The SiC power revolution is ready for high-volume car manufacturing

Manuel Gärtner, Gianfranco Congi
EMEA Region - Marketing and Application
Director Wide Bandgap & Electrification

STMicroelectronics

Agenda

1 Motivation: The impact of global energy consumption

2 Silicon and compound semiconductor overview

3 Challenges of automotive electrification

4 800V accelerates SiC adoption in EV subsystems

5 Key SiC applications in EV

6 SiC MOSFET automotive technology

7 How car electrification impacts power semiconductors

8 ST SiC MOSFET manufacturing strategy

9 Key takeaways

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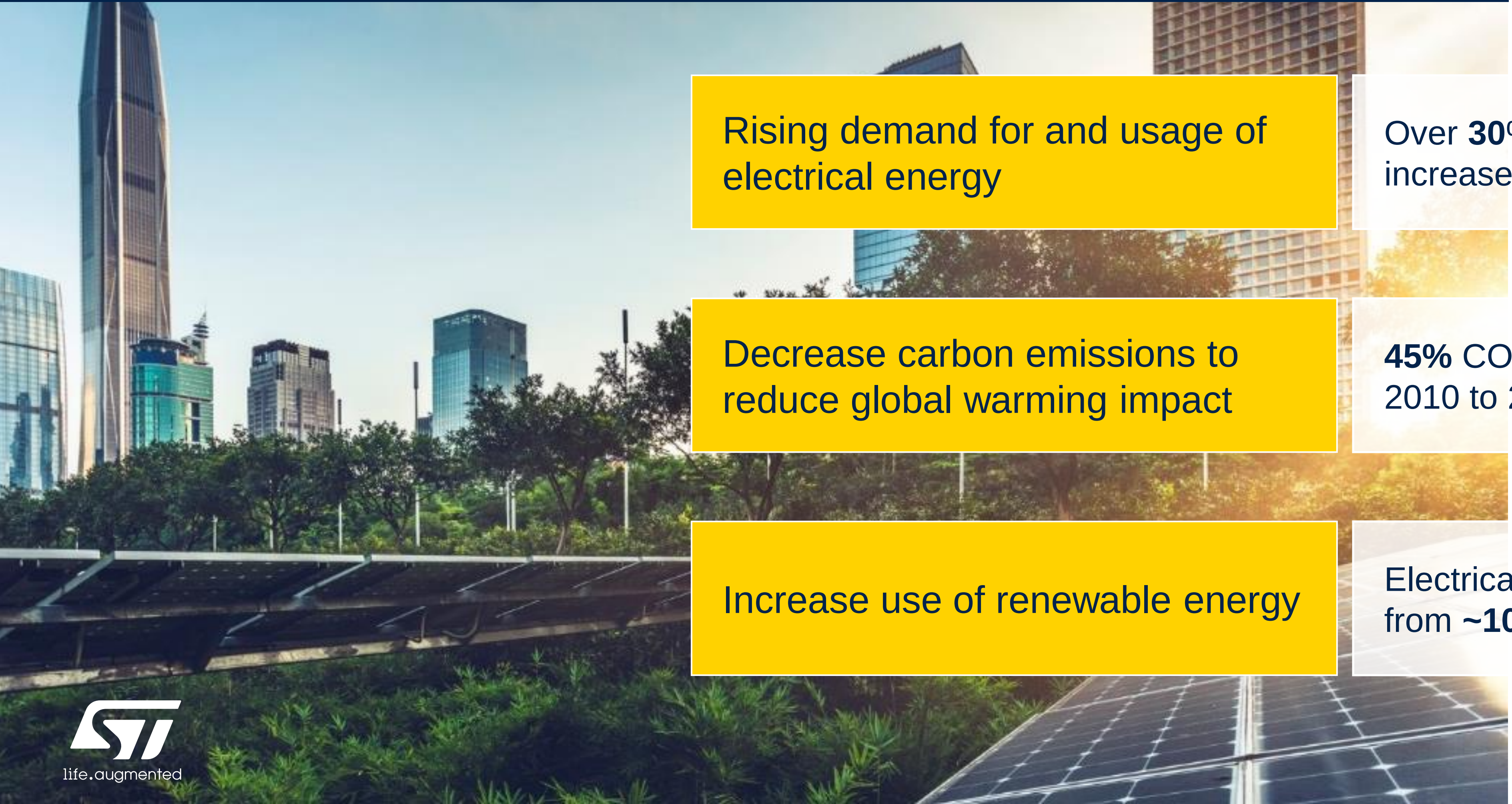
Power & energy

ST technology and solutions enable customers to increase energy efficiency everywhere & support the use of renewable energy sources



Rising demand for and usage of electrical energy

Over **30**% global electricity demand increase from 2020 to 2030

Decrease carbon emissions to reduce global warming impact

45% CO_2 emission reduction from 2010 to 2030 to limit warming to 1.5°C

Increase use of renewable energy

Electrical energy from renewal sources from **~10%** in 2020 to **~20%** in 2030

Sources: IEA, IPCC, BP

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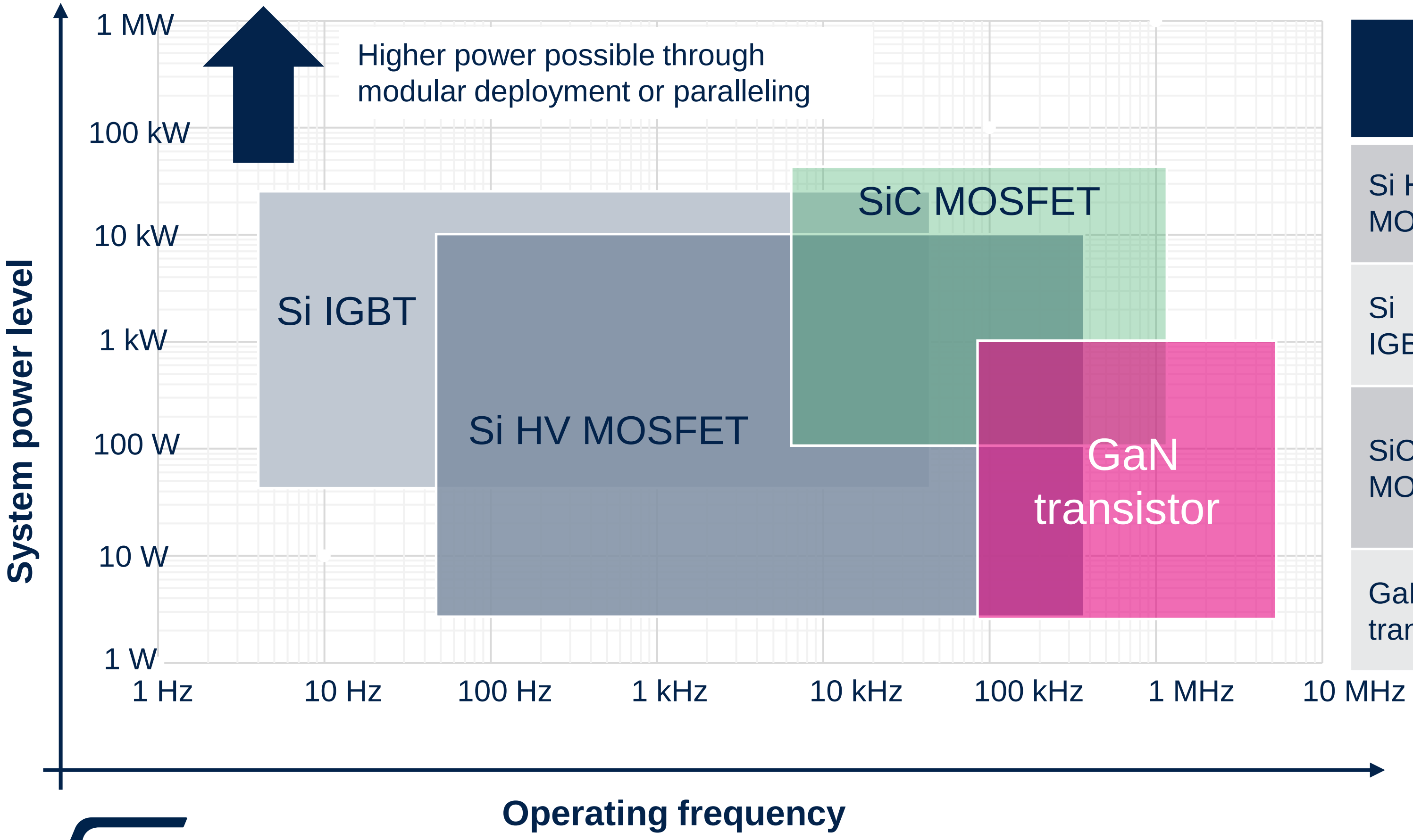
Silicon and wide-bandgap overview

