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# ST developments in SiC manufacturing to address the EV revolution

## FPC2024

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STMicroelectronics

# Agenda

1. EV market development
2. SiC demand in electric vehicle subsystems
3. Continuous development of the technology node
4. SiC manufacturing challenges
5. Introduction of new manufacturing technologies
6. Vertical integration of the manufacturing cycle
7. Capacity expansion to support growth
8. Key takeaways

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# Semiconductors addressing carbon neutrality

**Silicon and wide-bandgap (silicon carbide & gallium nitride) power transistors**

Tens of millions of cars

Millions of chargers

Hundreds of thousands of stations

Millions of solar inverters

- Electrification of energy consumption
- Transportation decarbonization
- Renewable energy generation

- Powertrain electrification
- Smart vehicle / connectivity
- ADAS / autonomous drive
- Software / Hardware decoupling

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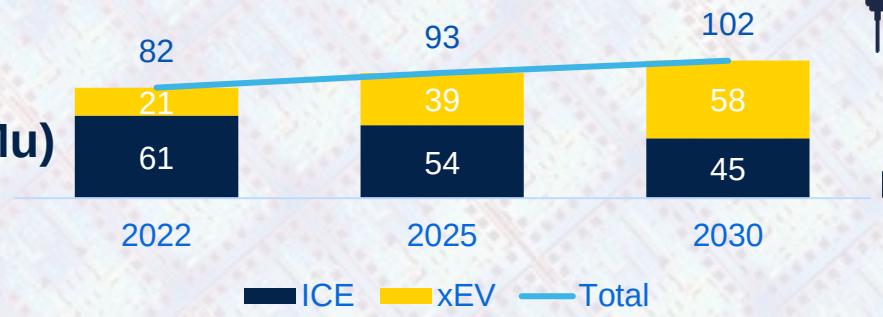
# Chip demand rising faster than vehicle production

