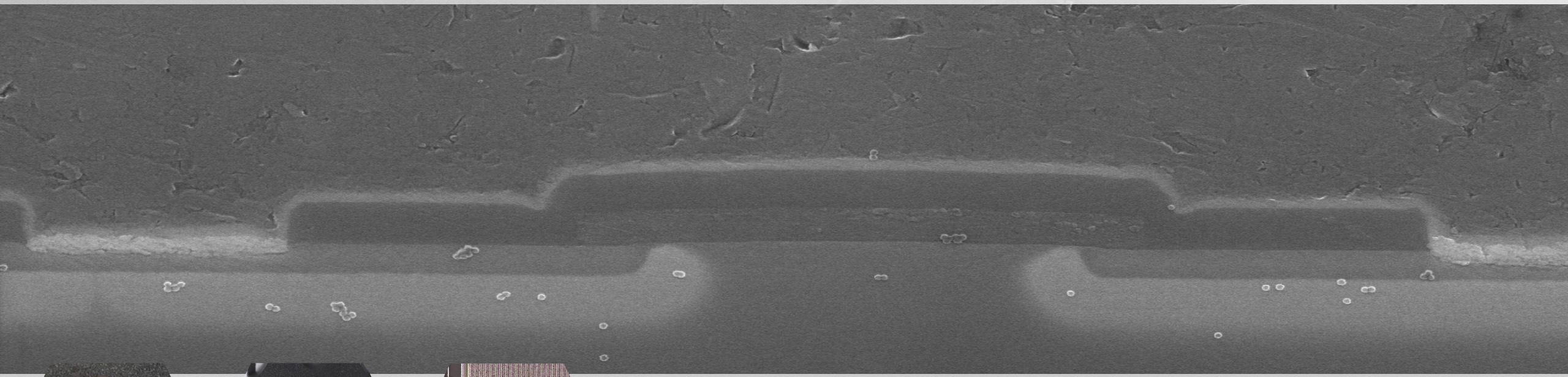

Si vs SiC Power modules in HEV integration: a cost point of view

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March 2017

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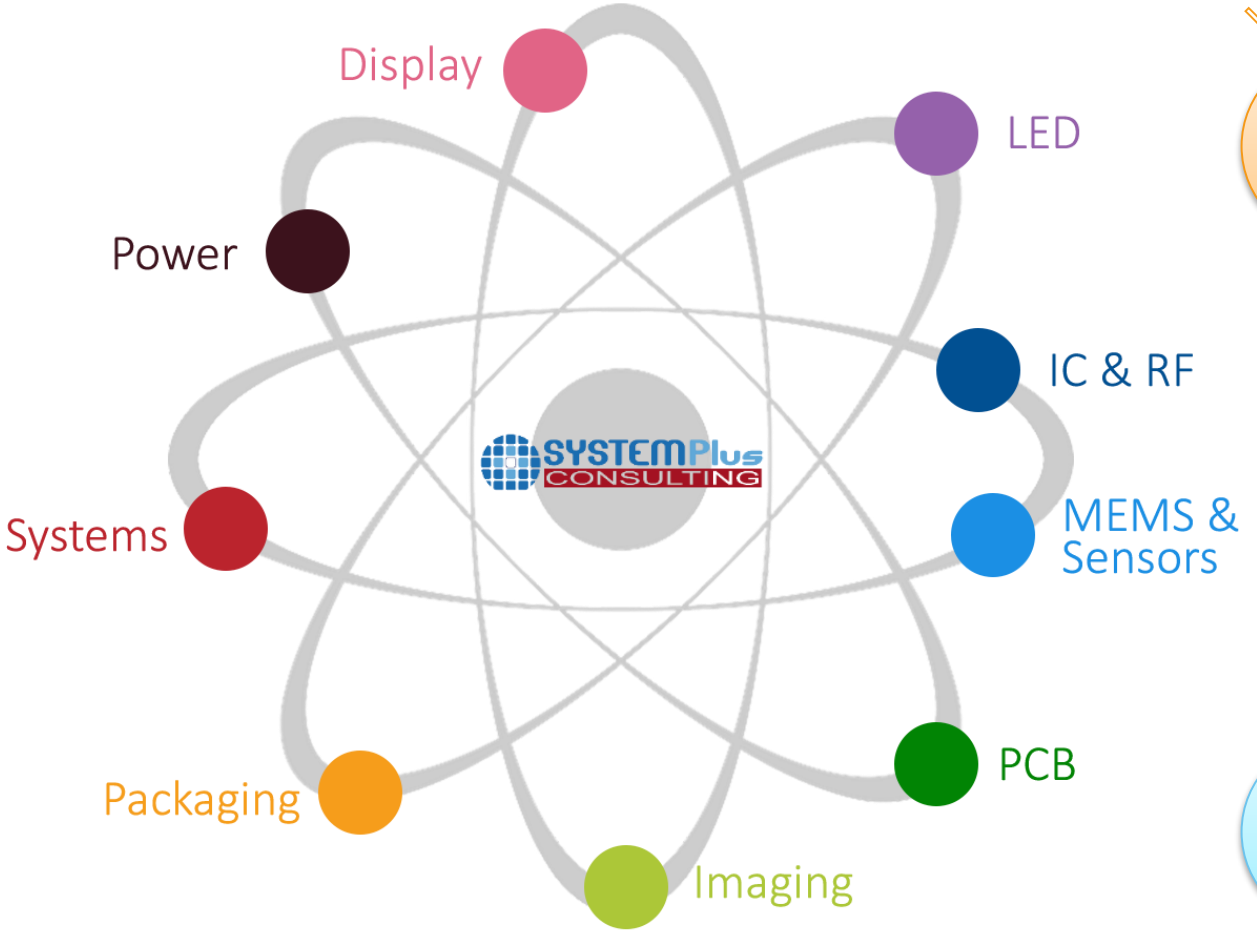
Business Models and Fields of Expertise

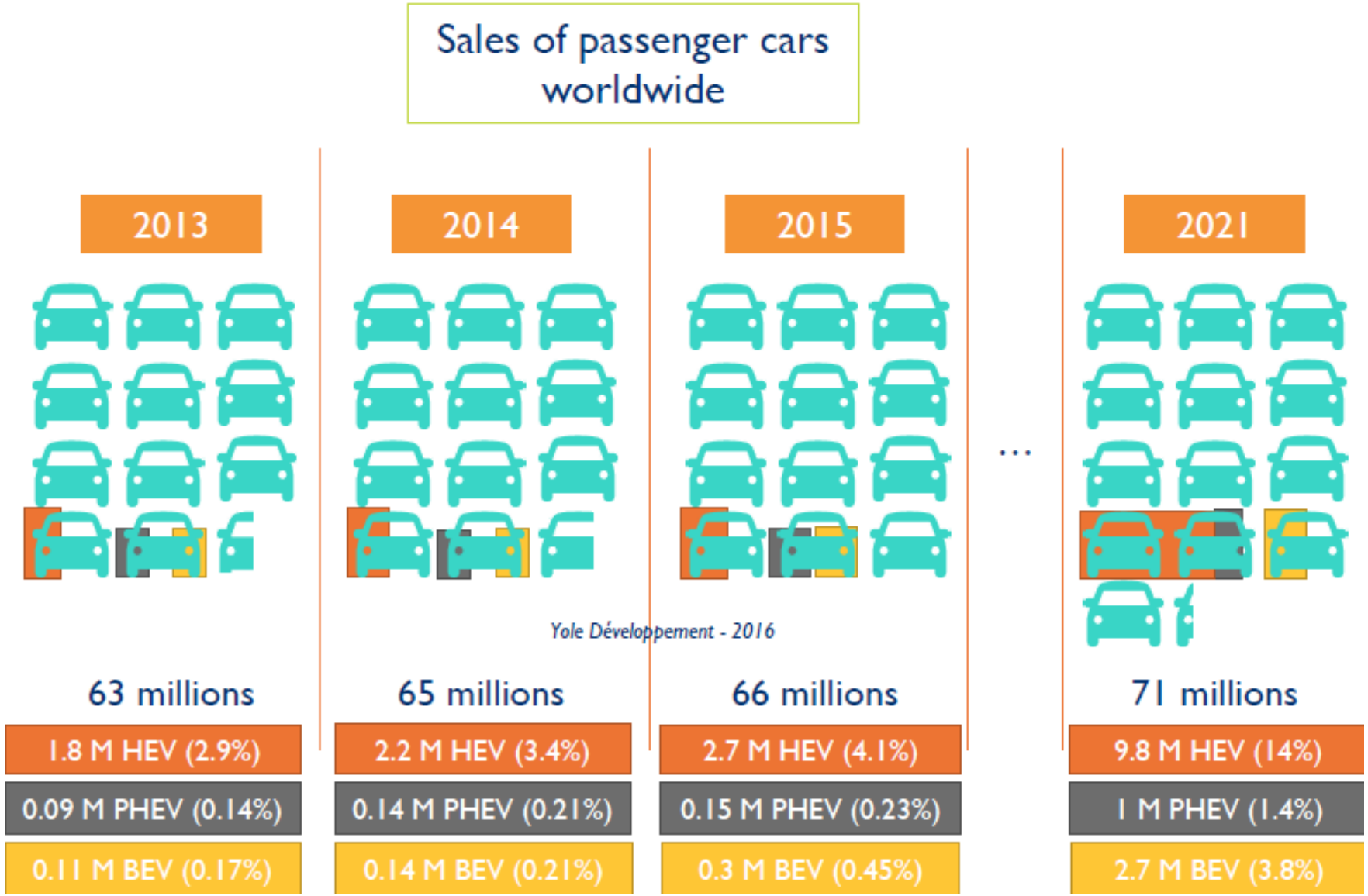
SYSTEM Plus CONSULTING mission is to provide decision makers with arguments coming from a bottom-up cost and technology simulation.