Wide product range targeting automotive and industrial power applications



Automotive examples of power applications	
Si HV MOSFET	DC-DC converter, low-power motor control, OBC, charging Station, DC link discharge …
Si IGBT	HV motor control, PTC heating, traction inverter, DC link discharge…
SiC MOSFET	High power DC-DC converter, charging station, traction inverter, OBC, e-climate compressor, battery disconnect switch, smart power distribution, fuel cell (DC-DC and high-pressure pump), DC link discharge
GaN HEMT transistor	Class D amplifier, wireless charger DC-DC converter, OBC, LiDAR, …

Si = Silicon; HV = High voltage; SiC = Silicon Carbide

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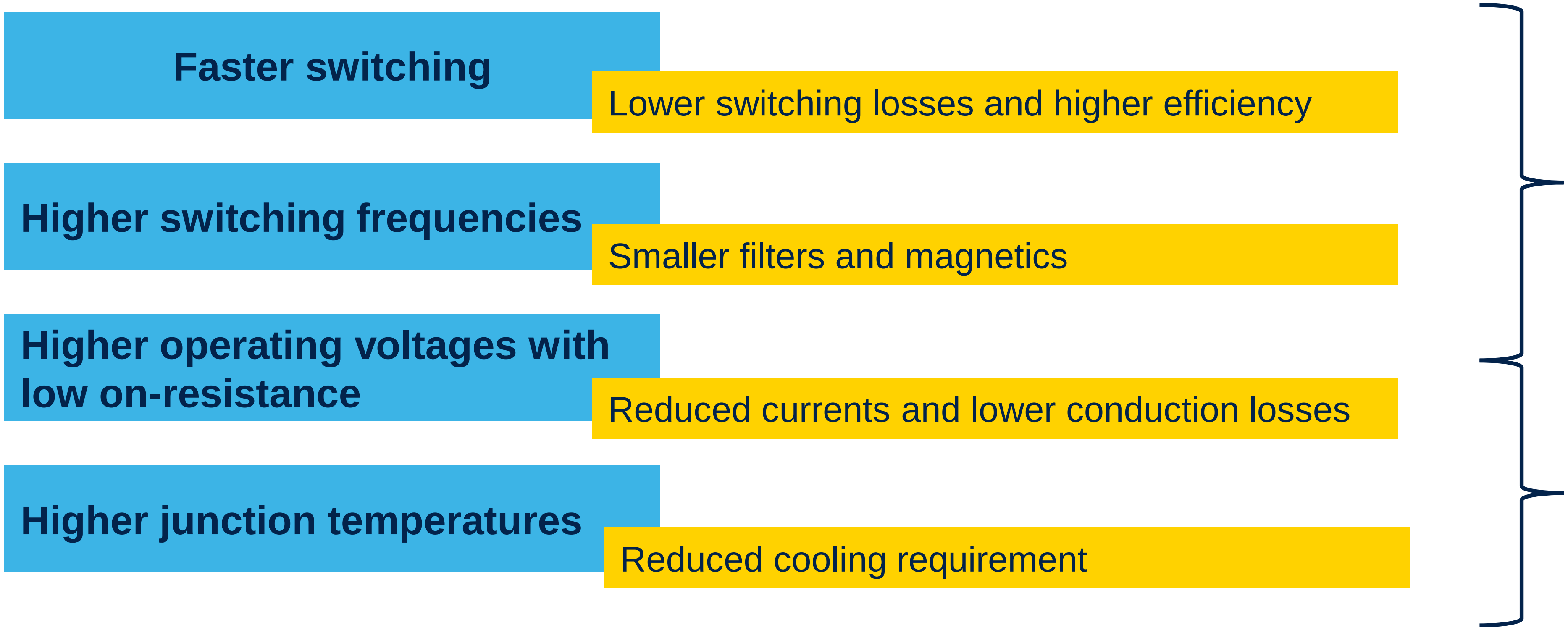
SiC (and GaN next) targets energy-efficient applications

Wide-bandgap semiconductors offer superior performance and characteristics thanks to:

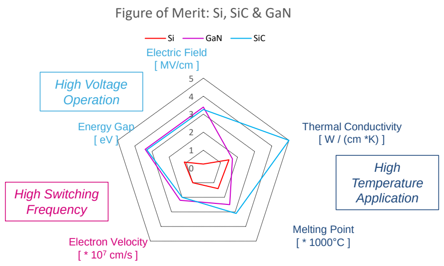


Faster switching – Lower switching losses and higher efficiency

Higher switching frequencies – Smaller filters and magnetics

Higher operating voltages with low on-resistance – Reduced currents and lower conduction losses