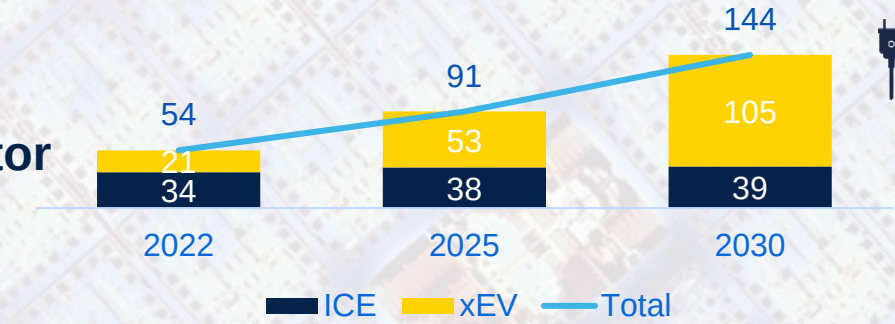
**Light vehicle production (Mu)**




**xEV: +14%**
CAGR '22-'30

**ICE: -4%**
CAGR '22-'30

**Semiconductor TAM (B$)**



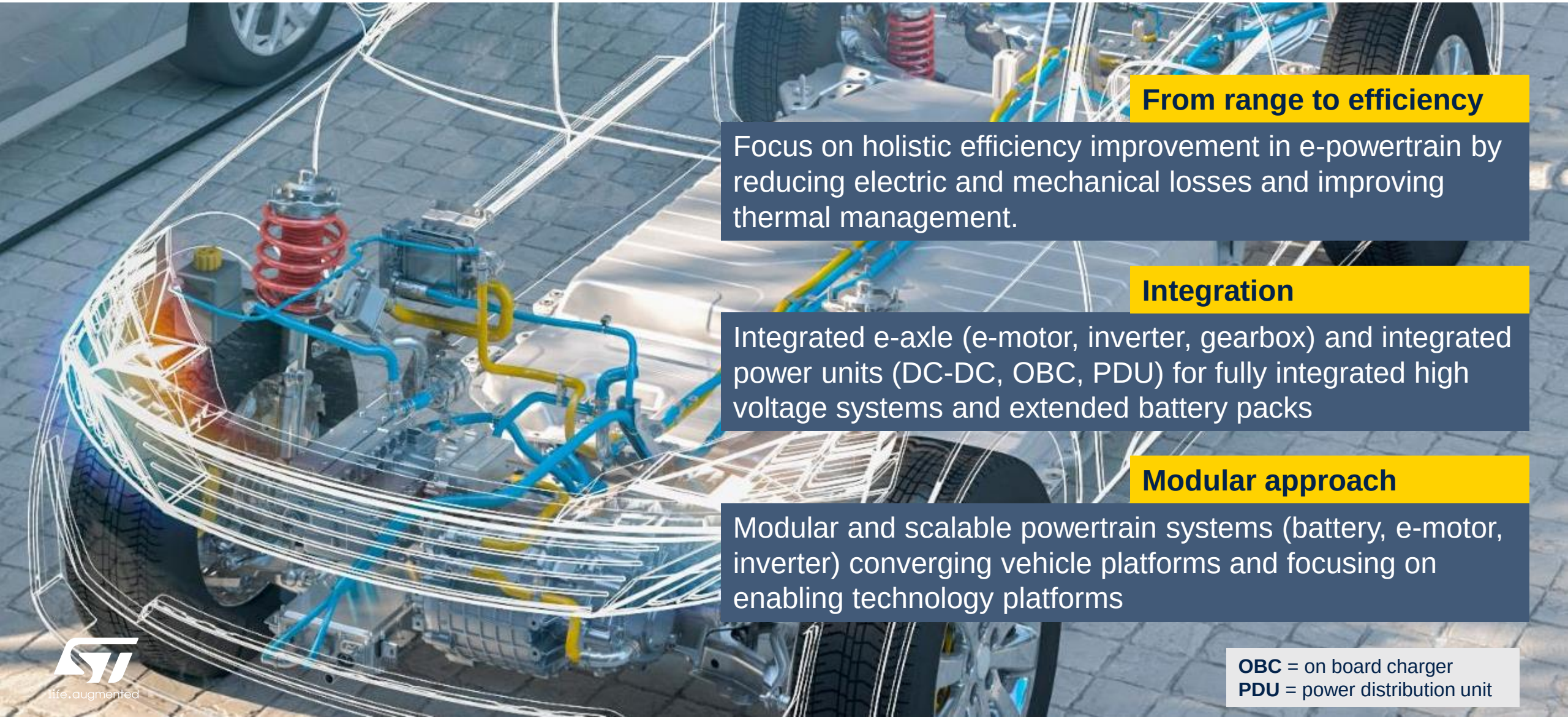

**xEV: +23%**
CAGR '22-'30

**ICE: +2%**
CAGR '22-'30

**ICE** = internal combustion engine
**xEV** = battery electric vehicle, fuel cell electric vehicle, full hybrid, plug-in hybrid, mild hybrid.

Source: Strategy Analytics

# Electric powertrain efficiency and integration



## From range to efficiency

Focus on holistic efficiency improvement in e-powertrain by reducing electric and mechanical losses and improving thermal management.

## Integration

Integrated e-axle (e-motor, inverter, gearbox) and integrated power units (DC-DC, OBC, PDU) for fully integrated high voltage systems and extended battery packs

## Modular approach

Modular and scalable powertrain systems (battery, e-motor, inverter) converging vehicle platforms and focusing on enabling technology platforms

**OBC** = on board charger
**PDU** = power distribution unit

# How car electrification impacts power semiconductors

| | | | | | |
|---|---|---|---|---|---|
|  | 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 | 6-14 transistors |
|  | Charging station DC-DC | 100k-250kW | 0.15x | SiC MOSFET | 12-18 transistors |
|  | Energy storage | >1MW | 0.015x | SiC MOSFET | >100 transistors |