EV/HEV Market

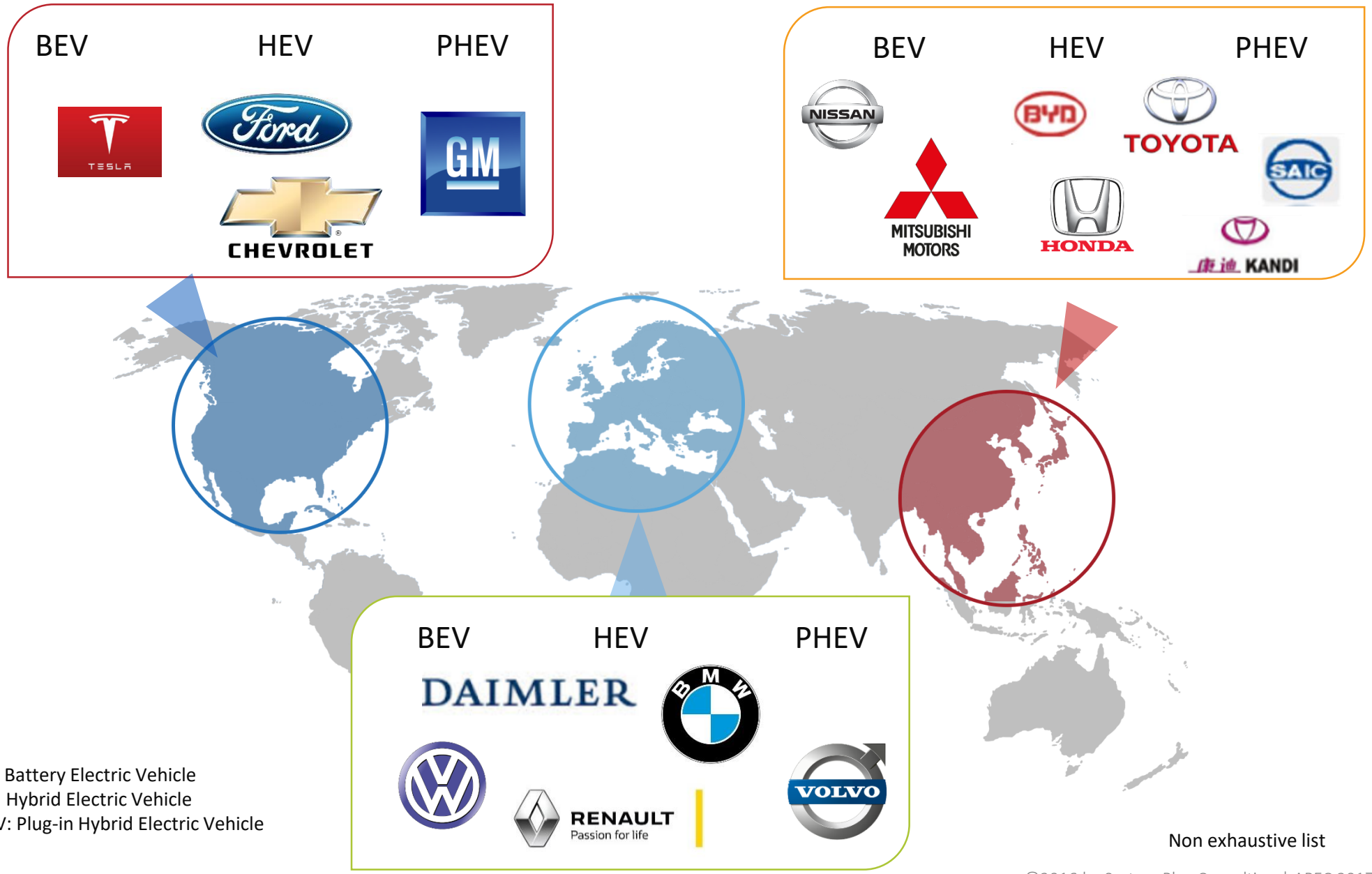
Between 2014 and 2015, the amount of full electric cars sold was multiplied by 2, which is very encouraging for the future

By 2021, we expect electrified cars to represent almost 20% of the sales



EV/HEV Main Manufacturers

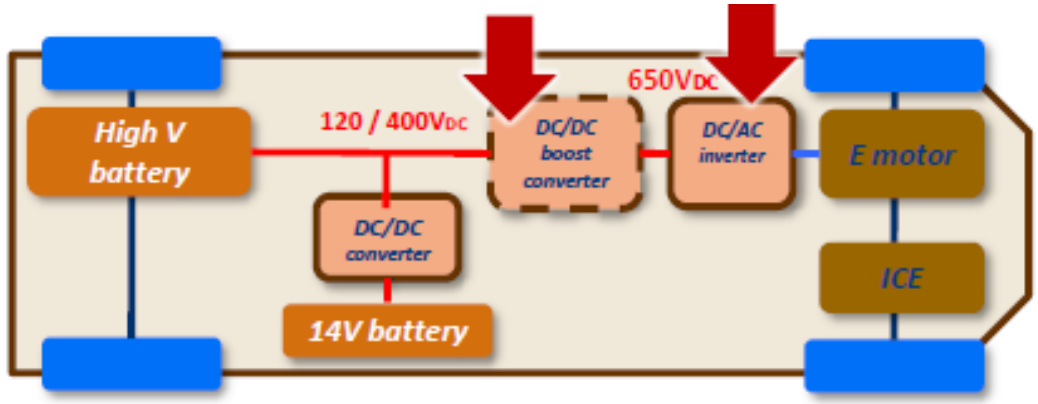
Electrification trends depend on the strategy of local car manufacturers, and local governments



BEV: Battery Electric Vehicle
HEV: Hybrid Electric Vehicle
PHEV: Plug-in Hybrid Electric Vehicle

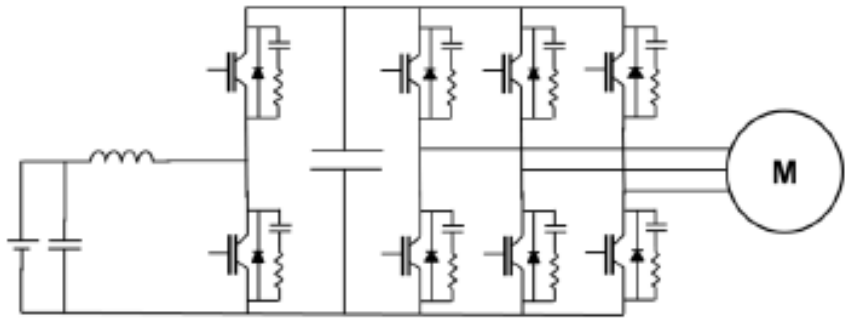
Non exhaustive list

DC/AC inverter+ DC/DC booster option (full hybrid+ PHEV + BEV)



DC/AC Inverter:

- ✓ Generates a 3-phase AC signal from the high voltage battery DC current (200/400Vdc) to actuate the electric motor. The inverter is bi-directional.
- ✓ 400 -650 VAC
- ✓ Power: 20 –100 kW. Average power: 50 kW
- ✓ Water cooled with a dedicated cooling circuit
- ✓ Devices: IGBT + diodes



DC/DC booster: option :

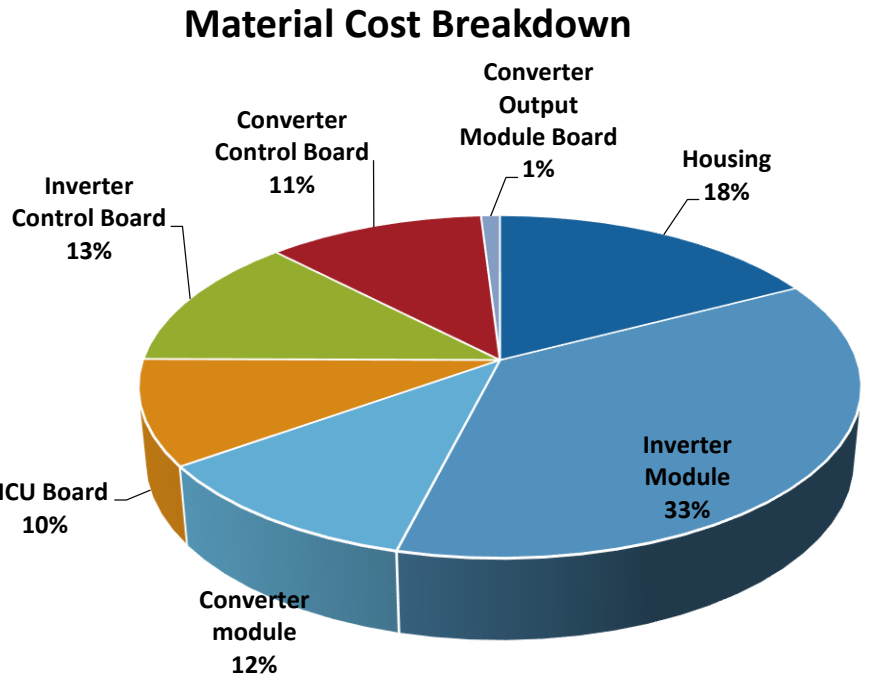
- ✓ Boosts the battery DC current (200/400Vdc) to provide higher voltage(600/650V) to the inverter. The converter is bi-directional. The booster is integrated in the same packaging as the inverter (Toyota Prius configuration).The booster allows the reduction of the overall powertrain cost.
- ✓ 400 -650 VAC
- ✓ Power: 20 –100 kW
- ✓ Water cooled
- ✓ Devices: IGBT + diodes