Higher junction temperatures – Reduced cooling requirement

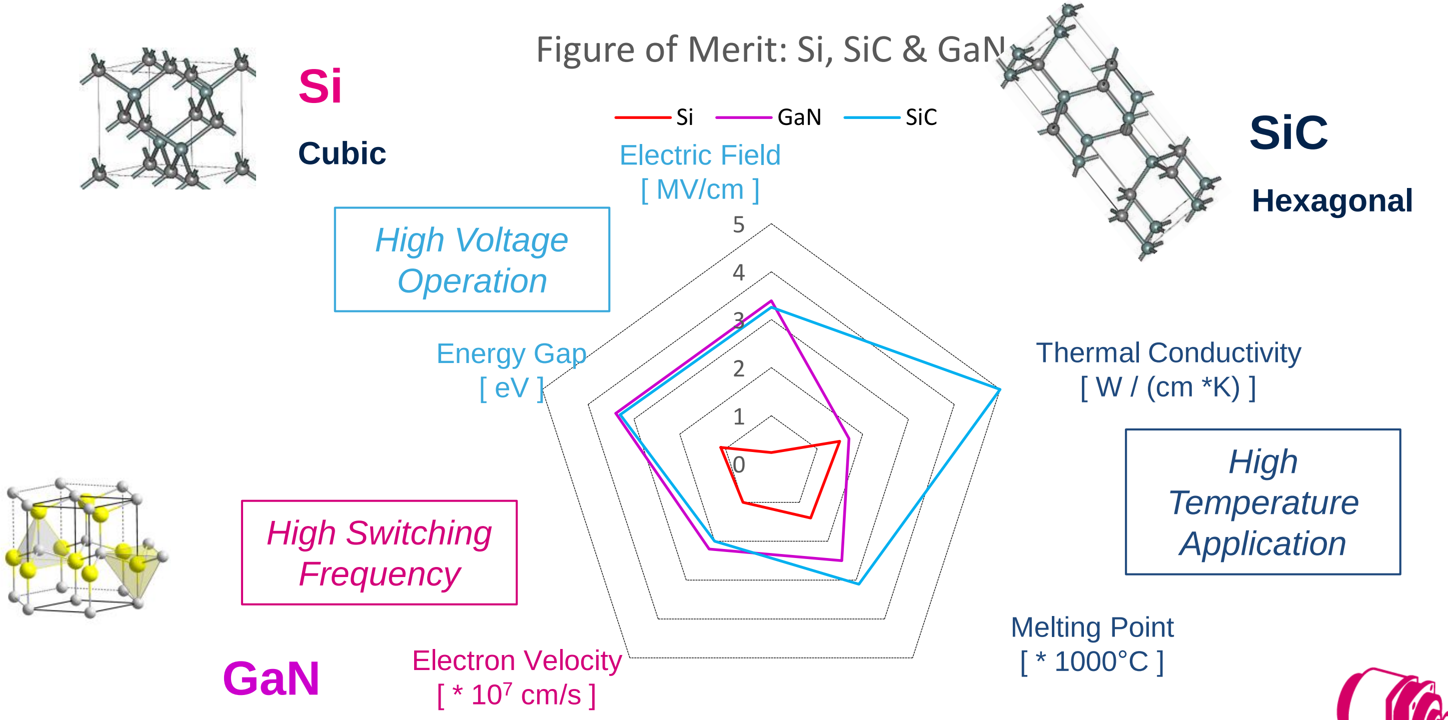


SiC and GaN

SiC

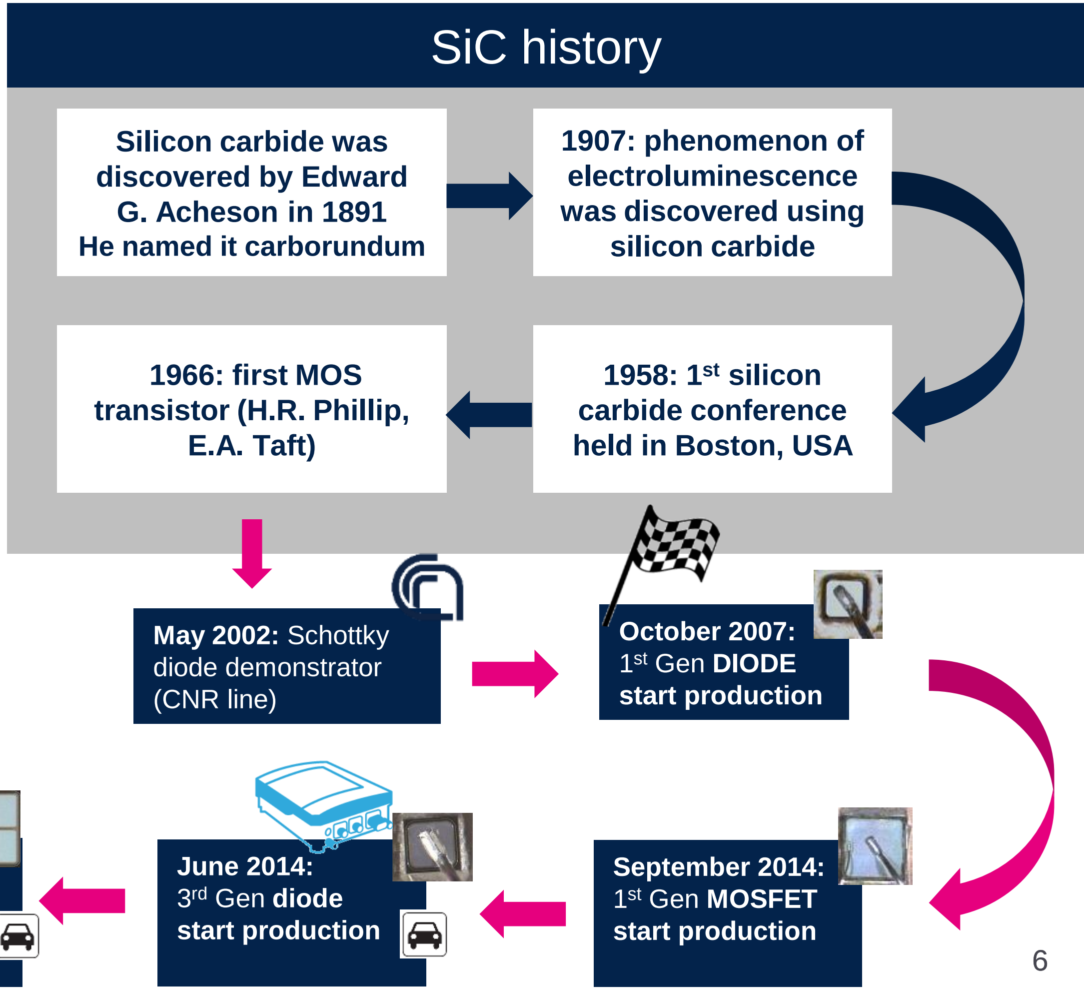
More than 25 years of focus on SiC in STMicroelectronics

Si - Silicon | **GaN -** Gallium Nitride | **SiC -** Silicon Carbide



Hexagonal (cubic)

SiC history



Silicon carbide was discovered by Edward G. Acheson in 1891 He named it carborundum

1907: phenomenon of electroluminescence was discovered using silicon carbide

1958: 1st silicon carbide conference held in Boston, USA

1966: first MOS transistor (H.R. Phillip, E.A. Taft)

May 2002: Schottky diode demonstrator (CNR line)

October 2007: 1st Gen **DIODE start production**

September 2014: 1st Gen **MOSFET start production**

June 2014: 3rd Gen diode **start production**

June 2017 2nd Gen **MOSFET start production**

Dec 2020 3rd Gen **MOSFET Qualification**

Oct 2022 Integrated substrate manufacturing facility in Italy

Challenges of electrification

Mobility is all about efficiency

Reduce weight and cost of cooling systems

Reduce power losses and heat dissipation

Extend driving range above 600 km

Reduce the number of recharges

Increase reliability

Cost reduction

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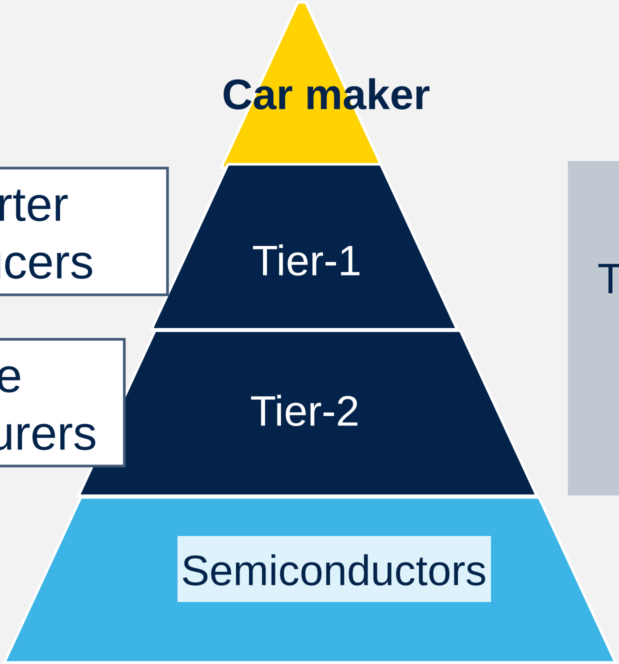
From car makers to mobility providers