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# New automotive applications powered by SiC

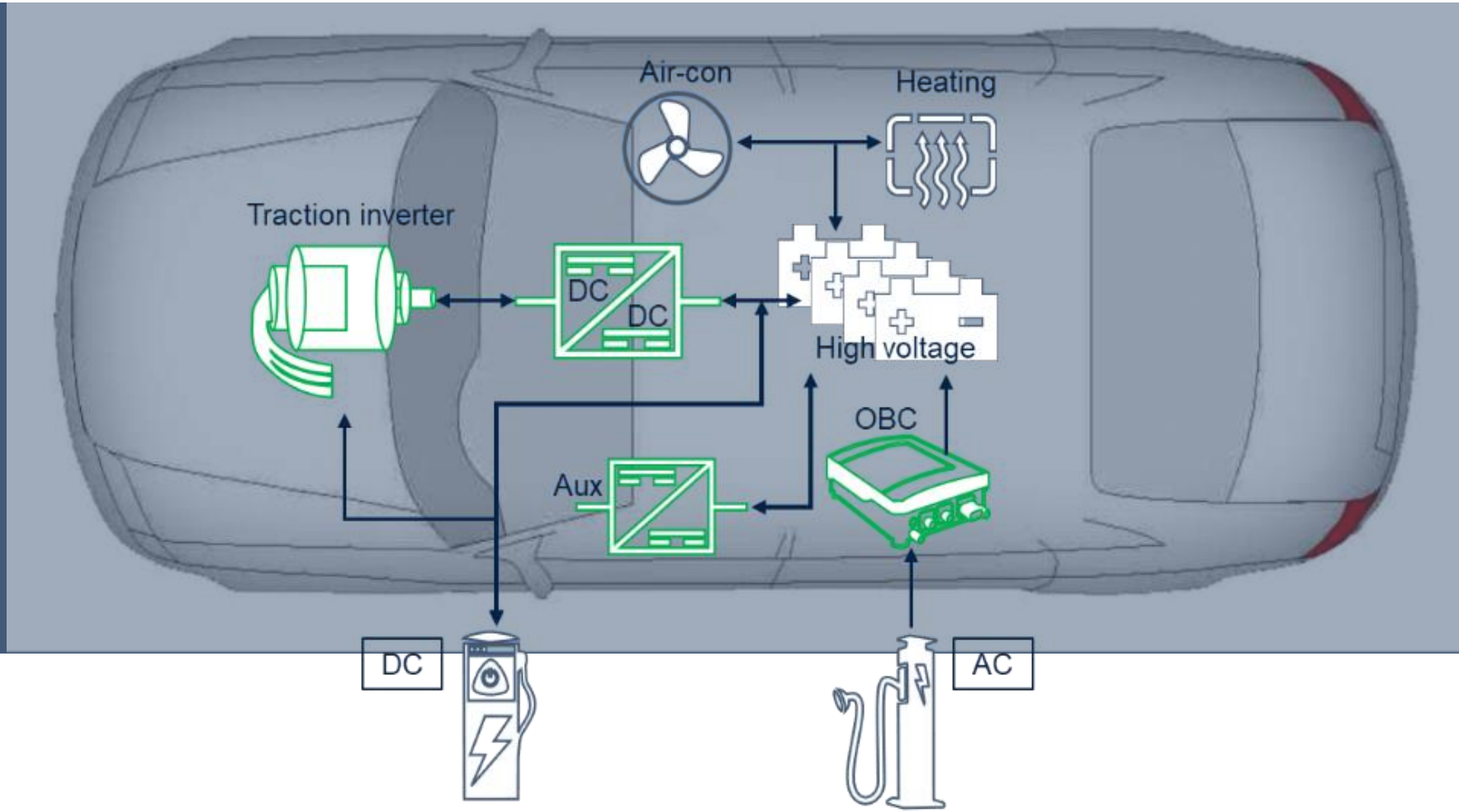
Fuel cell applications
- Interleaved power DC-DC
- High speed pump

