Key power electronics trends in EV traction inverters

FPC2022

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Agenda

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Opportunities and challenges in EV inverter design

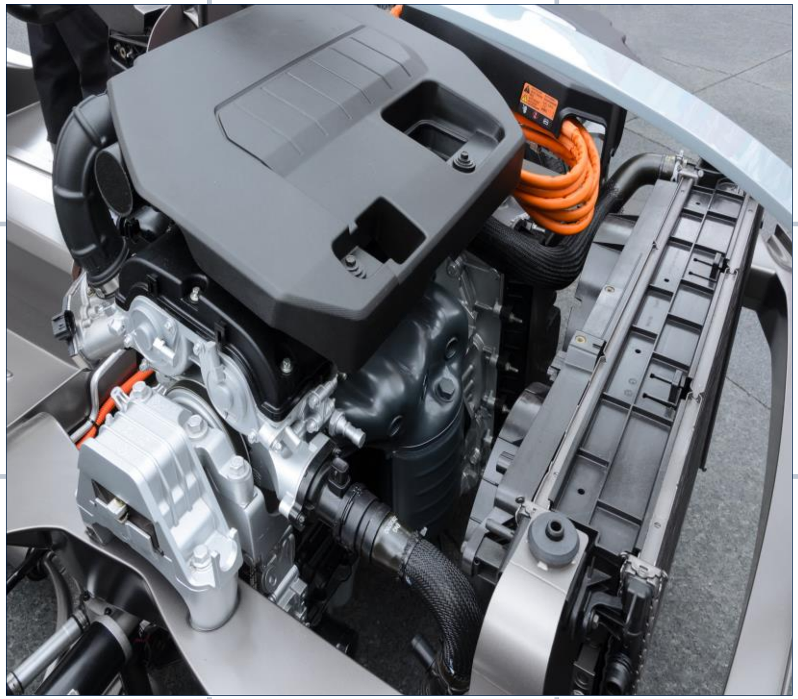
More power with battery voltage increase to 800V

New architectures offer higher power density (axial flux, synchronous reluctance) and increased motor speed

Reduced switching losses and system cost as well as higher working Tj up to 200c

SiC

Improved thermal and electrical performance through new packaging methodologies



EMC performance and creepage & clearance more challenging

Requires better thermal management

SiC

Extensive system analysis required to optimize cost

System integration and cost can be more challenging

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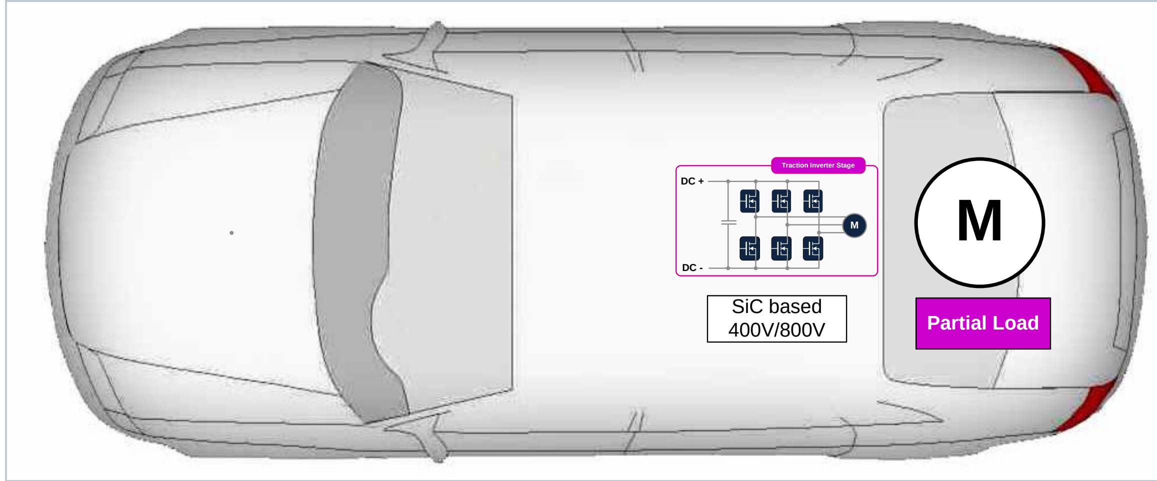
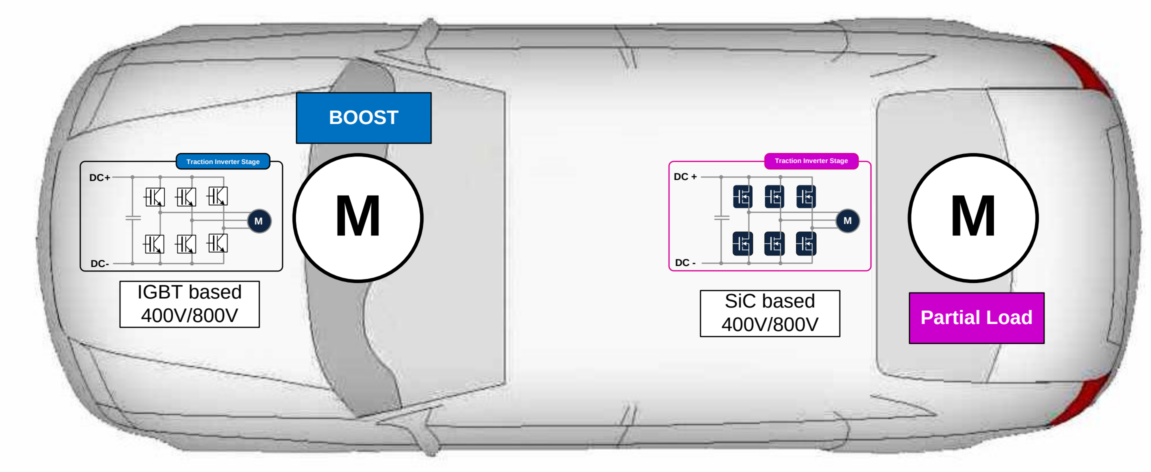
Single and multiple motor concepts