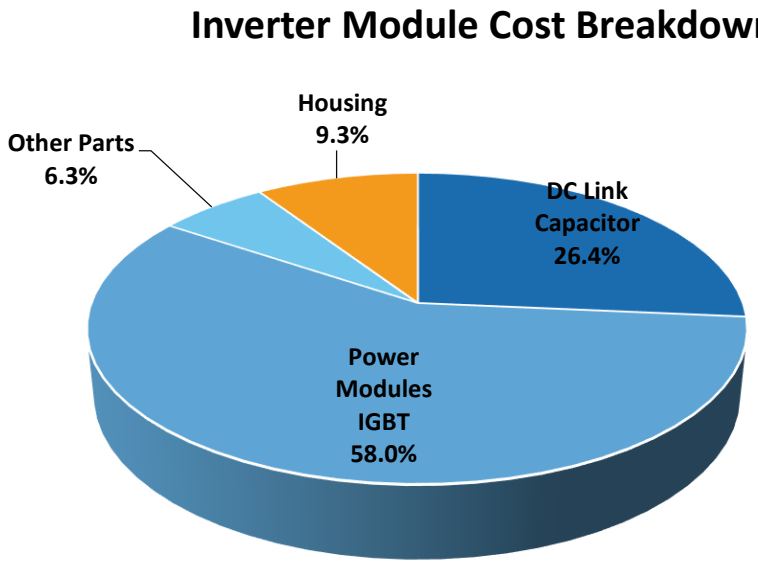
DC/AC Inverter Average Cost Breakdown

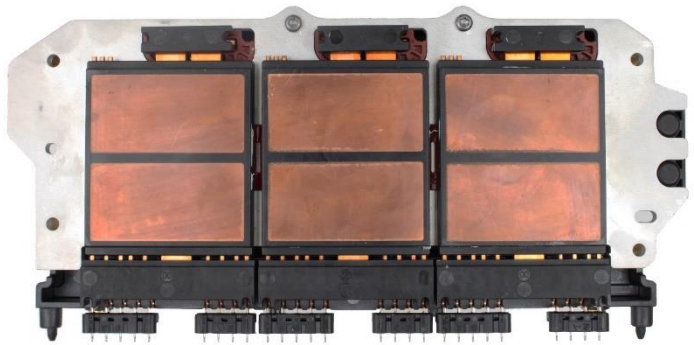
VW e-Up! Inverter from Bosch

In a DC/AC Inverter the higher cost is due to the specific inverter module.

In the Inverter module the power IGBT module has the highest impact on the cost





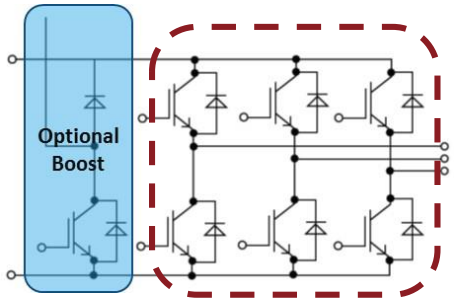


Bosch power modules

POWER MODULE IGBT LEVEL: different integration

To achieve further system cost and package volume reduction, it is common to integrate the electrical motor and the motor drive inverter.
These offer new space saving solutions that require high power density electronics

6-in-1 power module



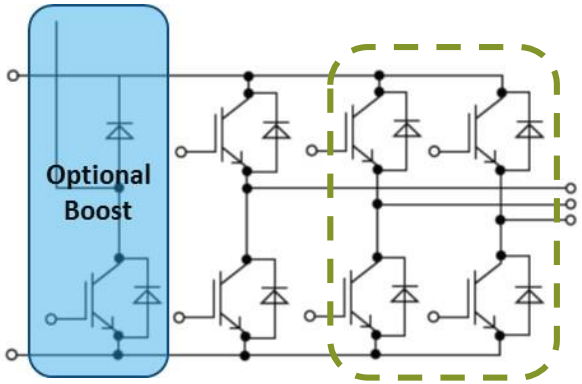
Ford Focus 2014

Nissan Leaf 2011

Nissan Leaf 2012

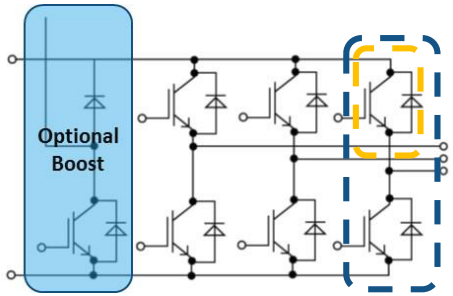
Renault Zoe 2013

4-in-1 power module



Ford C-max 2015

1-in-1 power module



Chevrolet Volt 2015

2-in-1 power module

Volkswagen e-up! 2013

Volkswagen Golf 2014

Honda Civic 2010

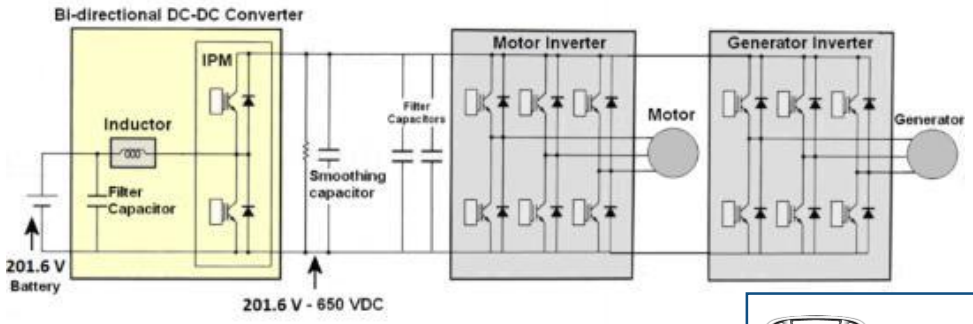
Honda Fit 2010

Toyota Camry 2013

Toyota Prius 2015

Mitsubishi Outlander 2014

all-in-1 power module



Toyota Prius 2004

Toyota Prius 2010

Toyota Auris 2011

Toyota Yaris 2012

Honda Accord 2013

All-in-1 solution: Toyota & Honda

Toyota and Honda integrates several converters together in a central box (motor inverter + generator inverter + boost + low voltage DC/DC):

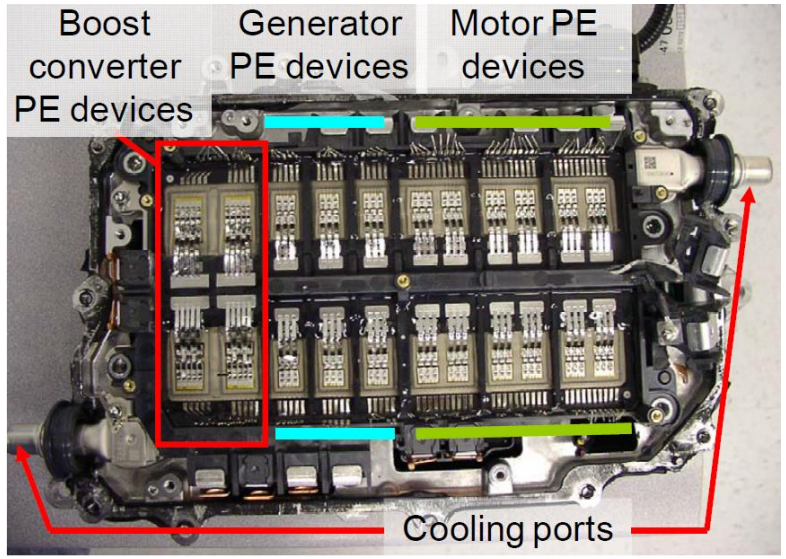
- ✓ Shared cooling systems
- ✓ Semiconductors from different conversion stages sharing a power module
- ✓ Reduction of wire connection.

Toyota Prius:

- ✓ Motor inverter, generator and boost have different die sizes
- ✓ Evolution of IGBT and Diode size and design

Toyota Prius II (2004)

Toyota Prius III (2010)



Toyota Prius III (2010)

HISTORY OF TOYOTA IGBTS FOR HVS

Item		The 1st generation	The 2nd generation	The 3rd generation
Chip appearance				
Device structure	Gate	Planar	Planar	Trench
	Vertical	PT	PT	Thin wafer
	Lifetime control	He irradiation	He irradiation	None
Chip size (The 1st generation=1)		1	0.79	0.65
Chip thickness (μm)		380	380	165

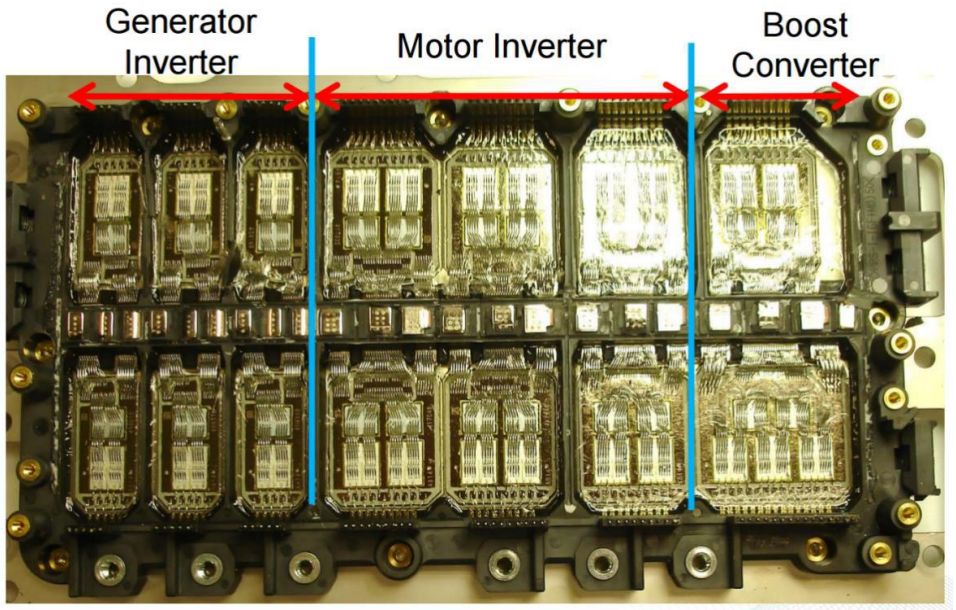
	Generator Inverter	
	IGBT size	Diode size
Prius II – 2nd gen	131	40
Prius III – 3rd gen	108	67.5
Prius IIIc – 3rd gen	86.5	63.4