Vehicle content and car differentiation is strongly dependent on semiconductors

Traditional approach

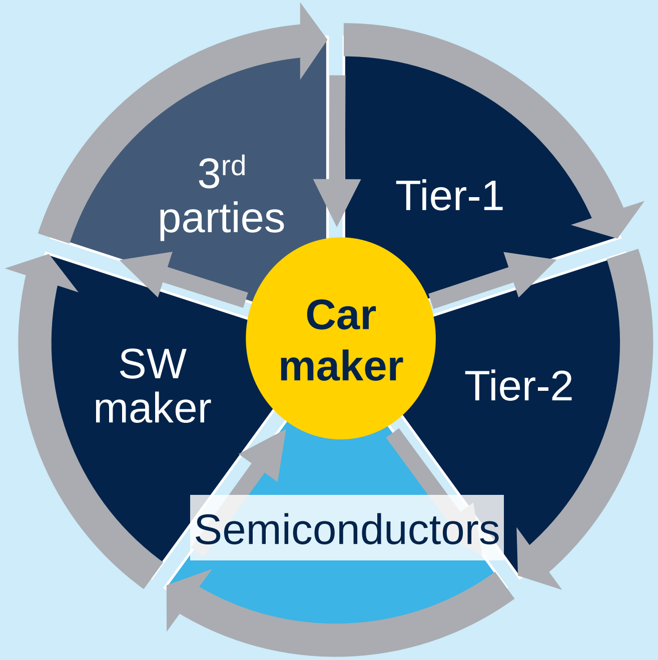
Inverter producers

Module manufacturers



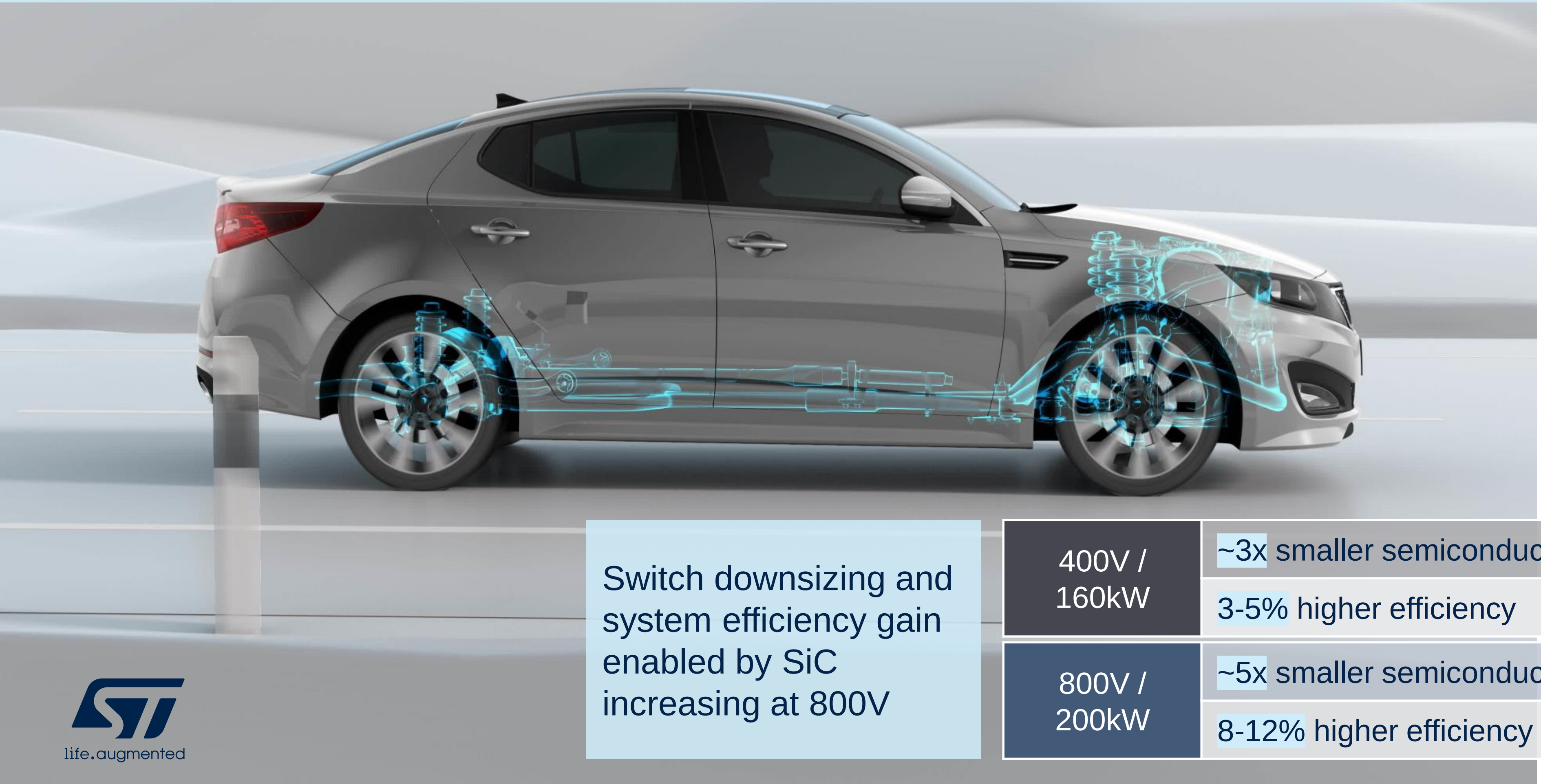
To capture the **value of innovation**

New ecosystem



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

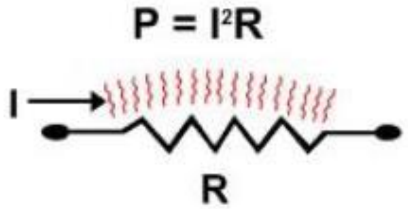


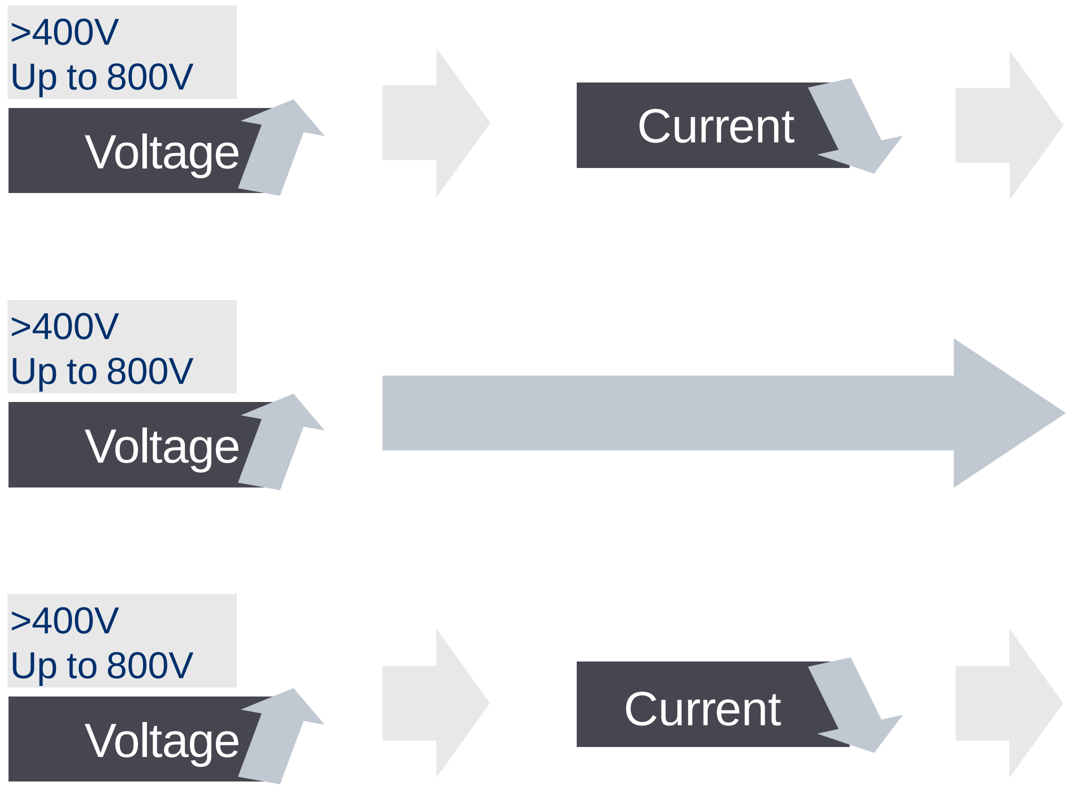
Switch downsizing and system efficiency gain enabled by SiC increasing at 800V

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

Widespread adoption of 800 V bus

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





Joule loss reduction

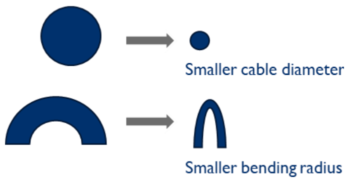
Ultrafast charging enabler (down to about 20 min of charging time)