Single motor concept



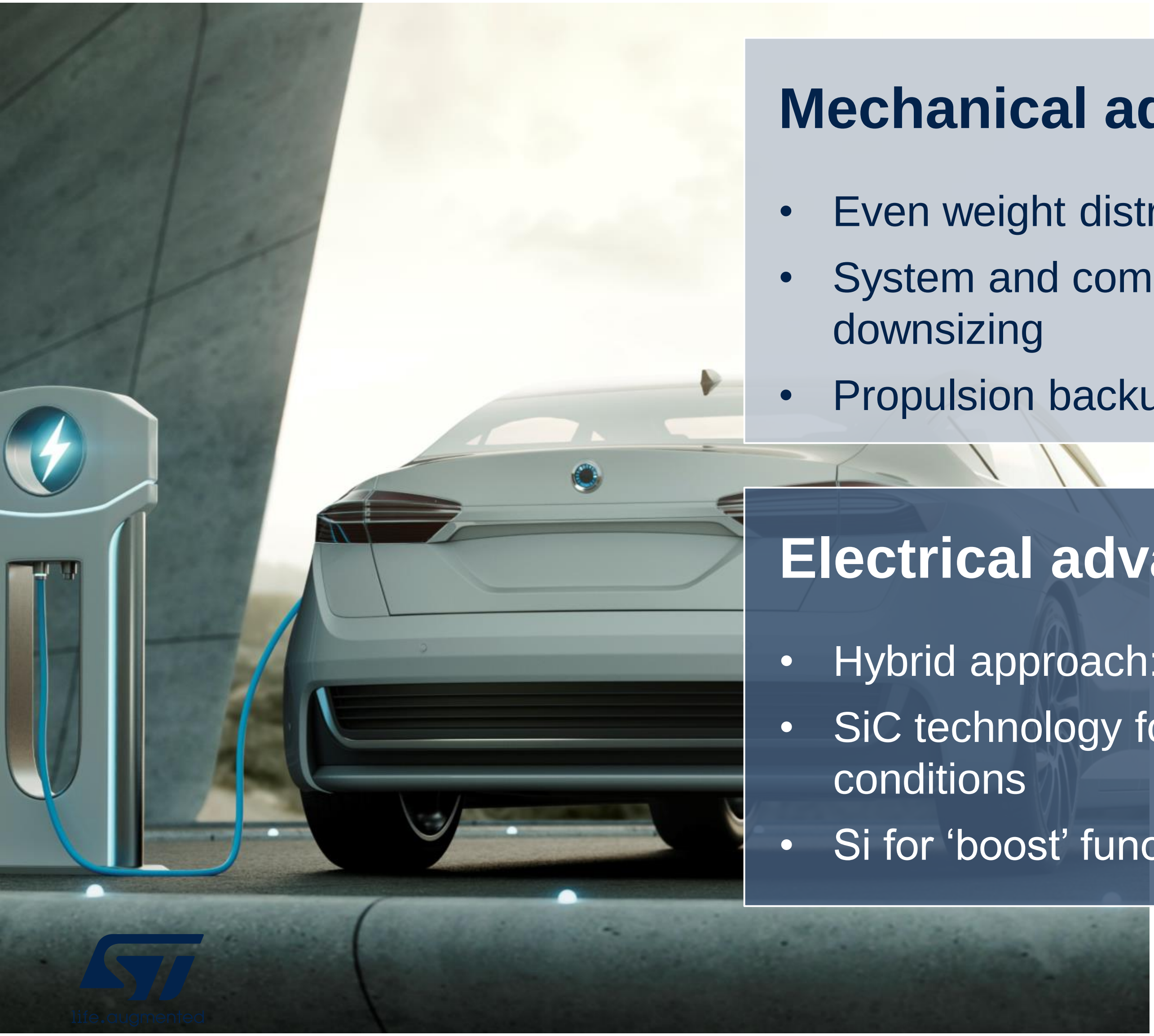
Less than 150kW

Dual motor concept



Over 250kW

Advantages of multiple motors



Mechanical advantages

- Even weight distribution
- System and component downsizing
- Propulsion backup

Electrical advantages

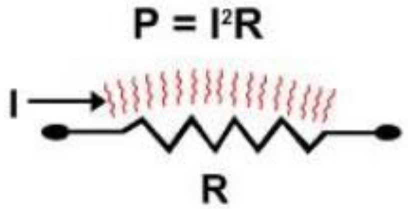
- Hybrid approach:
- SiC technology for partial load conditions
- Si for ‘boost’ function

Commercial advantages

- No need for single large & expensive motor and inverter combination
- Partial load motor inverter dimensioned for common use case only (less SiC cost)
- Smaller and cheaper motor components

Widespread adoption of 800 V bus