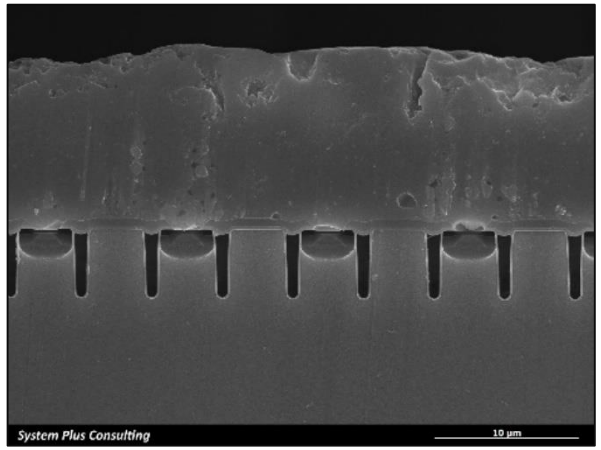
Toyota Prius IIIc (2011)

All-in-1 solution: Toyota & Honda

Honda Accord:

- ✓ Motor, generator and boost have the same dies
- ✓ IGBT size: 15.26x12.25 mm
- ✓ Diode size: 11.07x12.18mm



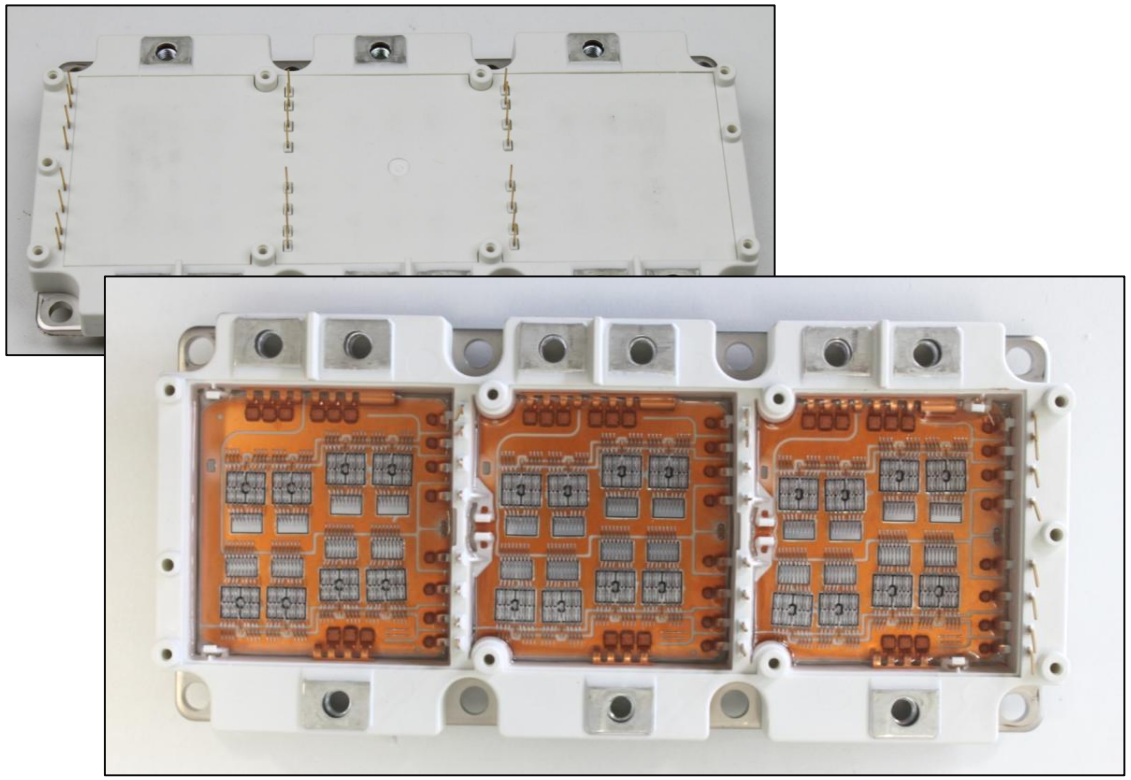


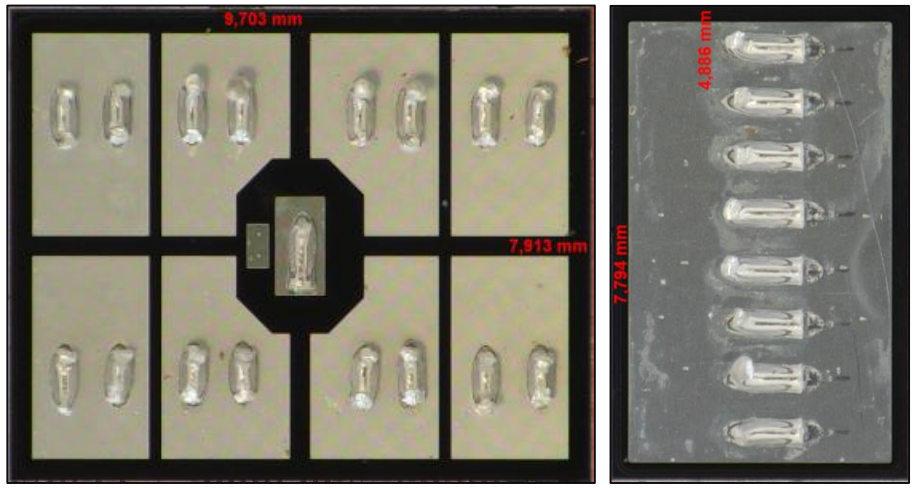
6-in-1 solution: Infineon

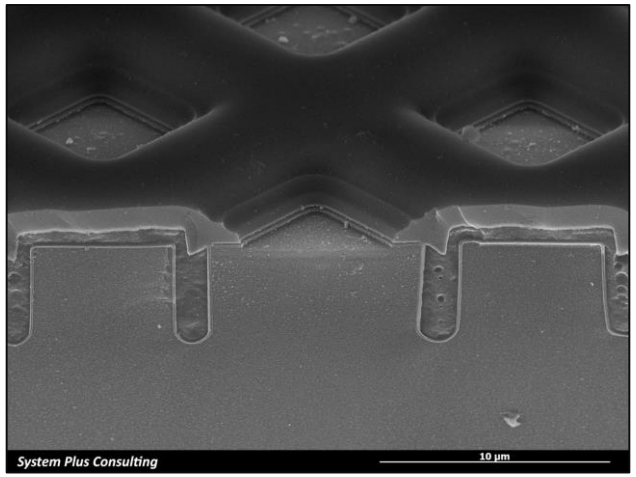
The standard solution for power module is the 6-in-1 module.

Infineon proposes a solution with:

- ✓ 100kW continuous power
- ✓ 4 IGBT & FWD for configuration
- ✓ 650V/150A IGBT & diode