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

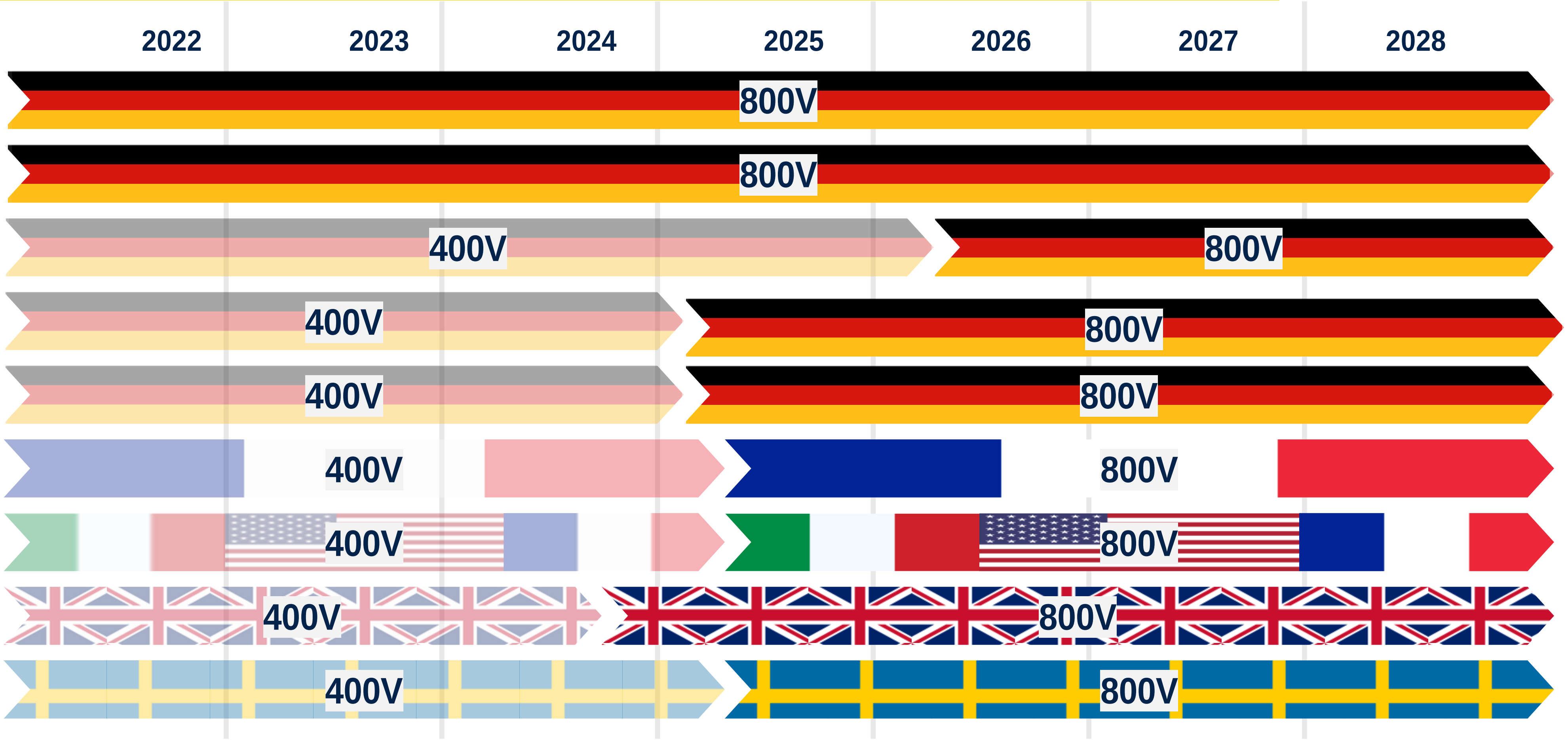
Cost and weight reduction

Easier integration in vehicle

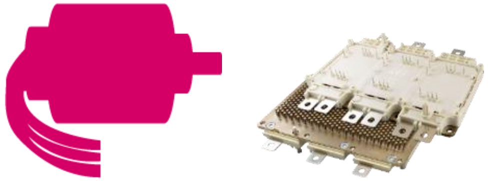


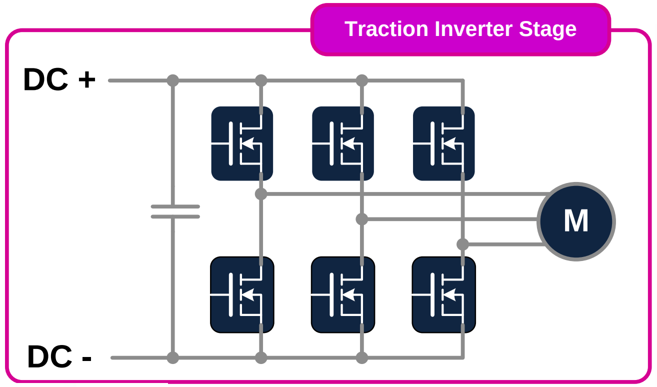
EMEA market DC BUS voltage evolution

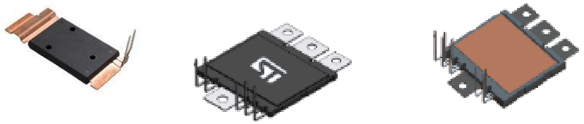
BUS voltage in EMEA converged to 800V in 2025 for BEV / PHEV very likely to stay on 400V

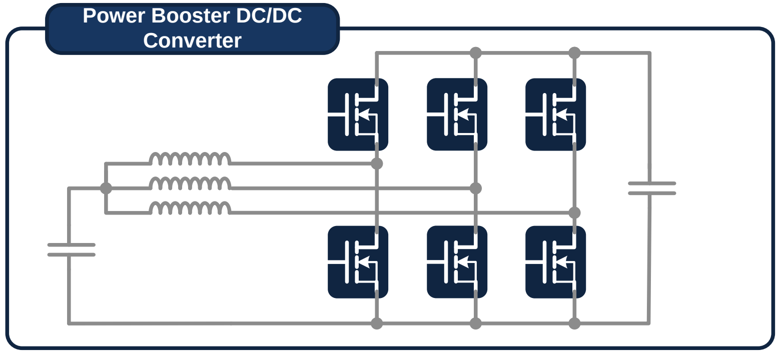


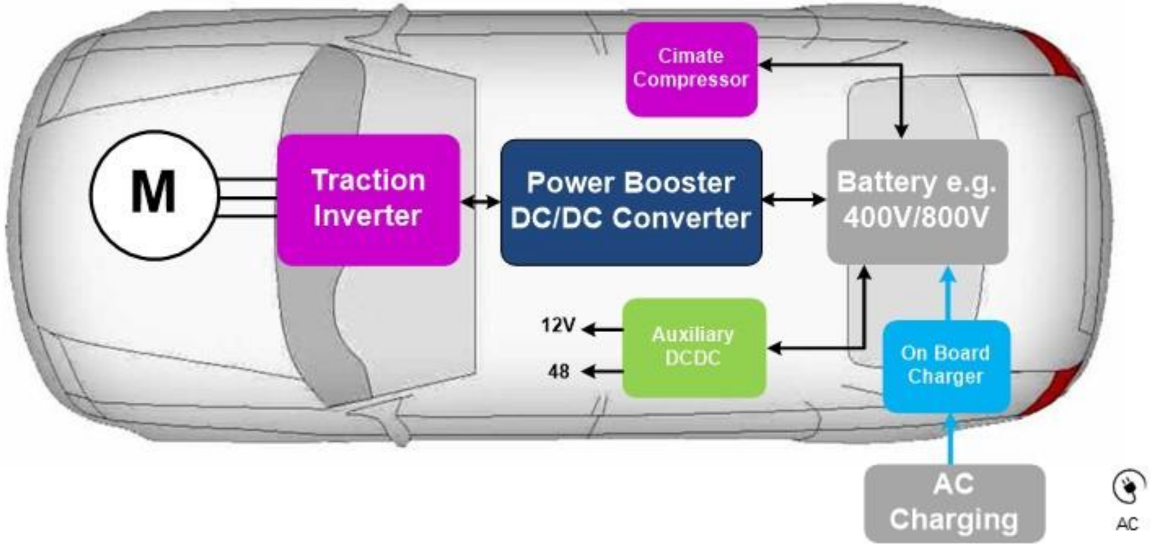
Key SiC applications in EV addressed by tailored packaging