Higher battery voltage in EV/HEV reduces losses in inverters and other EV subsystems, and facilitates faster charging



>400V
Up to 800V

Voltage

Current

Joule loss reduction

>400V
Up to 800V

Voltage

Ultrafast charging enabler (down to about 20 min of charging time)

Power increase

- More powerful cars while keeping device currents down to acceptable levels
- Allows use components with lower current rating (higher voltage)
- Enables fast battery charging

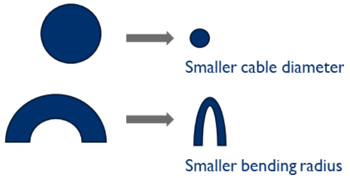
>400V
Up to 800V

Voltage

Current

Cost and weight reduction

Easier integration in vehicle



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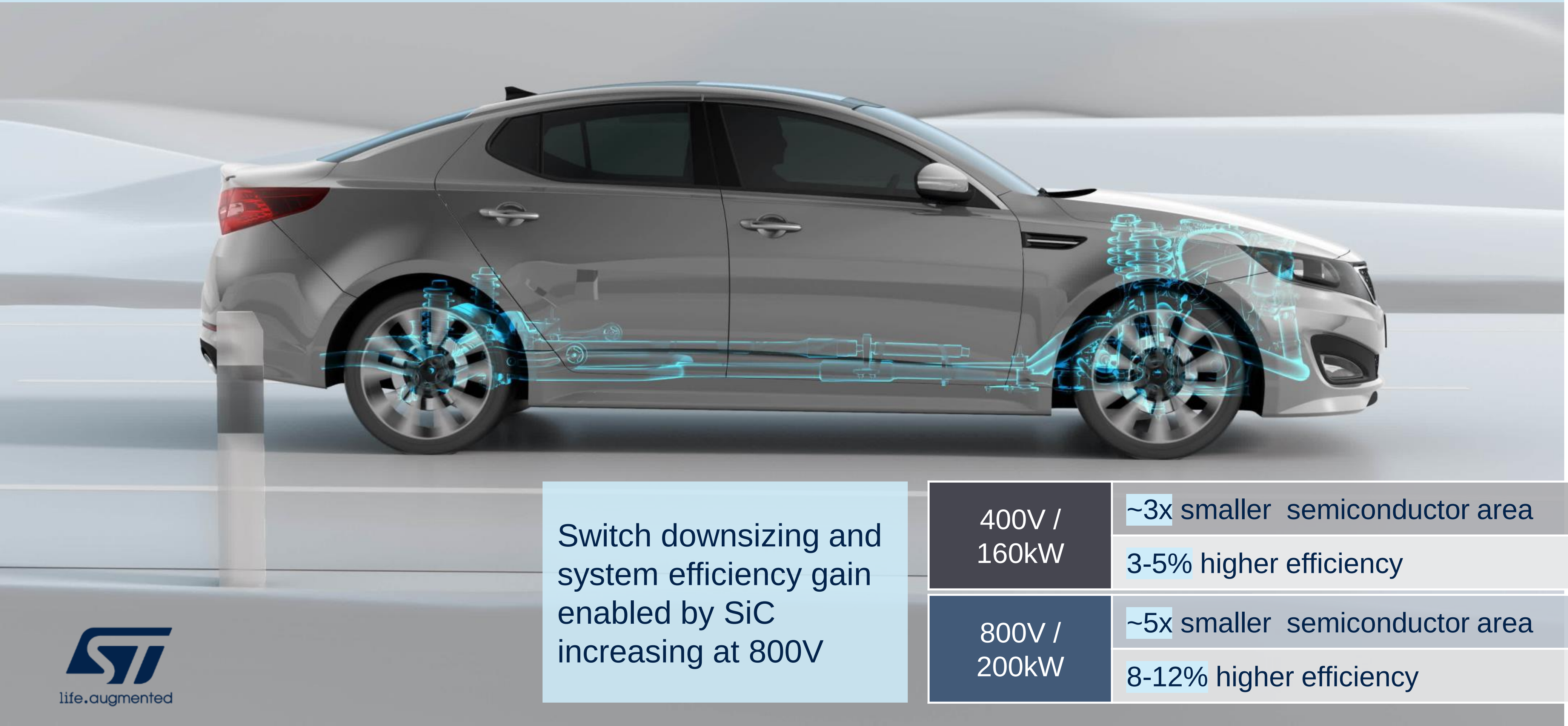
800V accelerates SiC adoption in EV subsystems