Battery disconnect
- Replace mechanical relay / solid state contactors

DC link discharge
- Discharging HV for safety

Smart power distribution
- Protection of auxiliaries
- Boardnet optimization

Various
- Heating control
- High speed pump (turbo)
- E-Compressor

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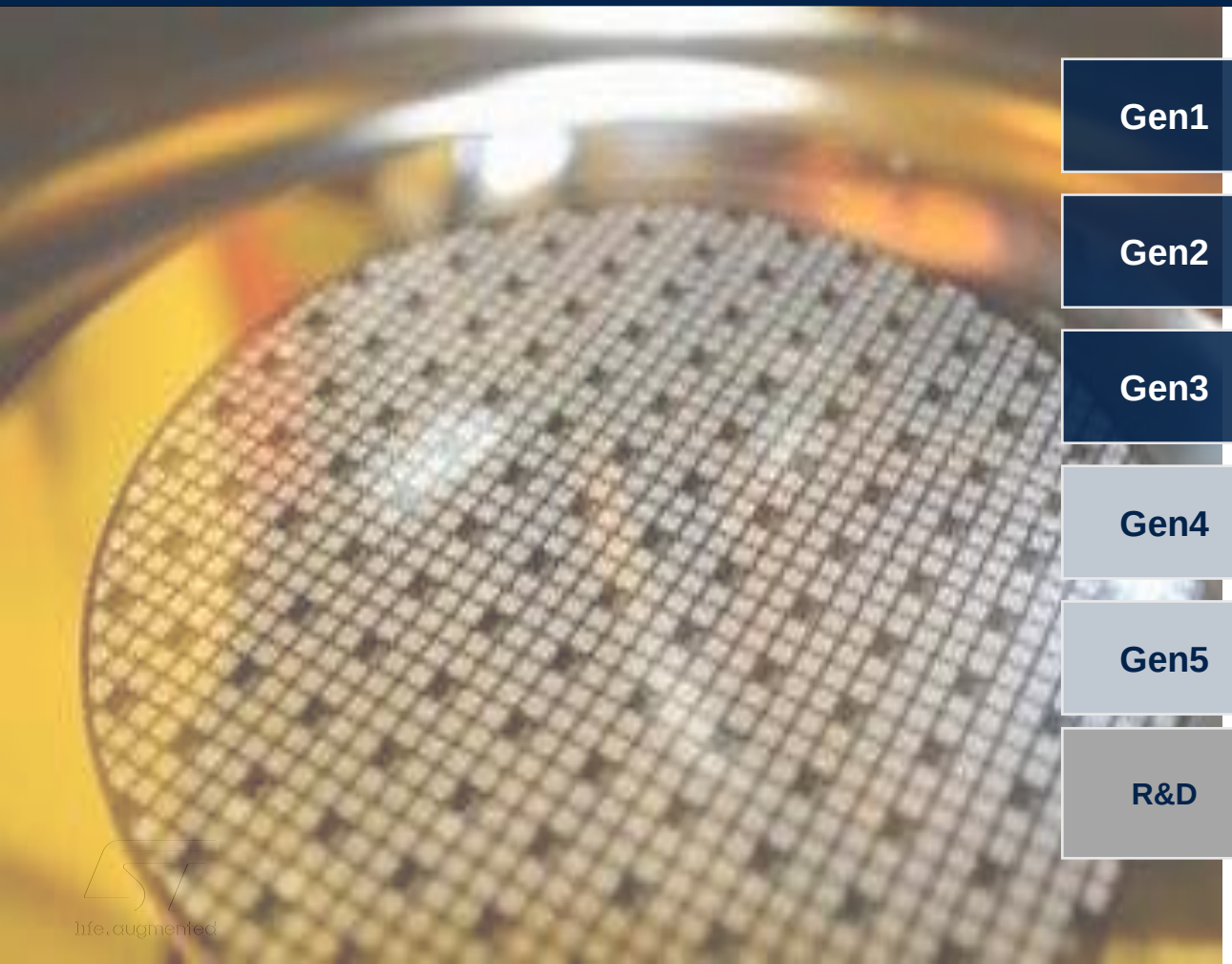
# SiC MOSFET technology development