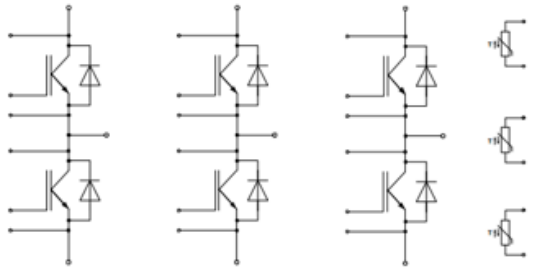






	Size
Power Module	216x99mm
IGBT	76.63 mm2
Diode	38.2 mm2

3-phase Six-Pack configuration



V_{CES} = 650V

$I_{C\ nom}$ = 600A / I_{CRM} = 1200A

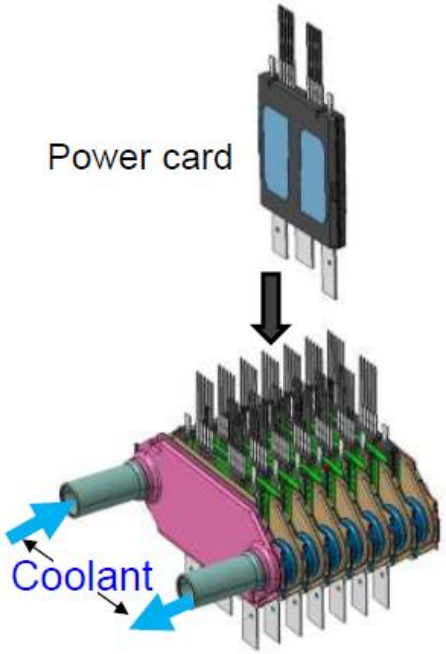
2-in-1 solution: Toyota Prius IV 2015

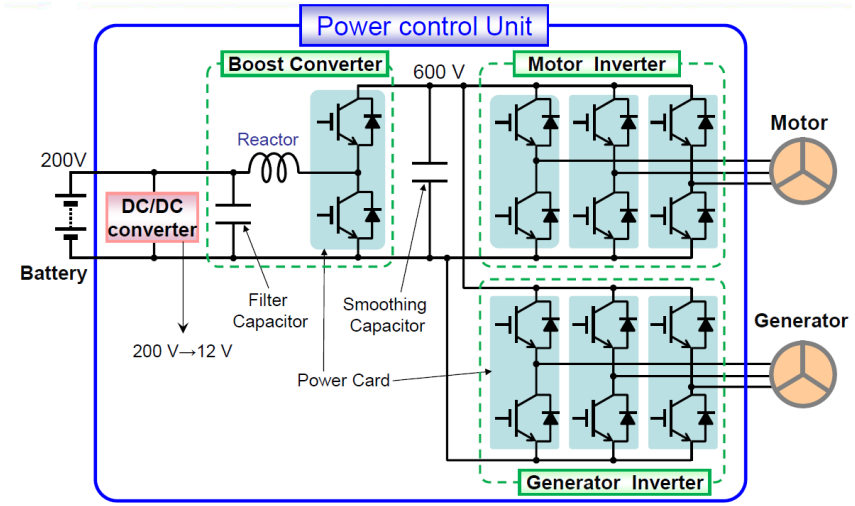
For the 4th generation of Prius, Toyota proposes a completely different inverter structure with 2-in-1 power module integrated in a specific modulable cooling system.

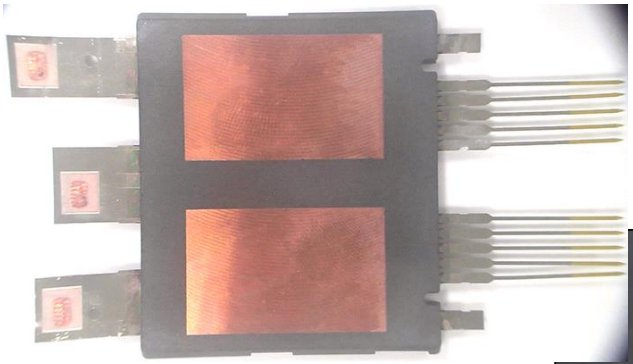
The PCU groups the inverter + DC/DC boost converter + generator AC/DC + DC/DC step-down converter in one box.

This structure allows a 35% of reduction of PCU size:

- ✓ Dooble side cooling
- ✓ Reduction of IGBT size
- ✓ Thickness of DC-DC converter reduced







2-in-1 solution: Toyota Prius 2015

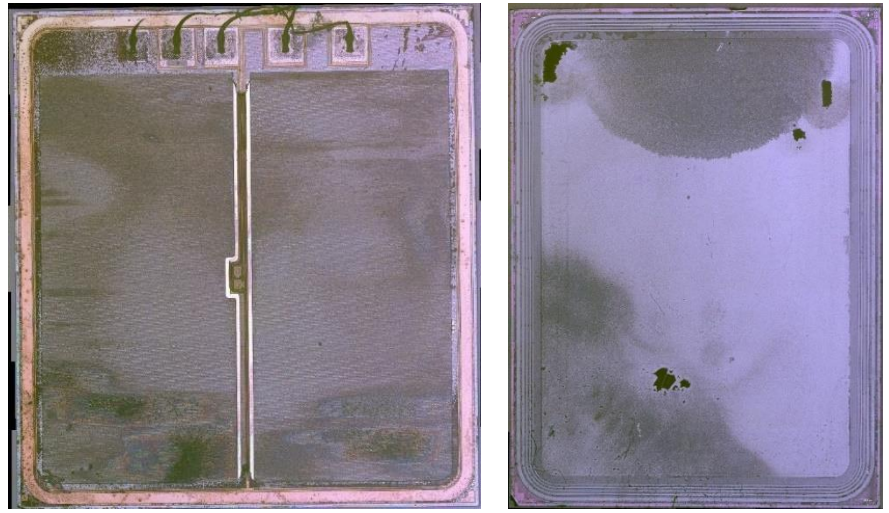
Toyota improves its device design allowing of a miniaturization of the dies

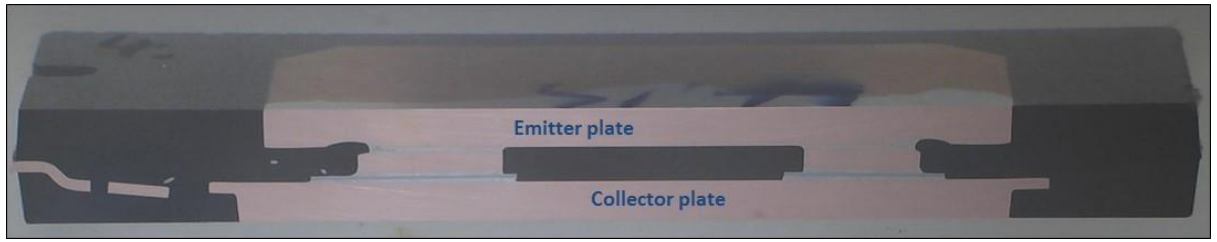
		Generator Inverter	
	Techno	IGBT size	Diode size
Prius II – 2nd gen	Planar	131	40
Prius III – 3rd gen	Trench	108	67.5
Prius IIIc – 3rd gen	Trench	86.5	63.4
Prius IV- 4th gen	Trench	78.3	60.9

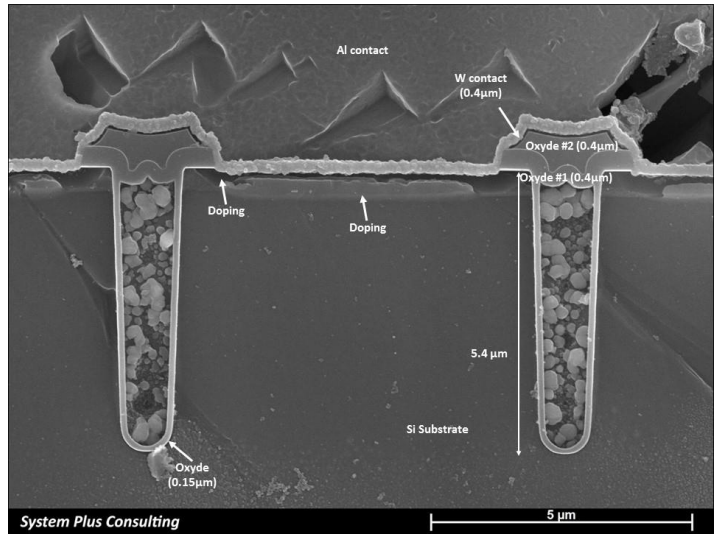
- 17% /+40%

- 20% /-6%

- 9% /-4%







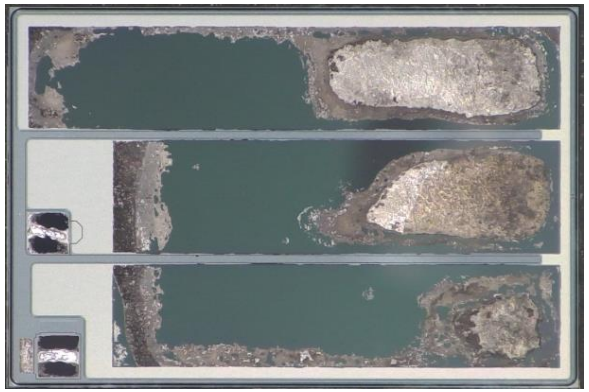
FS Trench IGBT technology

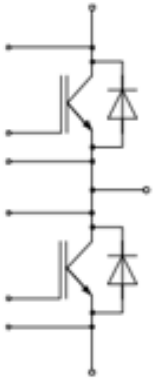
2-in-1 solution: Bosch

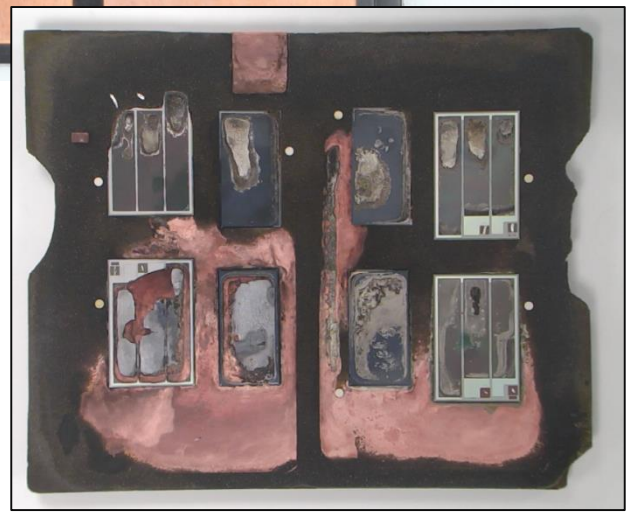
Bosch proposes for the VW e-Up! A 2-in-1 solution:

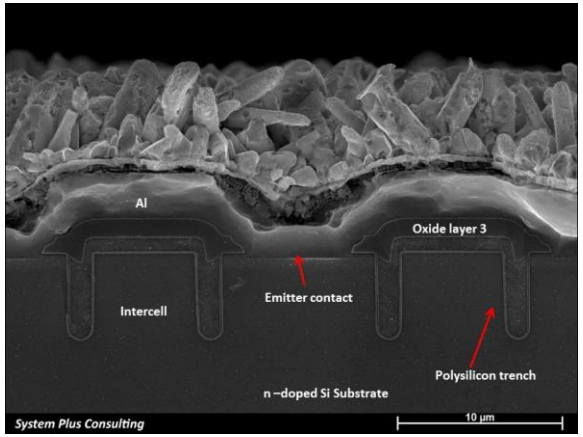
- ✓ 2IGBT & 2 diodes for configuration
- ✓ FS Trench IGBT of Infineon
- ✓ Molded package
- ✓ Chip on massive copper substrate
- ✓ Temperature sensor inside the package
- ✓ Thin film insulator