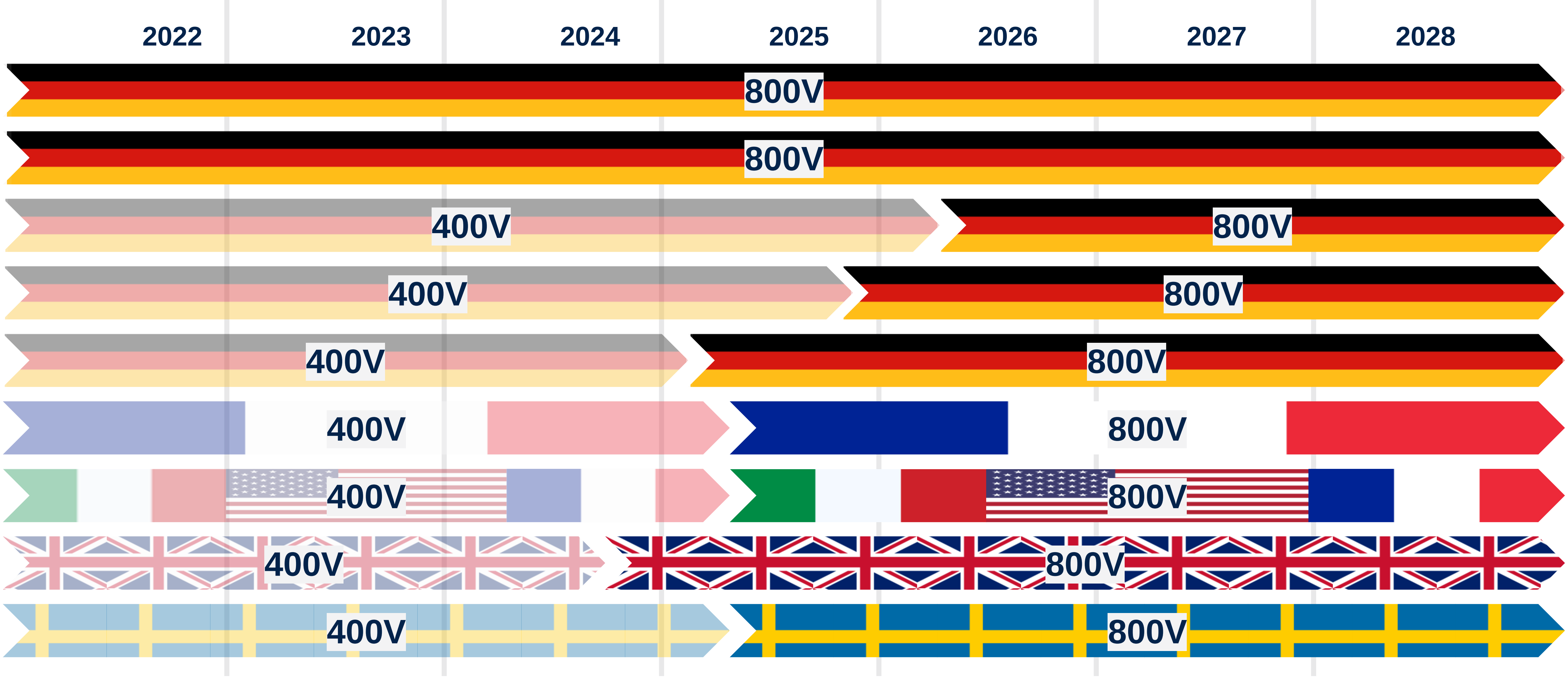
- Higher breakdown voltages more easily addressed by SiC
- System and component downsizing more easily realized with SiC
- At 800V the benefit of low switching losses in SiC become more prevalent