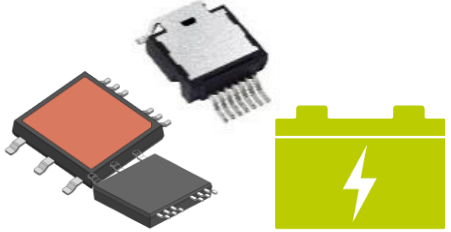


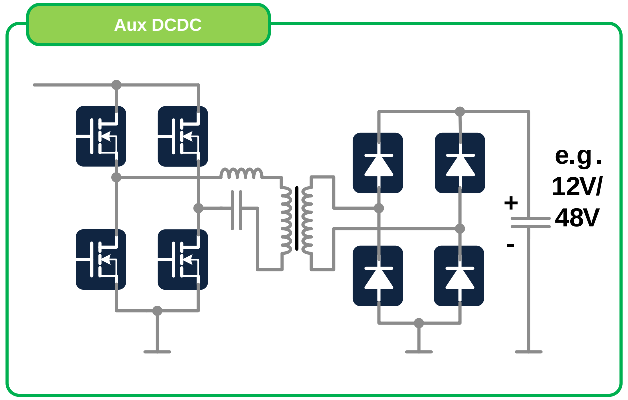


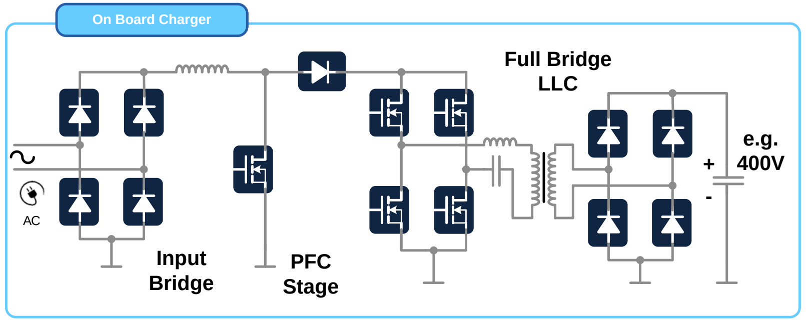


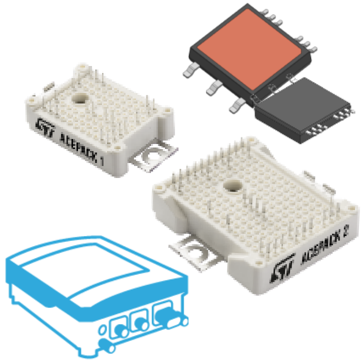




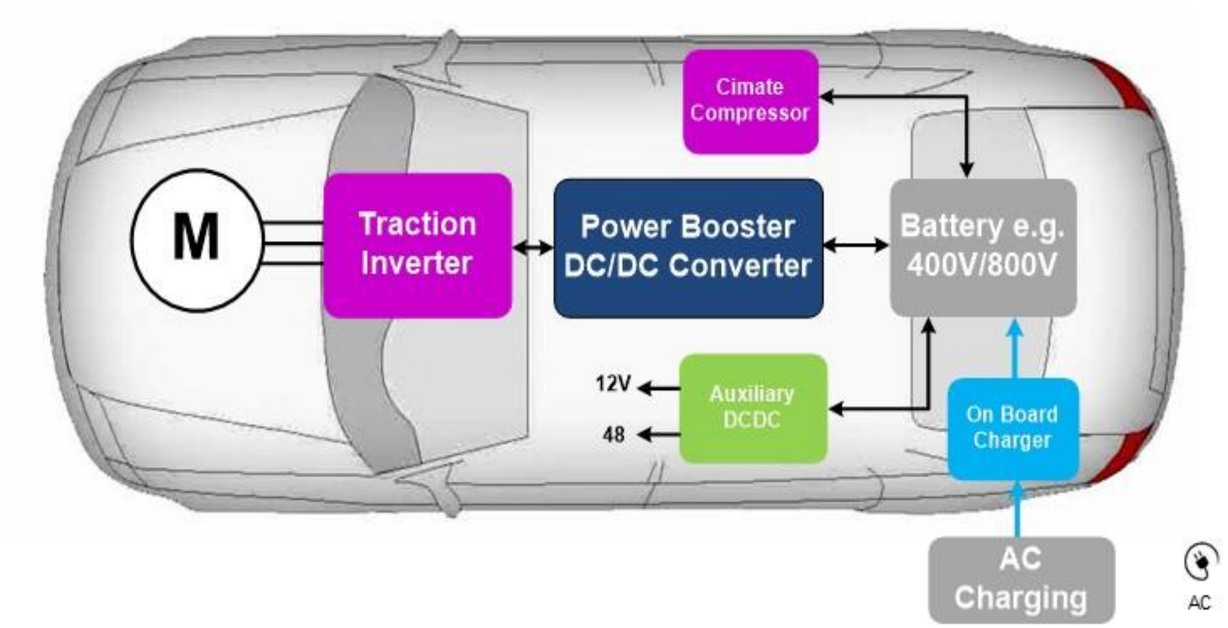








New automotive application use cases powered by SiC



Fuel cell applications

- Interleaved power DCDC
- High Speed Pump

Battery disconnect

- Mechanical relay replacement / Solid State Contactors

DC link discharge

- Discharging HV due to safety requirements

Smart power distribution

- Protection of auxiliaries
- Boardnet optimization

Various

- Heating Control
- High Speed Pump (Turbo)

New applications realized with SiC

>60% *

Today market share in automotive

SiC MOSFET automotive technology

Technology roadmap

Gen1	Optimized **Ron** and **Tj** for **motor drive** applications	🟥
Gen2	Balanced **Ron** and **Qg** for industrial and automotive	🟥
Gen3	**Lower Ron** vs. **Gen2** maximizes the driving range of EVs	🟥
Gen4*	**Reduced Ron** vs. **Gen3** tailored for traction inverter	🟥
Gen5**	Innovative **high power density technology** structure	🟥
MDSiC™ **	Radical innovation, outstanding Ron value at hot temperature and further Ron reduction vs. **Gen5**	🟦

Gen4: Technology qualification >2023
Gen5: Technology qualification >2025
MDSiC: Technology qualification > 2027

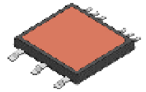
Advanced packaging

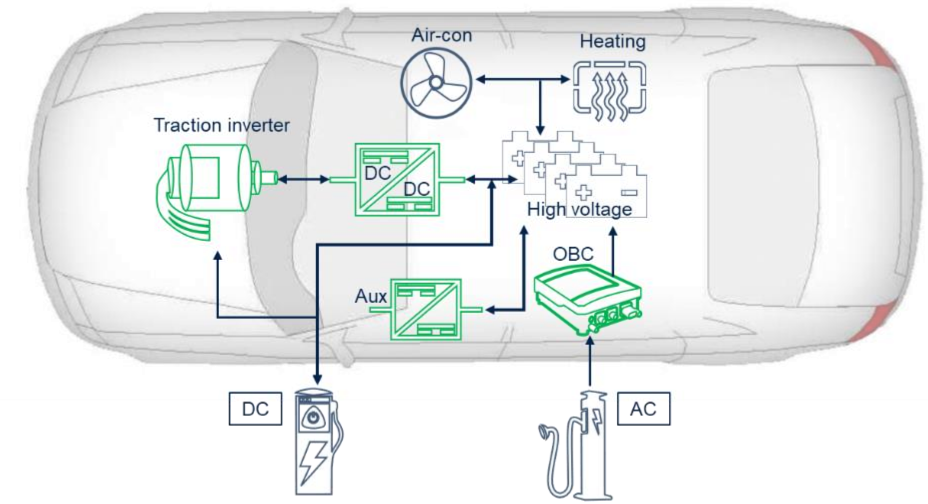

Bare die


HiP247-4 leads


HU3PAK


STPAK


ACEPACK SMIT



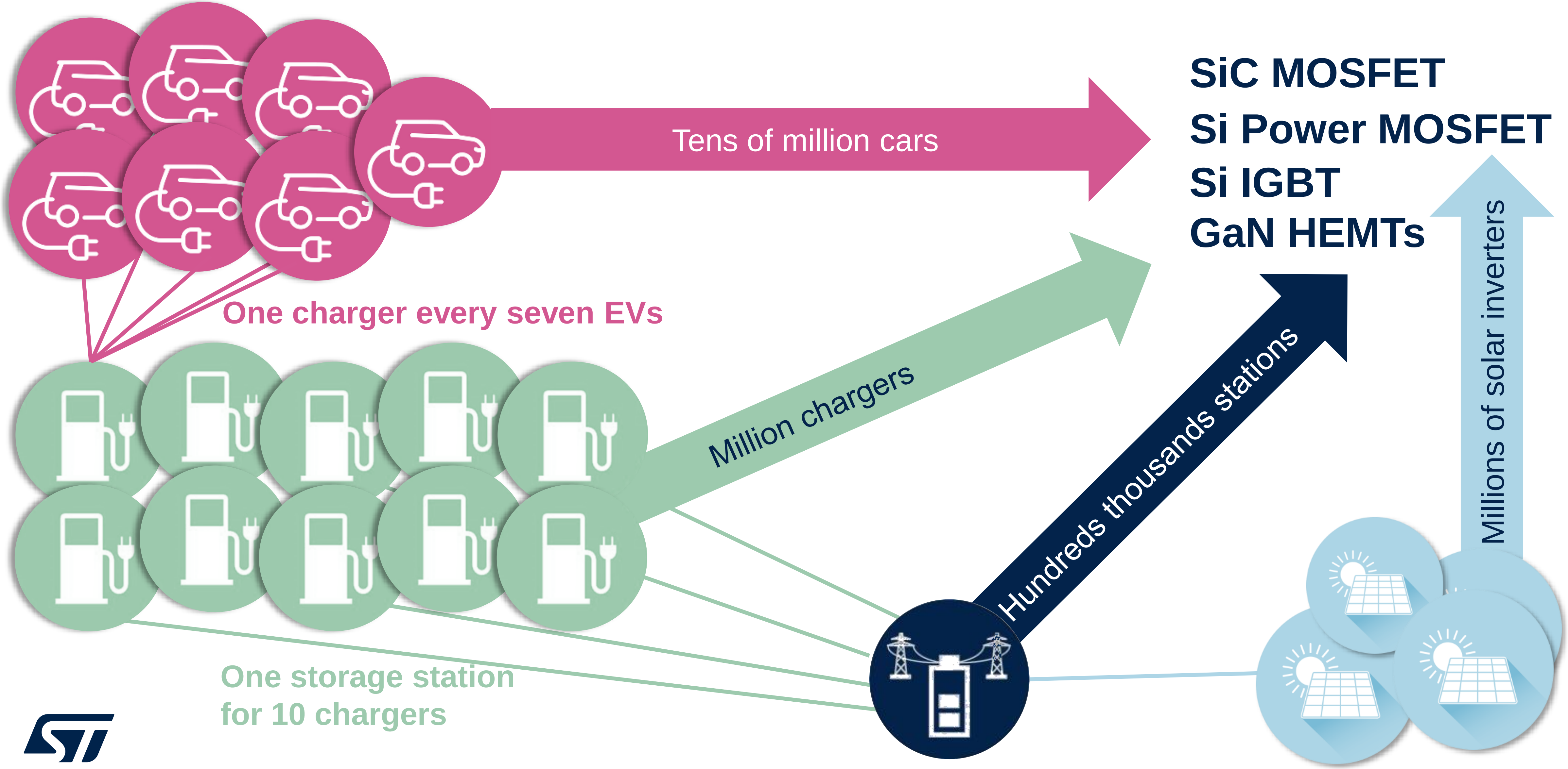
Traction inverter	From Gen2 to Gen5
DC-DC converters	From Gen1 to Gen5
OBC	From Gen2 to Gen5

