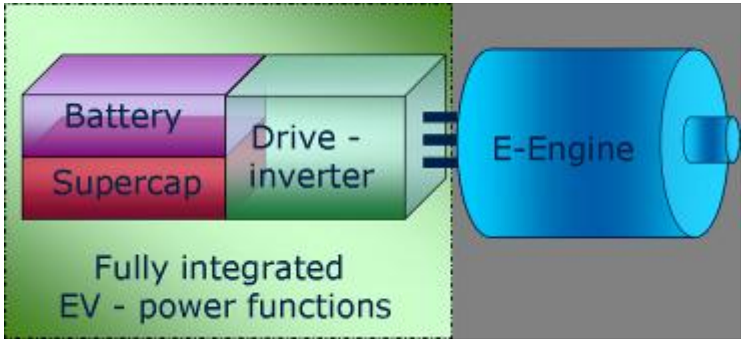
Fire or Explosion

How can the drive train be cheap and efficient?

Integration of power electronics and motor	**Separate**  Source: Bosch	**Built-On**  Source: EfA, ZF	**Fully Integrated**  Source: electronicdesign.com
Cost	O	++	+
Size, Weight	-	+	++
Availability	+	+	O
Maintenance	++	+	-

Power train architecture depends on Propulsion System

Castor



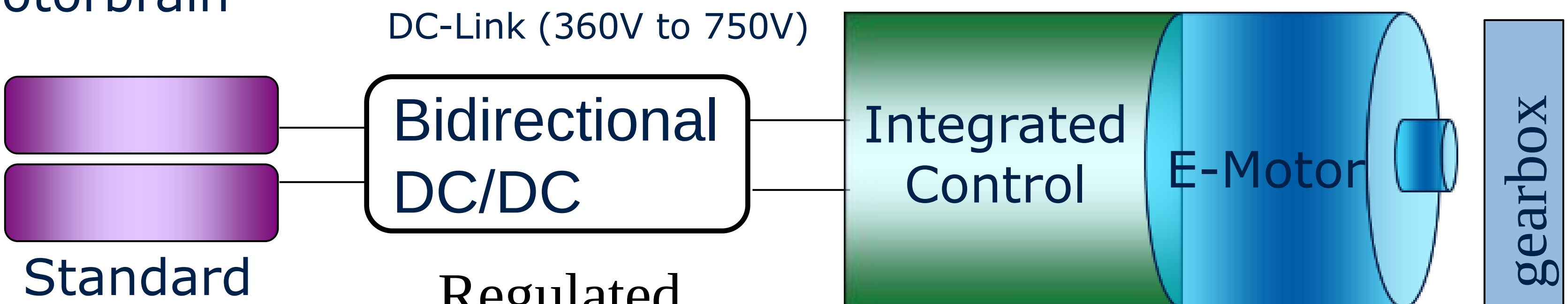
Low voltage DC-Link
Low power rating for uCar,

400V voltage DC-Link
35/50KW power rating for class A Car

Multiphase motor enables integrated control for EV´s

Motorbrain

Controlled and variable
DC-Link (360V to 750V)