Switch downsizing and system efficiency gain enabled by SiC increasing at 800V

400V / 160kW	~3x smaller semiconductor area
	3-5% higher efficiency
800V / 200kW	~5x smaller semiconductor area
	8-12% higher efficiency

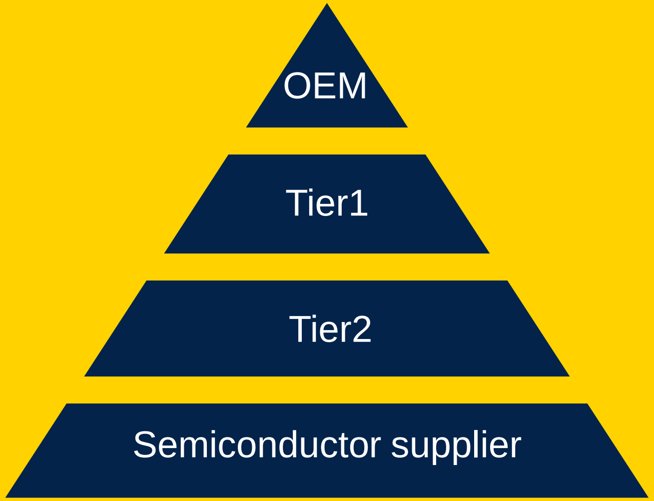
400V to 800V roadmap of major European car manufacturers



Evolution of the automotive ecosystem ‘make’ or ‘buy’

OEM taking control of the value chain

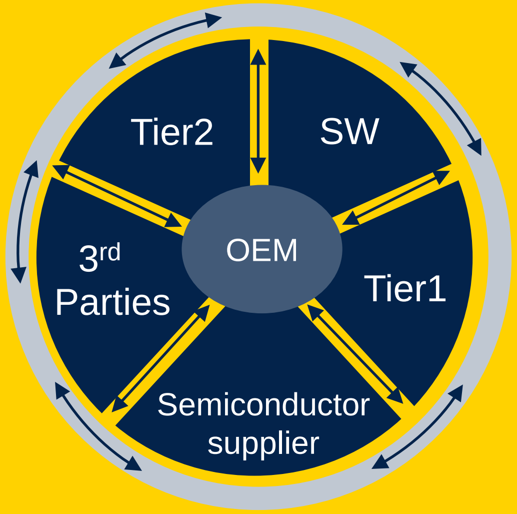
Old pyramidal approach	Possible ‘MAKE’ scenario for 2030	New ecosystem



Traction Inverter

60%

Low standardization and strong link with OEM powertrain system



OEM direct contact with semiconductor supplier

- To deploy new technologies and semiconductor solutions more effectively and rapidly to the car
- To directly drive the semiconductor roadmap with a closer link to final application
- To secure capacity of key technologies applicable to electric vehicles, such as silicon carbide

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Market acceptance of silicon carbide technology

Inverter SiC penetration

And more to follow

Benefits of SiC technology

Mechanical advantages:

- Weight reduction from system and component downsizing
- Reduced form factors from higher system integration