	Size
Power Module	65x56mm
IGBT	150 mm2
Diode	98.5 mm2







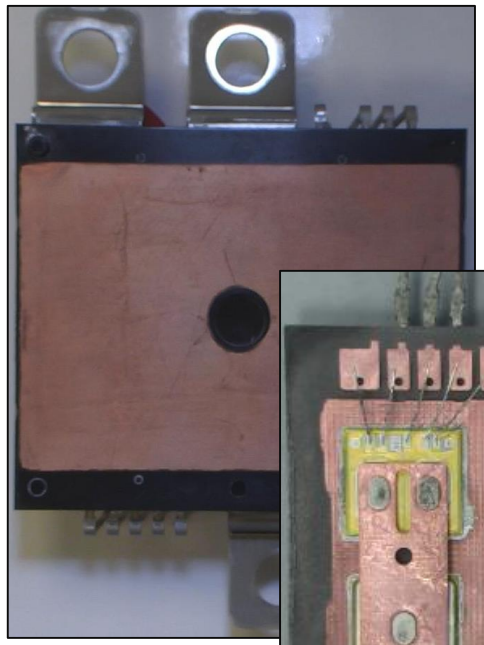


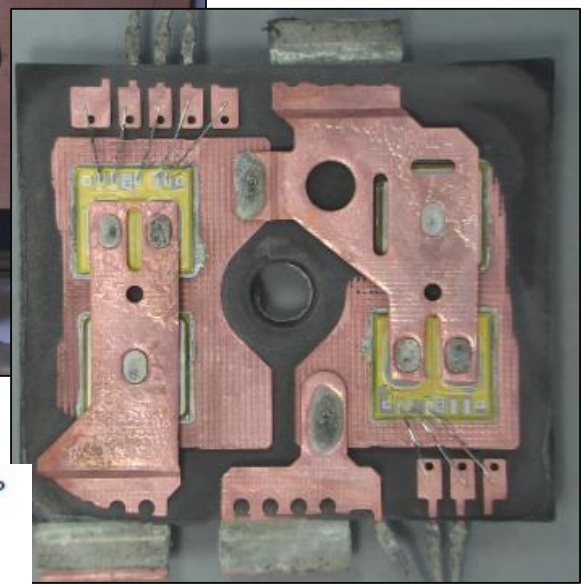
2-in-1 solution: Mitsubishi for Honda Fit

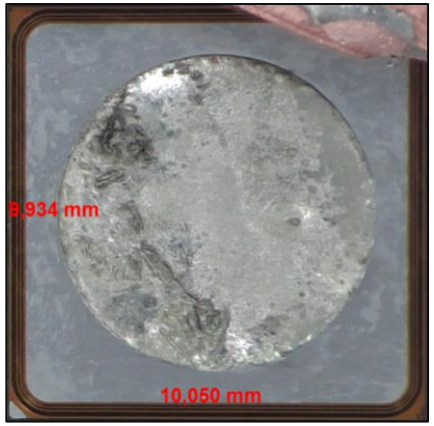
Mitsubishi Electric was one of the first companies to offer double-side cooled modules for automotive applications

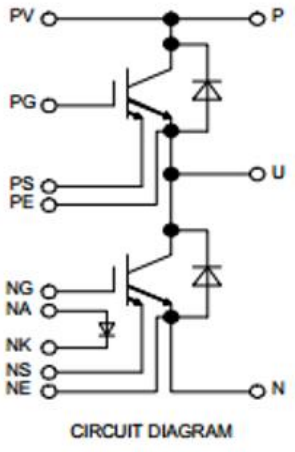
- ✓ 600V/300A capability
- ✓ Molded package

	Size
Power Module	50x42.7 mm
IGBT	110 mm2
Diode	100 mm

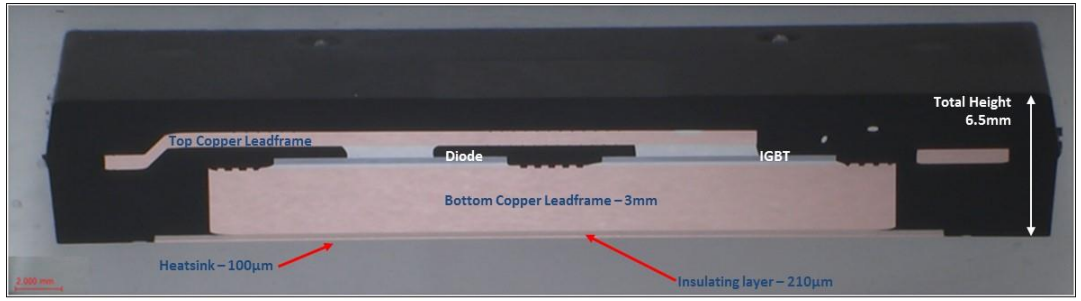


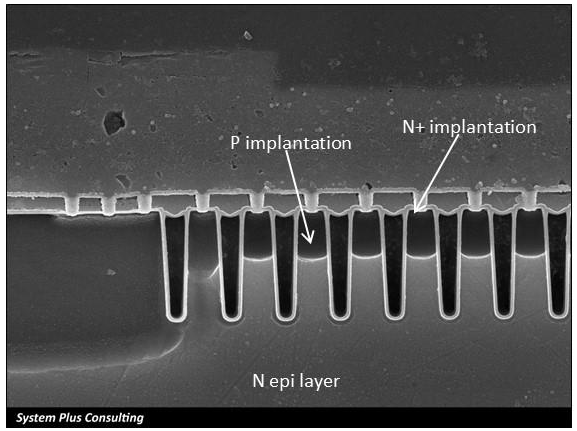






CIRCUIT DIAGRAM



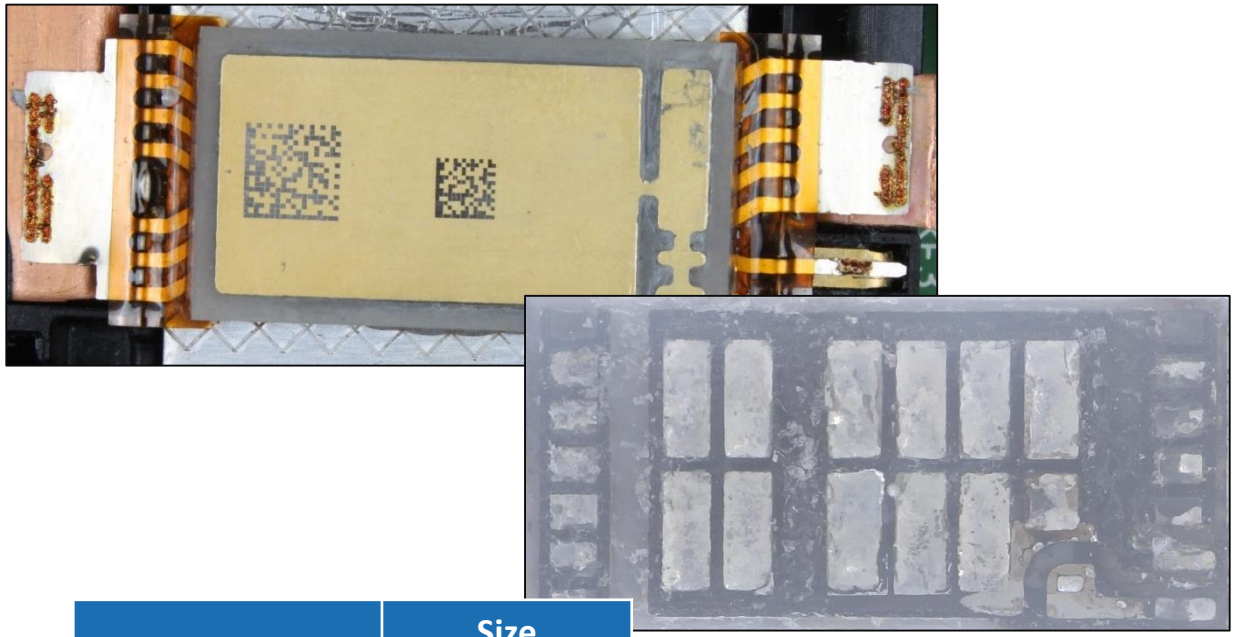


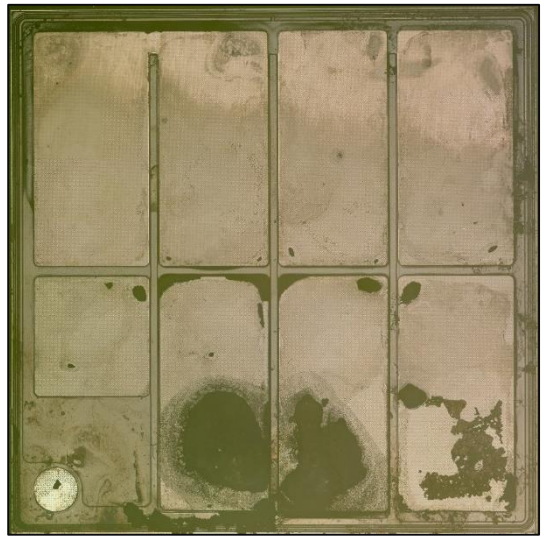
Mitsubishi CTSTB IGBT technology

1-in-1 solution: Viper for Chevrolet Volt

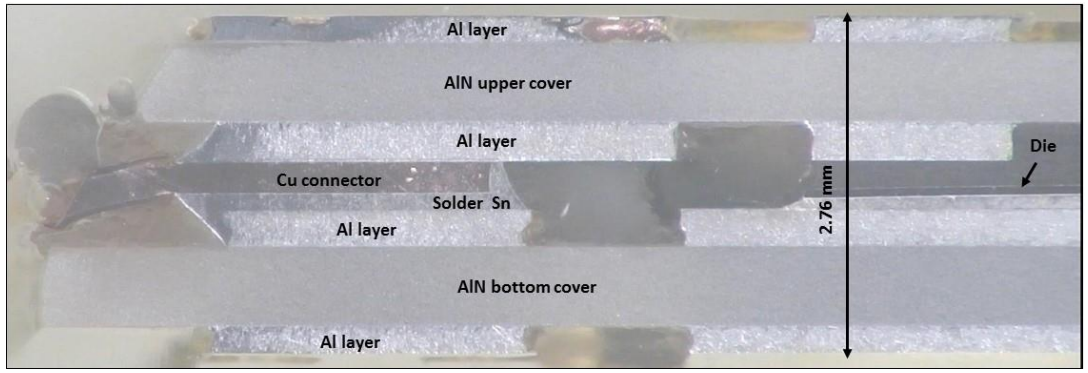
The Viper module in Chevrolet Volt is using double side cooling in a one-in-one package:

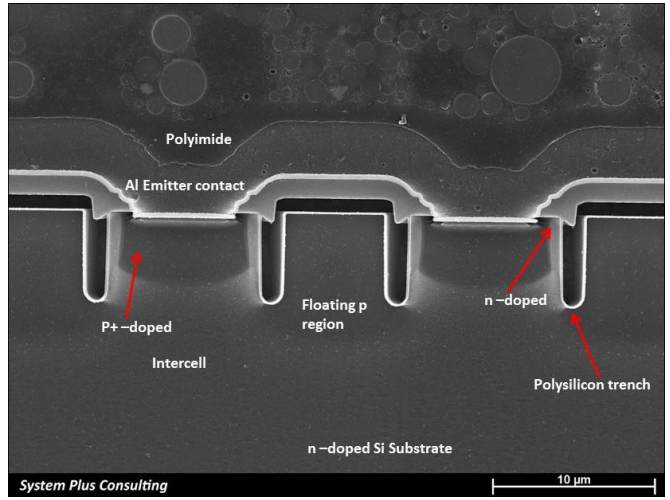
- ✓ Wirebond-less package with sintered packaging interconnections.
- ✓ Small size
- ✓ Ceramic covers





	Size
Power Module	31.5x17 mm
IGBT	144 mm2
Diode	72 mm2

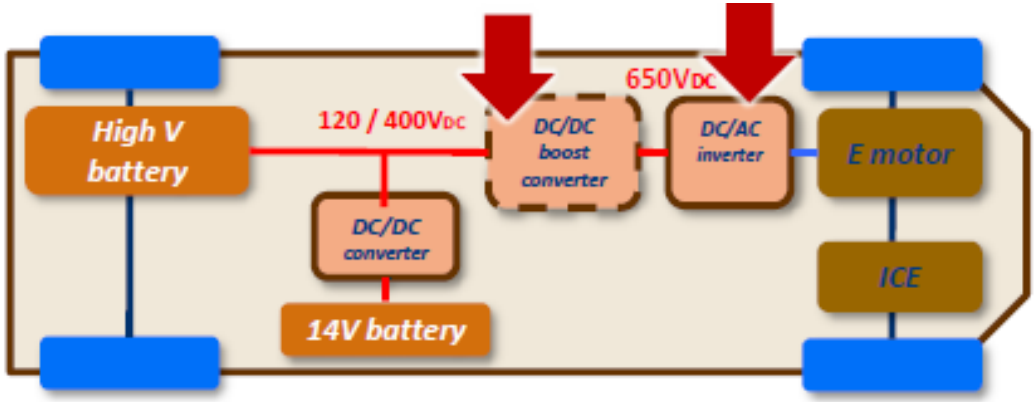


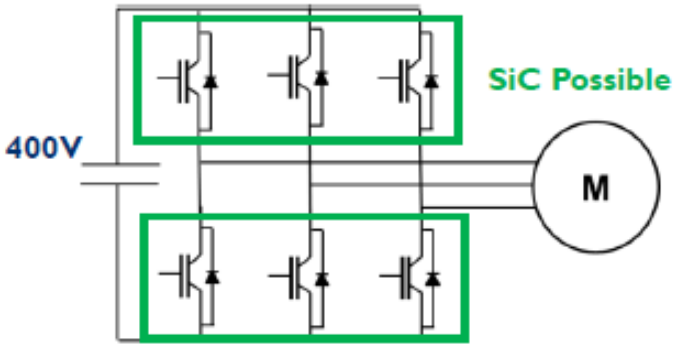


IR FS Trench IGBT technology

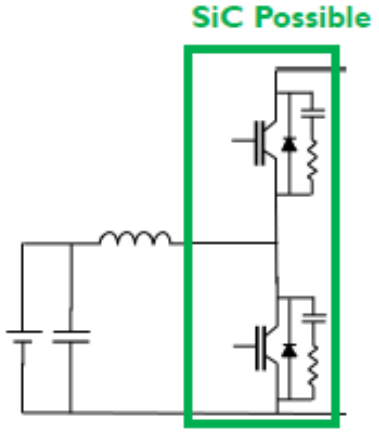
SiC integration

With an increase in power and the necessity of miniaturization, WBG materials could replace Si-based IGBT and MOSFETs in EV/HEV applications.





Standard Inverter Topology (generator)

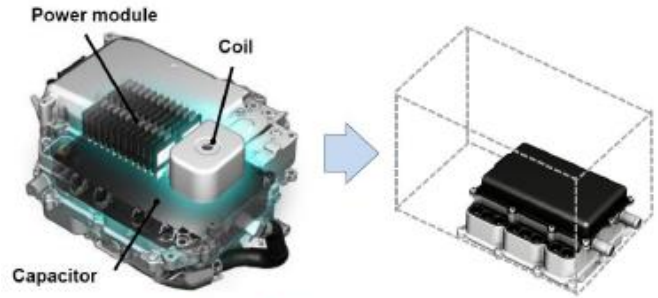


DC/DC booster

650V and 1200V IGBTs can be used in electric cars.

A DC/DC booster option can be added for full hybrid, PHEV and BEV and it needs an increase of IGBT voltages

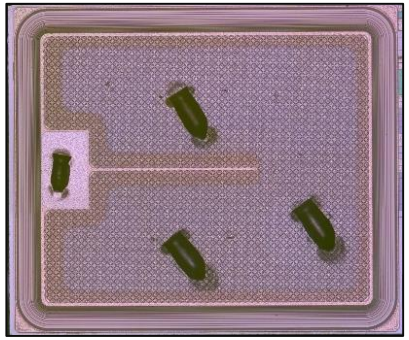
According to Toyota, SiC power devices allow increased fuel efficiency and reduced PCU size up to 80%.



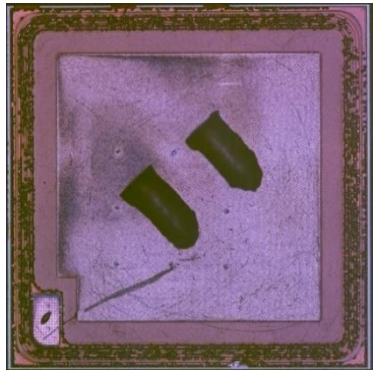
Courtesy of Toyota

1200V Si IGBT and SiC MOSFET: size

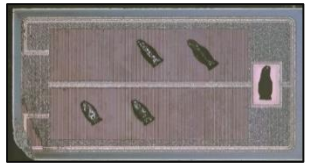
SiC and Trench structure allows a reduction of the die size.