Standard
Battery 100 cells
250V to 360V

Regulated
DC-Link

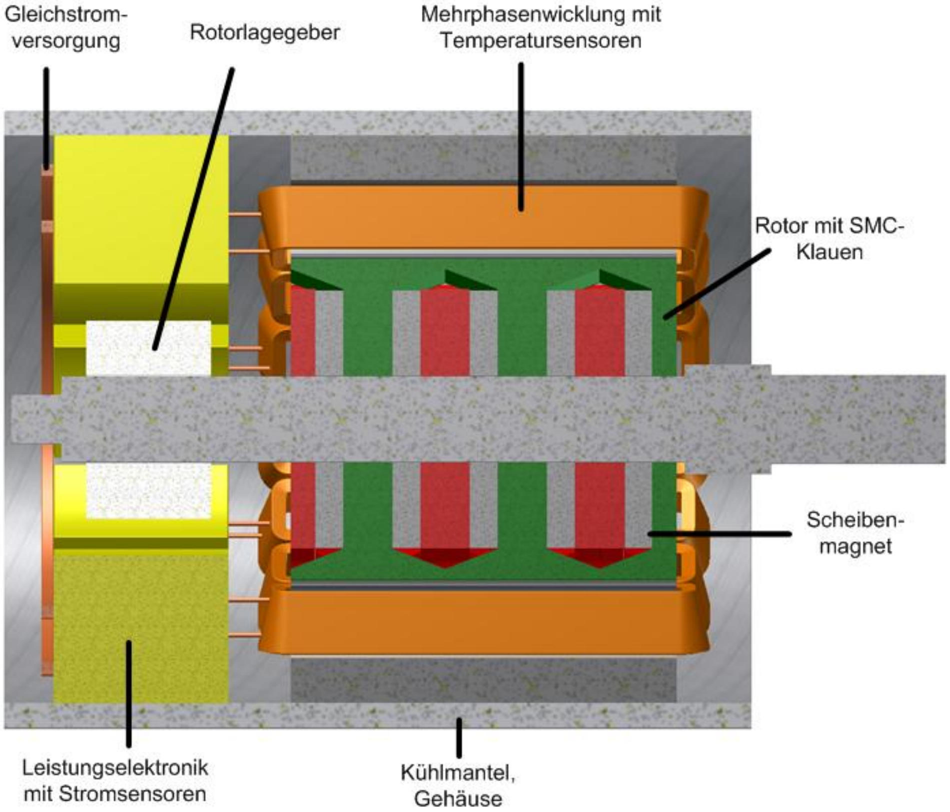
Battery Intependand DC-link

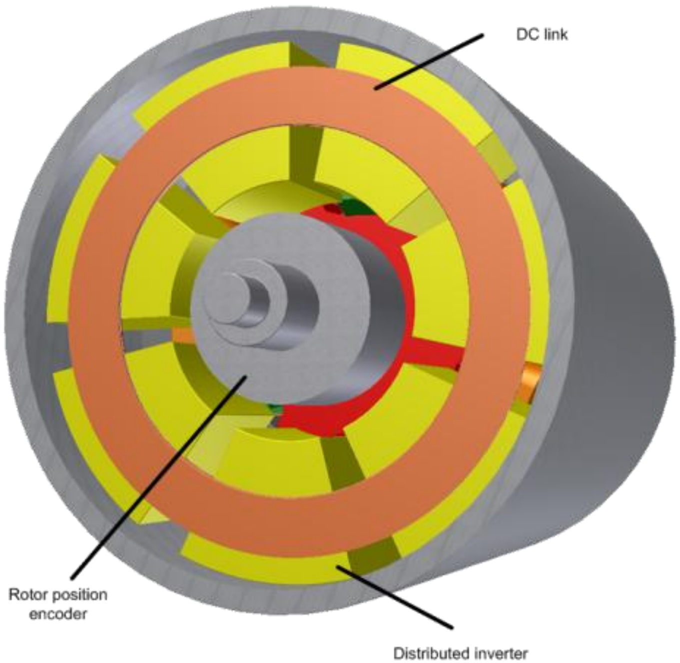
Inverter downsizing

Motor downsizing

Cost Efficient Inverter/Motor Integration

MotorBrain motor development example

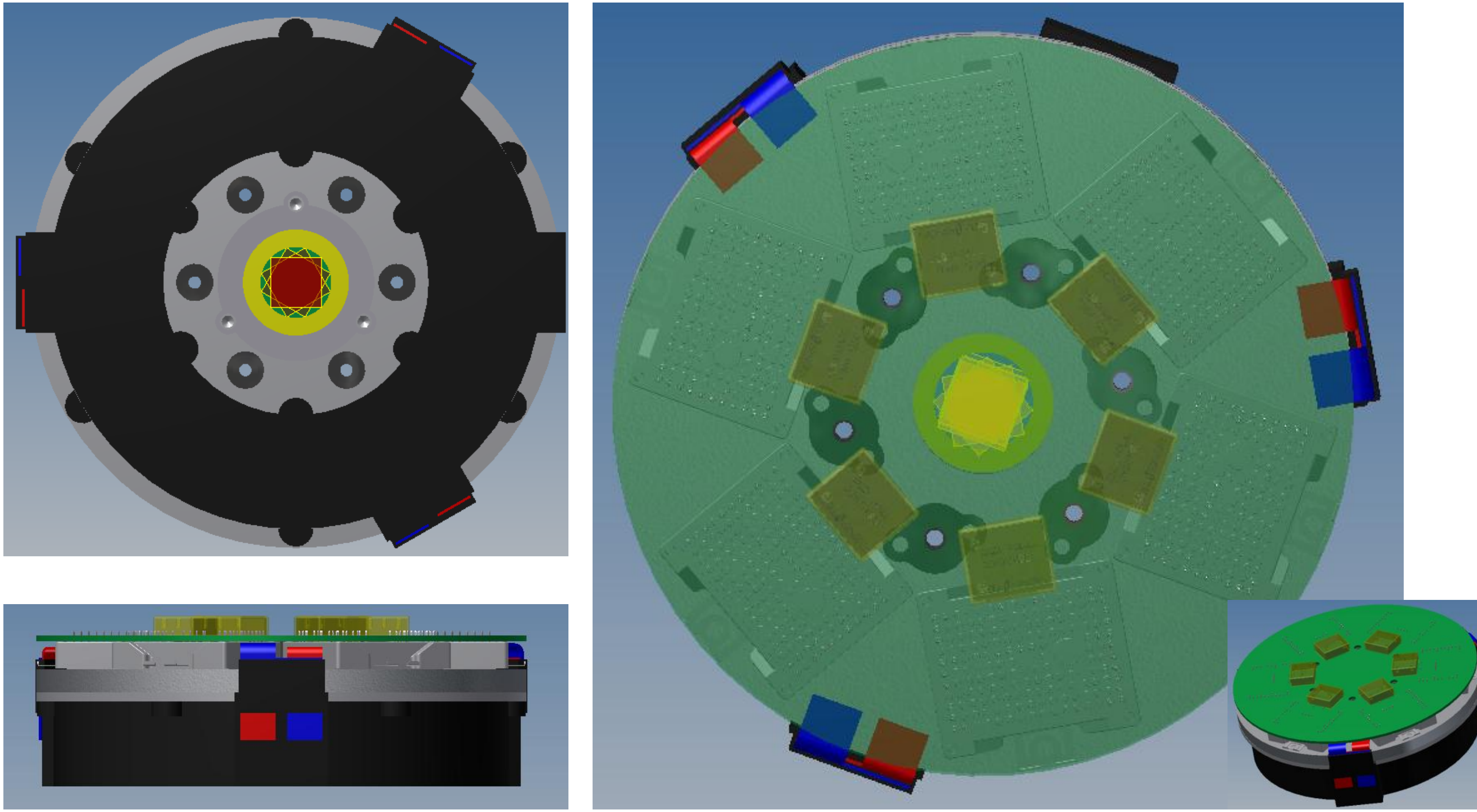




Source Siemens

First concept for machine without rare earth magnets and axial inverter integration.

MotorBrain Integration Approach



Source Infineon

Mechanical concept draft for axial inverter integration

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Enjoy Life!

Emissions -> **Electrical vehicle vs. combustion vehicle:**

CO: -99%, **HC**: -97%, **NOx**: -92%, **CO_2**: -50%

www.e3car.eu

www.MotorBrain.eu

www.castor-project.eu