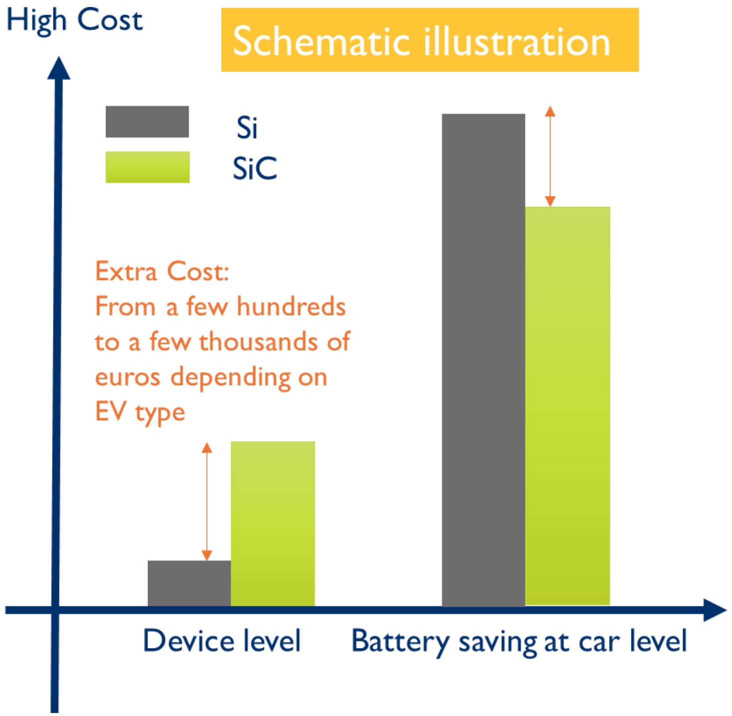
Electrical advantages:

- Silicon carbide enables up to **80%** reduction in switching losses
- Up to **12%** improvement in system efficiency leading to range extension or reduced battery cost

Commercial advantages:

- Smaller and cheaper components such as passives and cabling
- SiC cost is falling as many players invest in manufacturing know-how and capacity

Up to $750 USD saving in battery costs



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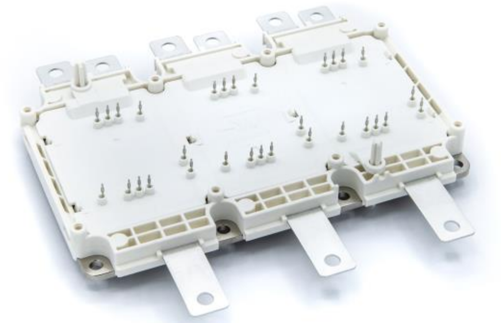
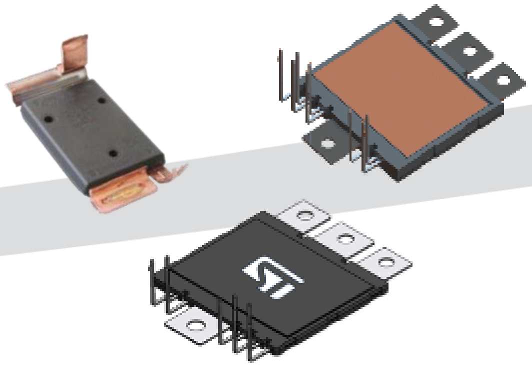
Transition to higher power and more scalable packaging

Key considerations for inverter power stage
• Reduction of thermal interfaces • Low inductance in the commutation loop • Accurate simulations to ensure the most cost effective use of semiconductors • Cost effective integration of power semiconductors to the cooler

Benefits of discrete package approach
• Flexible use of single or dual side cooling and indirect or direct cooling. Rthj-c **~0.035C/W** • Compact and scalable design approach • Lower loop inductance can be achieved **~4nH** • Use of silver sintering to substrate and cooler • High reliability due to lower Tj and better SCWT



Strong trend towards discrete molded packages



Typical dimensioning for an STPAK solution

Typical example for max peak current

- As a function of DC bus voltage
- PWM frequency

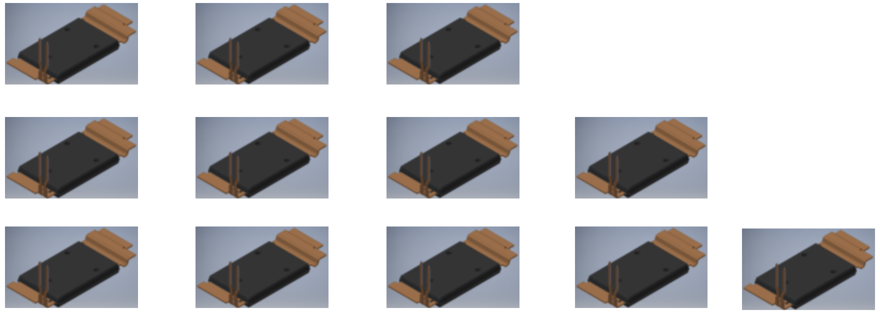
⇨ Peak current (ARMS)

		3 STPAK	4 STPAK	5 STPAK
DC BUS Voltage	PWM Frequency	ARMS		
870V	7.6 kHz	459	612	765
	10 kHz	432	576	720
	12 kHz	411	548	685
800V	7.6 kHz	471	628	785
	10 kHz	444	592	740
	12 kHz	420	560	700