## Technology Roadmap



Planar  Not Planar

| | |
|---|---|
| **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 |
| **R&D** | Radical innovation, outstanding Ron value at hot temperature and further Ron reduction vs. **Gen5** |

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# The major differences between Si and SiC

| | Si | SiC |
|---|---|---|
| State-of-the-art Wafer size | 8-12” | 6” |
| Ingot length | 1-2 meters | 0.04 meters |
| Time to growth | 1 day | 2 weeks |
| Wafers per ingot | ~2000 | ~50-100 |

SiC fabrication enlarges its scope to 8” dimensions.

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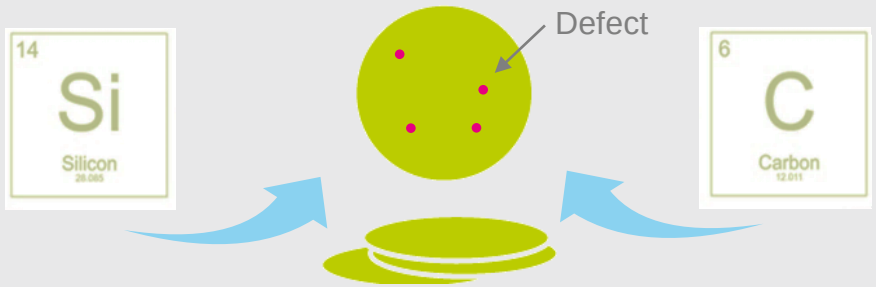
# Manufacturing challenges of silicon carbide

## Higher intrinsic material defectiveness leads to more complex manufacturing for quality & reliability targets



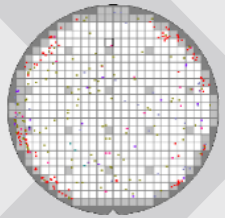

**SiC ingot manufacturing**


Seed defectiveness propagation

**Sawing process**


Physical defect mapping at wafer level

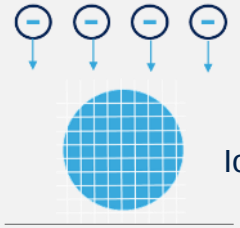
**Sic wafer testing**



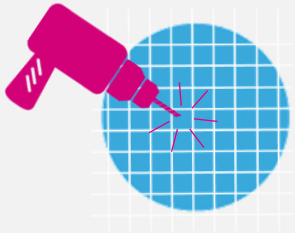
Electrical testing to verify mapped defectiveness area

## Harder material requires a more sophisticated manufacturing process at key diffusion steps

**>1700°C**
Annealing
(Vs. 800° Si)



**500°C**
Ion Implantation
(Vs. 25° Si)



Harder etching phase (similar to diamond)


More accurate photolithography to define dopant shape

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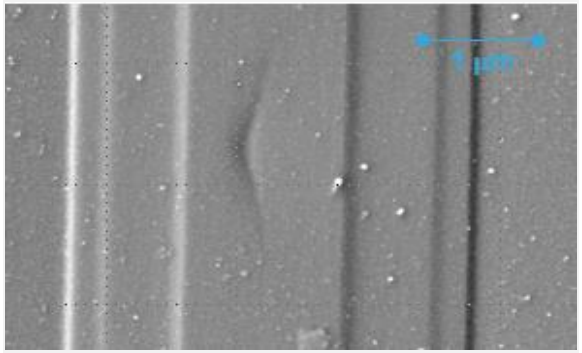
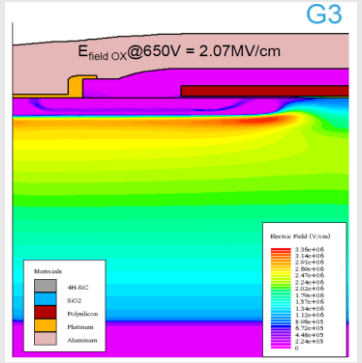
# Wide-bandgap deployment and validation