*Under development
** R&D stage

🟥 Planar 🟦 Not Planar

* Source: Omdia - Power Discrete and Module Market prelim. 2022 – May 2023

How car electrification impacts power semiconductors



SiC MOSFET

Si Power MOSFET

Si IGBT

GaN HEMTs

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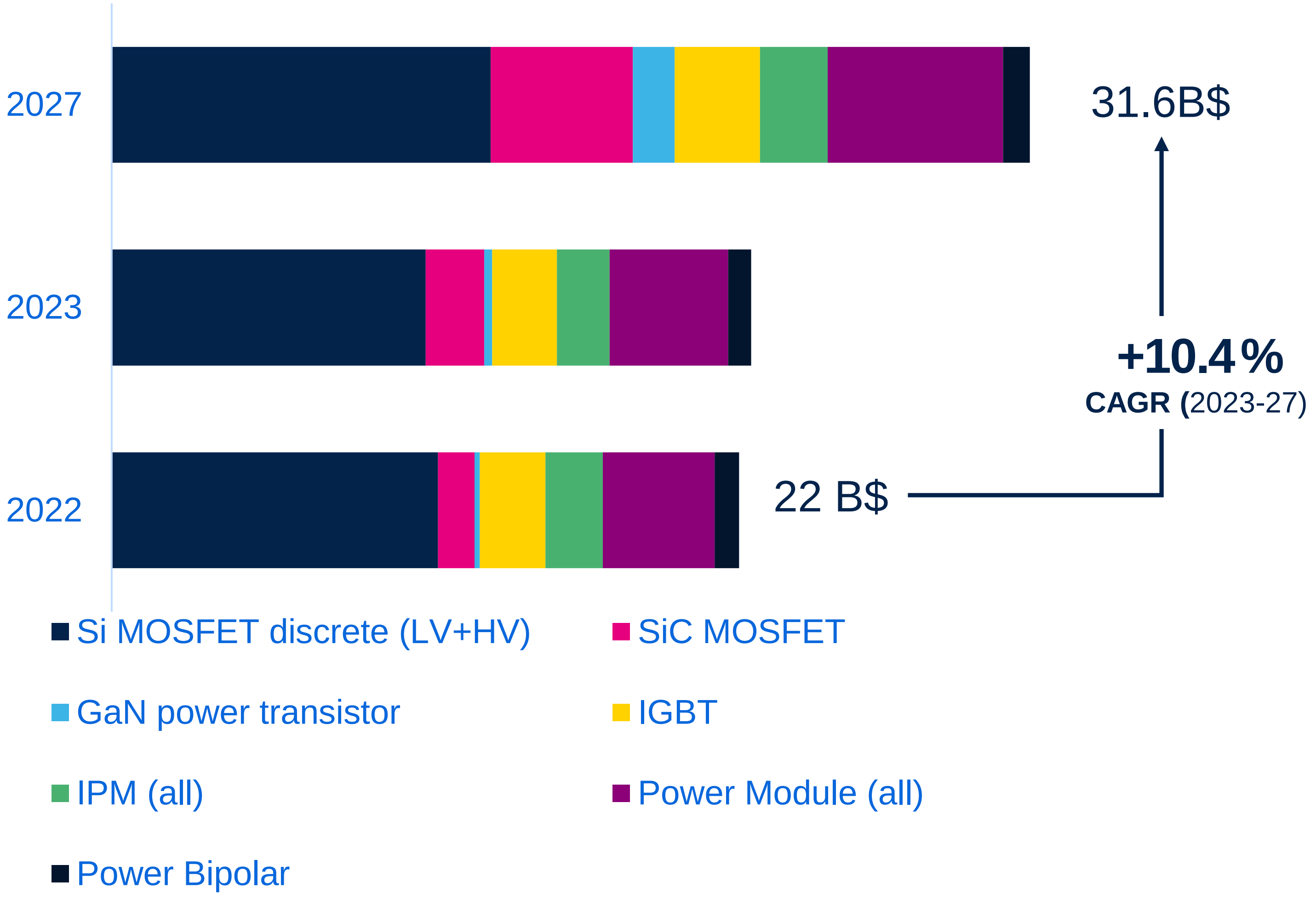
How car electrification impacts power semiconductors

System	Power	Systems/vehicle		
Traction inverter	100-250kW	1.5x	SiC MOSFET Si IGBT	24-48 transistors
OBC / DC-DC	11k-44kW	1x	SiC MOSFET Si HV MOSFET GaN HEMTs	6-12 transistors
Charging station DC-DC	100k-250kW	0.15x	SiC MOSFET	12-18 transistors
Energy storage	>1MW	0.015x	SiC MOSFET	>100 transistors

Power Transistors Market Outlook by macro technologies & focus applications



Industrial +6.4% CAGR (2023-27)
From 13B$ to 16.7B$

- Motor control and appliances
- SMPS and LED lighting
- 5G & datacenter power supplies
- Solar and energy storage
- Charging stations

Automotive +15.1% CAGR (2023-27)
From 9.6B$ to 16.8B$

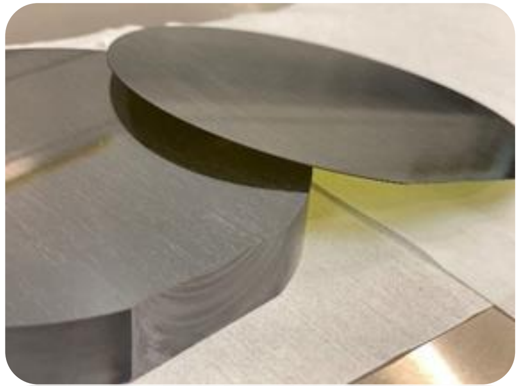
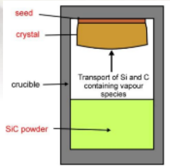
- Electric Vehicles
  - Traction inverters
  - DC-DC converters
  - On-board chargers
- Traditional automotive

Industrial includes Home Appliance, Motor Control, Power Supply, Renewable energy, Others

Sources: Omdia - Power Discrete and Module Market prelim. 2022 – May 2023
Yole Power GaN – Aug 2023. Yole Power SiC – Aug 2023

ST SiC MOSFET manufacturing strategy
Moving towards an integrated dual fab (**synoptic view**)

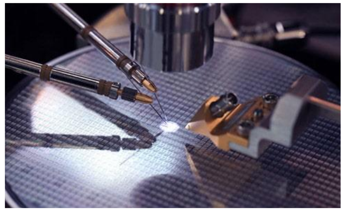
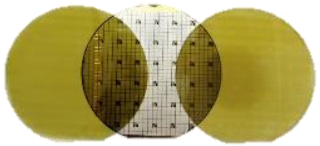
Substrate technology
From powder to ingot

Norrköping (R&D)

Catania substrate Fab production in 2024

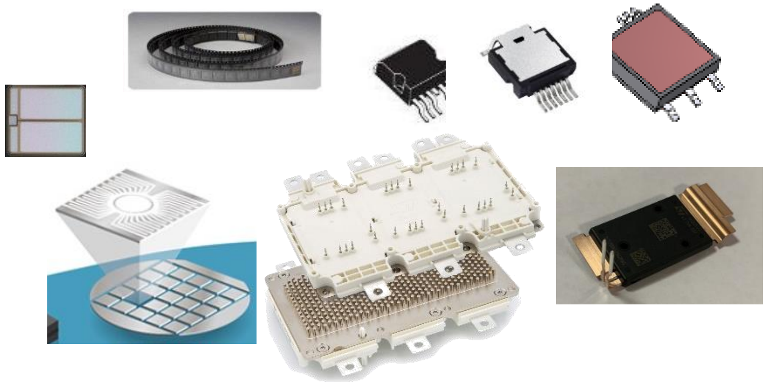
Front-end technology with Epy and EWS testing

Catania

AMK (S'pore)

Back-end technology
Bare dice, discrete, modules



Shenzhen(China)

Bouskoura (Marocco)

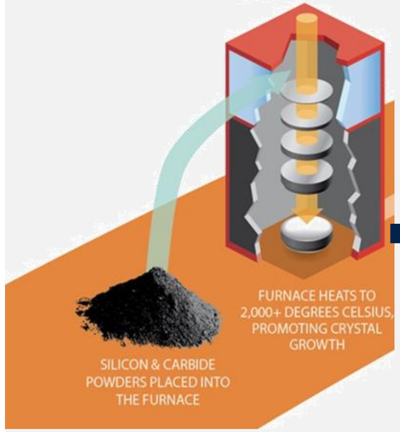
SiC MOSFET vertical integration from powder to final product

Substrate technology

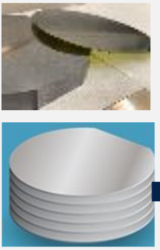
Front-end technology

Testing

Back-end technology (assembly)