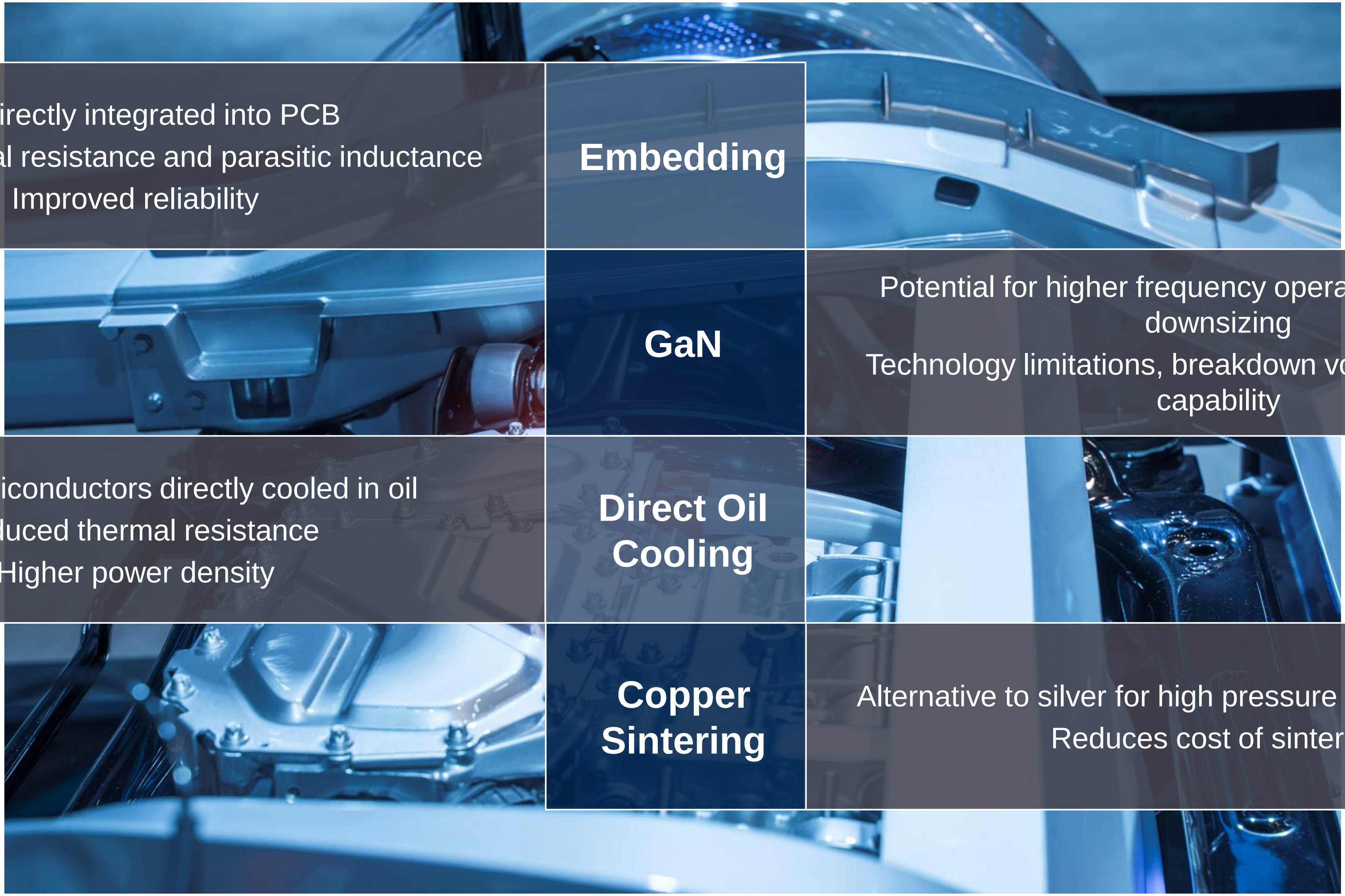
Parameter to dimension the peak performance:

- Flow rate of the coolant
- Fluid temperature
- Rgon and Rgoff setting
- Switching speed (SOA of semiconductor and/or application)
- Phase current
- PWM frequency (degraded operation)
- DC bus voltage

⇨ Conduction, switching and diode losses



Future methods…



Embedding

Die directly integrated into PCB
Reduced thermal resistance and parasitic inductance
Improved reliability

GaN

Potential for higher frequency operation and system downsizing
Technology limitations, breakdown voltage, avalanche capability

Direct Oil Cooling

Power semiconductors directly cooled in oil
Reduced thermal resistance
Higher power density

Copper Sintering

Alternative to silver for high pressure sintering process.
Reduces cost of sintering