## Failure analysis



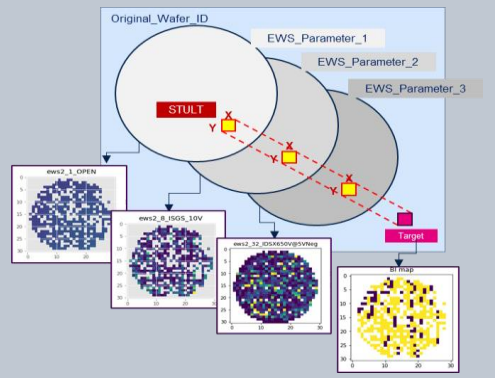
- Identification of new failure modes
- Effectiveness evaluation of screening methods
- Support for customer use in application
- New FA techniques

## Design improvement



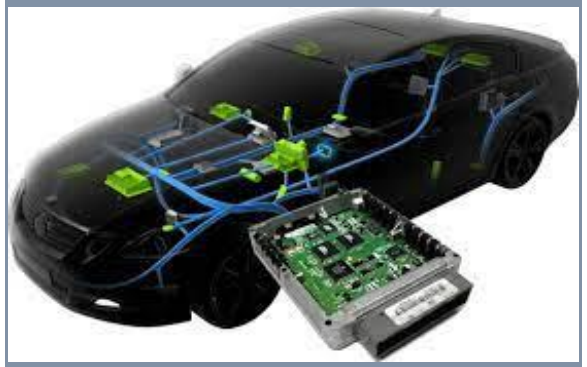

- Design fine tunings based on new failure mode
- Design for reliability and more margin
- Front-end & back-end new material and design solution evaluation

## Testing improvement




- Fine-tuning of testing in EWS and back-end
- Burn in testing for new technologies
- DOLI implementation for known defects

## Mission profile assessment



- Analysis of customer specific mission profile
- Fine-tuning of testing and reliability assessment
- Equivalent FIT evaluation

FA = Failure analysis, EWS = Electrical wafer sorting, DOLI = Defect offline inking, FIT = Failure in time