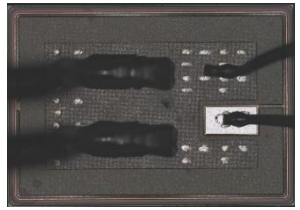
IXYS PT planar



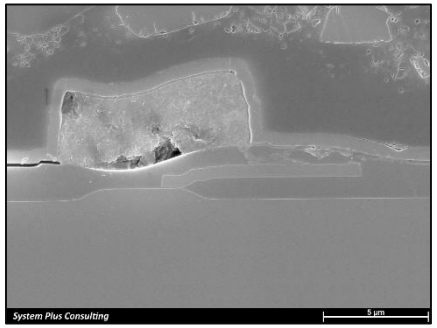
Infineon FS Trench

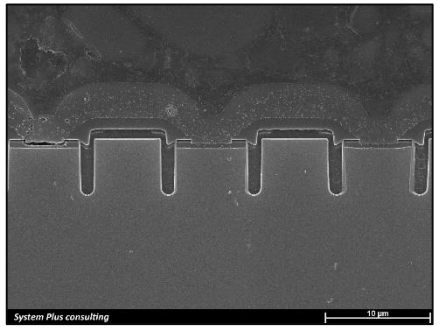


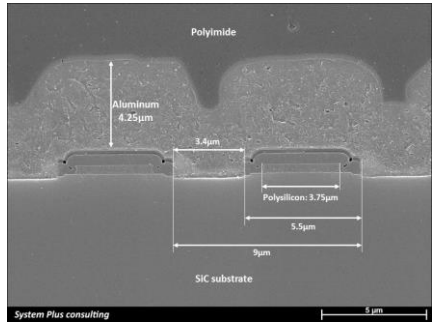
Wolfspeed SiC Planar

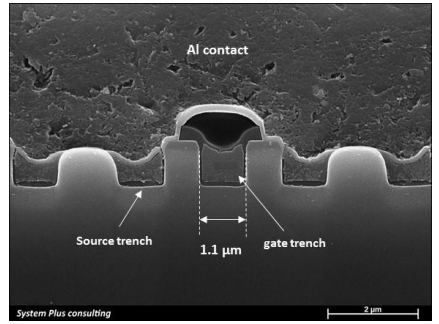


Rohm SiC Trench







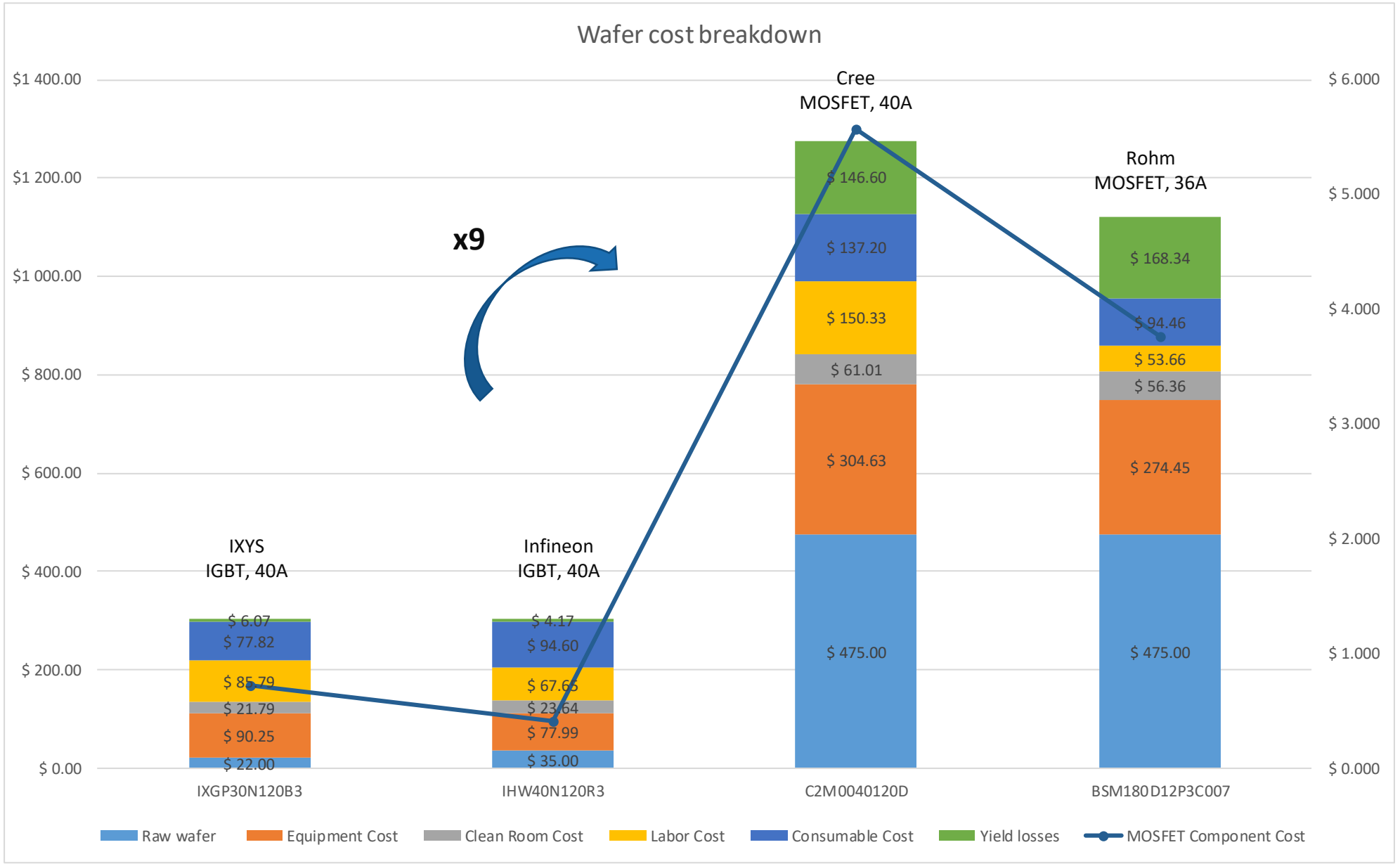


Transistor	Techno	Manufacturer	Current at 100°C	Current density	Die area
IXGP30N120B3	PT planar	IXYS	30A	0.98	30.6 mm²
IHW40N120R3	FS trench	Infineon	40A	1.37	29.16 mm²
C2M0040120D	SiC planar	Cree	40A	2.19	18.29 mm²
BSM180D12P3C007	SiC trench	Rohm	36A	2.79	12.9 mm²

55%

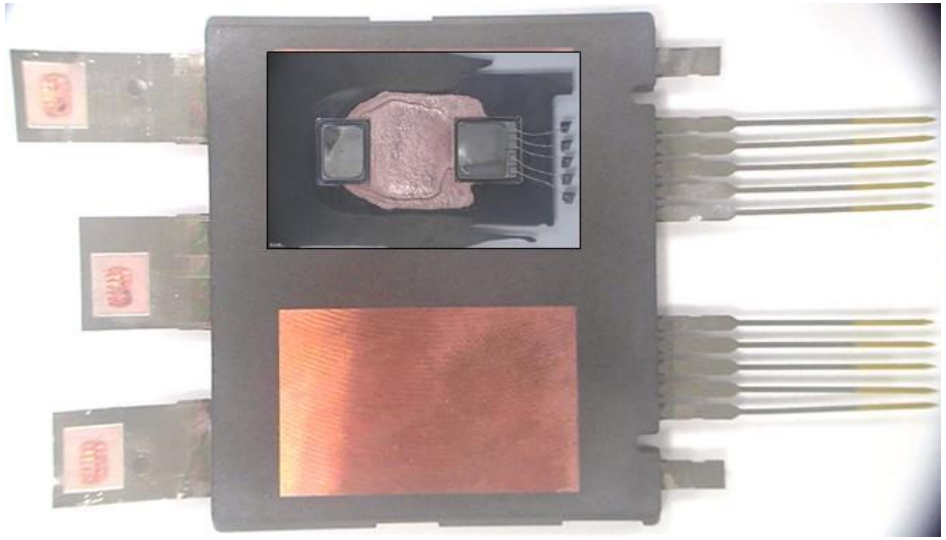
Si IGBT vs SiC MOSFET: cost

SiC dies are still very expensive comparing to Si-based dies



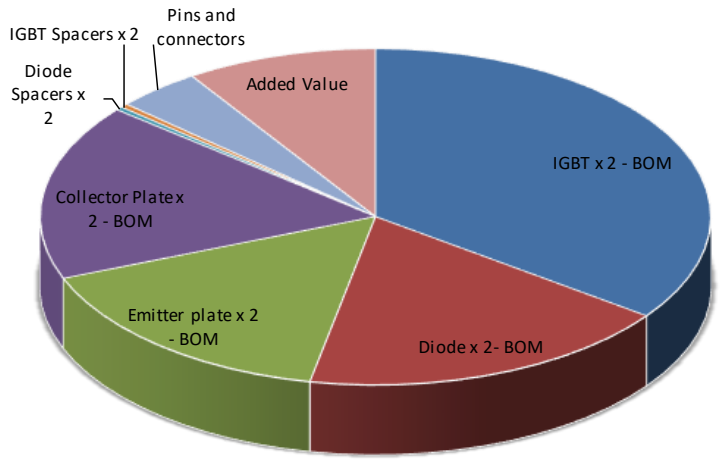
SiC power module impact

The implementation of SiC dies in EV/HEV modules should be driven by evident electrical performances and decrease of SiC manufacturing cost

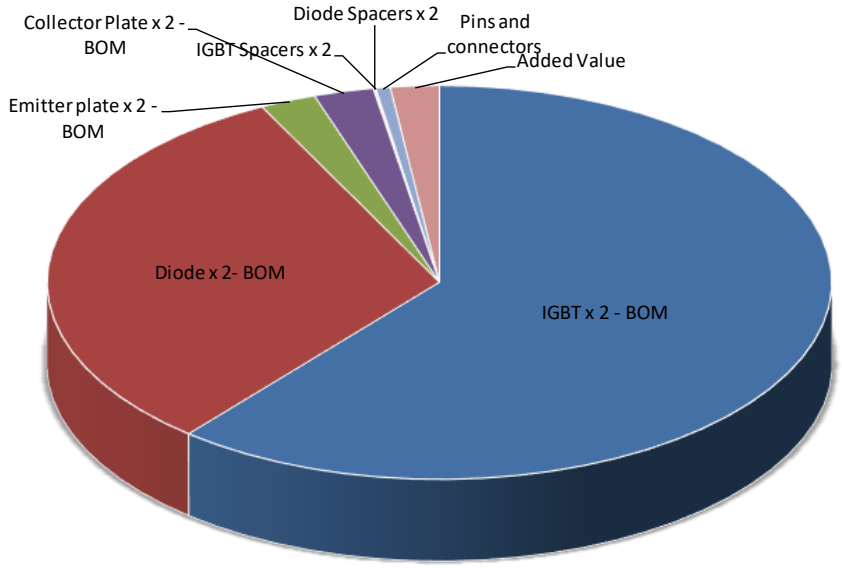


Considering the costs related to SiC dies and adapted packaging and, at the same time the size reduction of a complete power module; the SiC die cost will become predominant in the module breakdown.

Module Breakdown Cost - Si



Module Breakdown Cost -SiC



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