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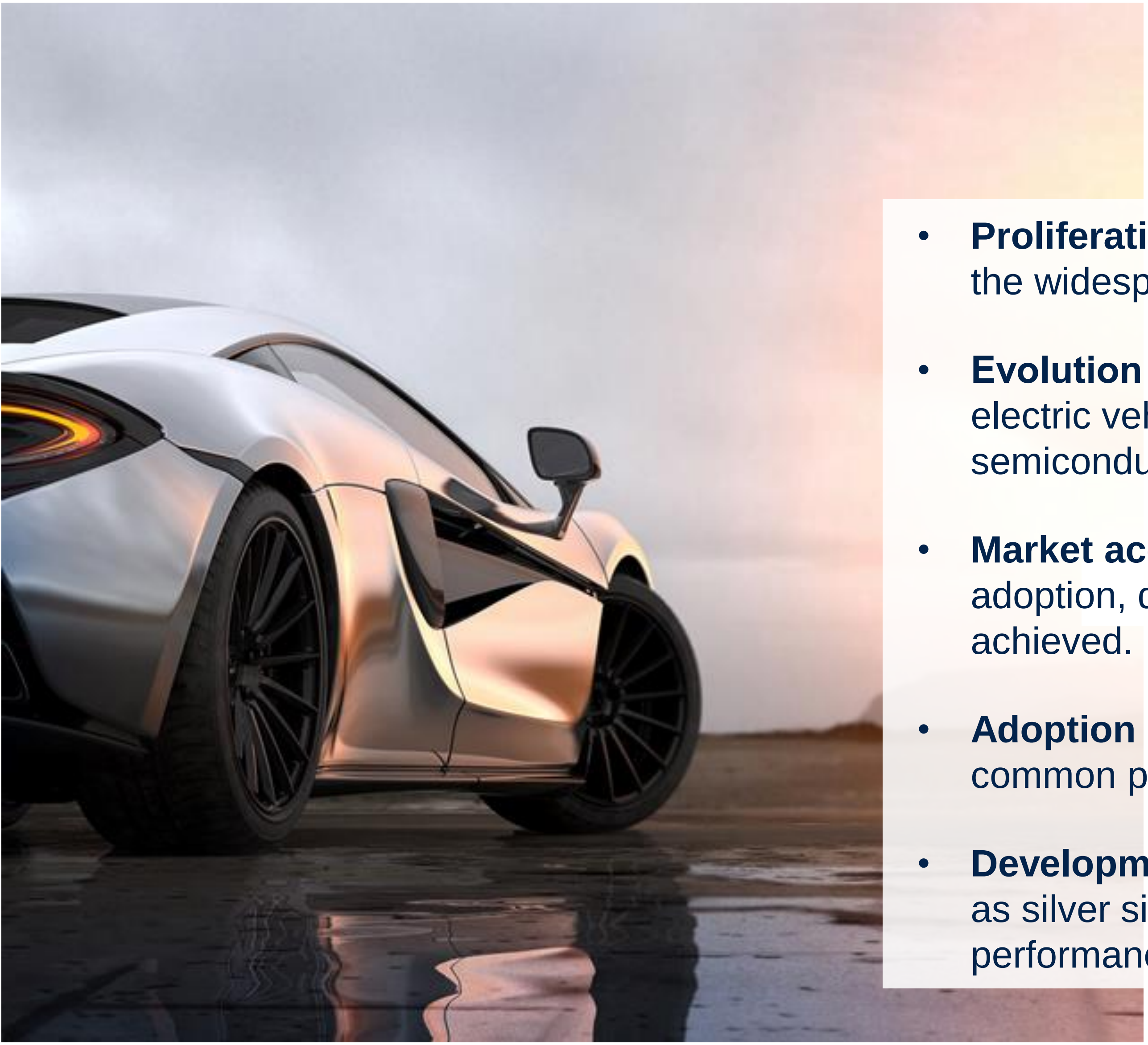

Key takeaways

- **Proliferation of 800V bus** will be one of the key enablers for the widespread use of SiC in electric vehicle traction inverters.
- **Evolution of carmaker ‘make’ or ‘buy’ strategy** for future electric vehicle sub systems and direct engagement with semiconductor vendors.
- **Market acceptance of SiC** is proven by widespread carmaker adoption, due to the overall system cost savings that can be achieved.
- **Adoption of high power and scalable packaging** becoming common place in large volume carmaker platforms
- **Development of innovative packaging technologies** such as silver sintering and direct embedding to improve the thermal performance and reliability of electric vehicle sub-systems.

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