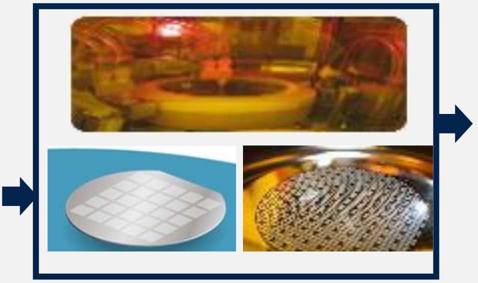


SiC ingot



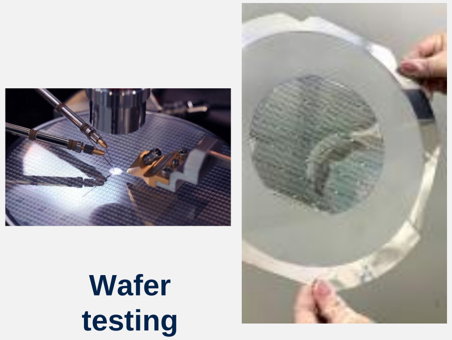
Wafer slicing & polishing

Epitaxy

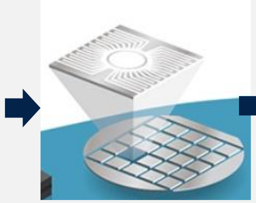


Device fabrication

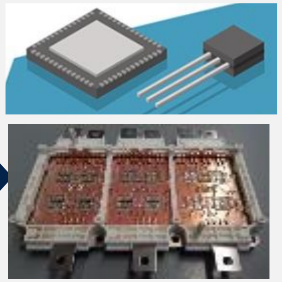
litho, deposition, etching, thermal treatment metallization, etc.



Wafer testing (electrical wafer sorting) & Wafer Level Burnin



Dicing (singulation)



packaging

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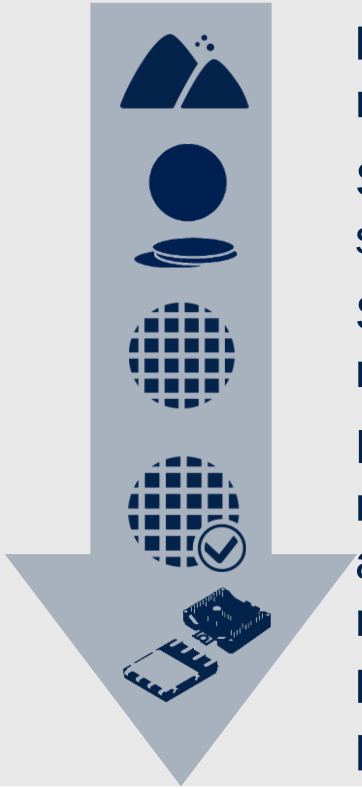
Vertically integrating for supply chain robustness

Improving process control and efficiency, from powder to final product



Raw material

SiC ingots & substrates

SiC dice manufacturing

Discrete & modules design, automated manufacturing

Finished products

SiC substrate R&D plant

Norrköping

- 150 mm production
- 200 mm with industrial quality and yields

New SiC integrated plant

Catania

- Pilot production in 2023
- 150 mm substrates + epitaxy (converting capability to 200 mm)

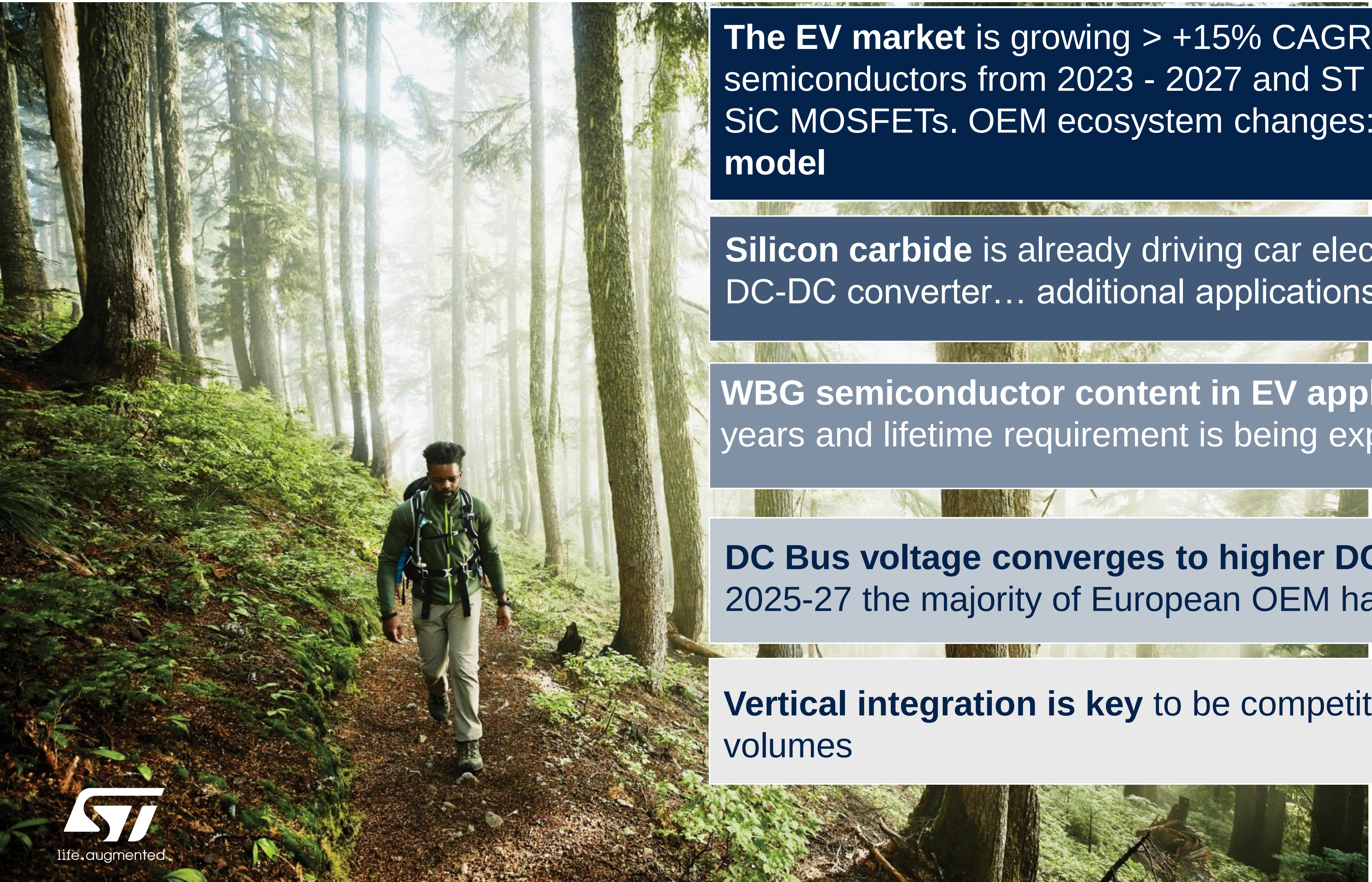
ST and Sanan Optoelectronics joint venture agreement

ST and Sanan Optoelectronics have signed an agreement* to create a 200mm silicon carbide (SiC) device manufacturing Joint Venture in Chongqing, China

- Supporting the rising demand in China for **car electrification and industrial power and energy** applications
- **Production** to start in **Q4 2025** and **full buildout** is anticipated **in 2028**
- JV to serve as a **dedicated foundry** to ST for its Chinese customers
  - Making SiC devices **exclusively for ST**
  - Using ST proprietary SiC **manufacturing process technology**
- Total amount for full buildout of the JV is expected to be **~$3.2B**, including **Capex of ~$2.4B** over the next 5 years
  - Financed by contributions from **ST and Sanan,** local government support and loans to the JV
- Sanan to build & operate separately a **200mm SiC substrate plant,** using its own SiC substrate process, to fulfill the JV needs

*The completion of the project is subject to regulatory approvals.

Key takeaways



The EV market is growing > +15% CAGR for automotive power semiconductors from 2023 - 2027 and ST today is market leader in SiC MOSFETs. OEM ecosystem changes: **from buy to make model**

Silicon carbide is already driving car electrification: inverter, OBC, DC-DC converter… additional applications are ramping up

WBG semiconductor content in EV application grows in the coming years and lifetime requirement is being expanded continuously

DC Bus voltage converges to higher DC link voltages: around 2025-27 the majority of European OEM has an 800V system

Vertical integration is key to be competitive and to deliver high volumes

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Our technology starts with You

Find out more at www.st.com/stpower

Manuel.gaertner@st.com

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