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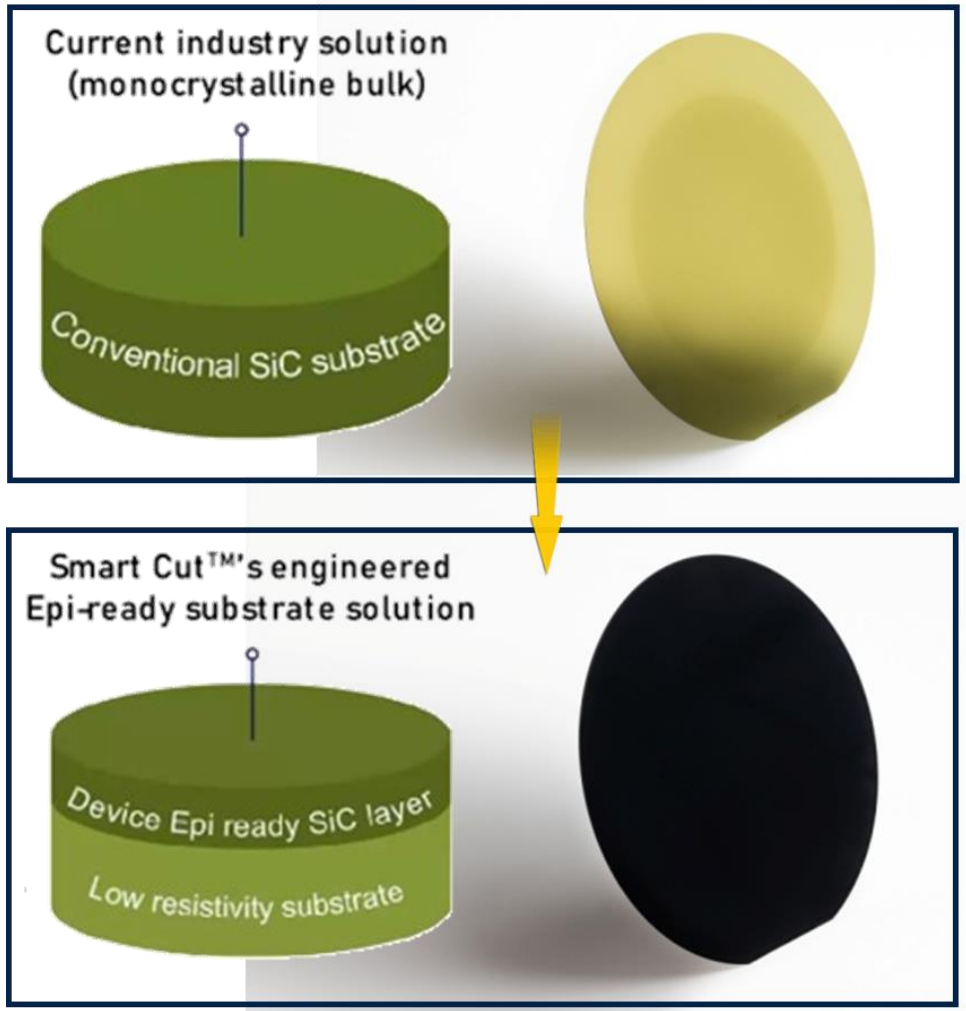
# Looking to use SOITEC SmartSiC to advance manufacturing

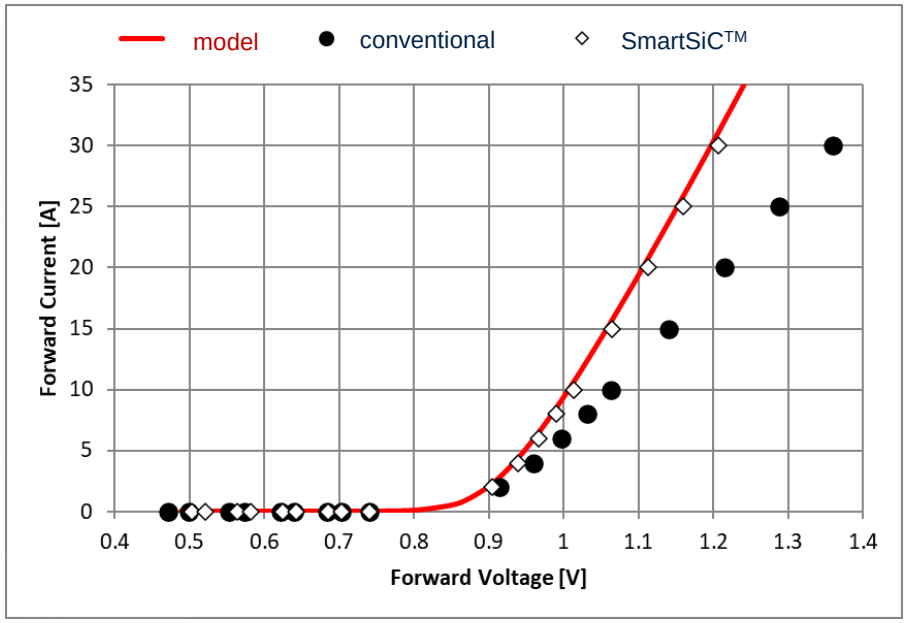


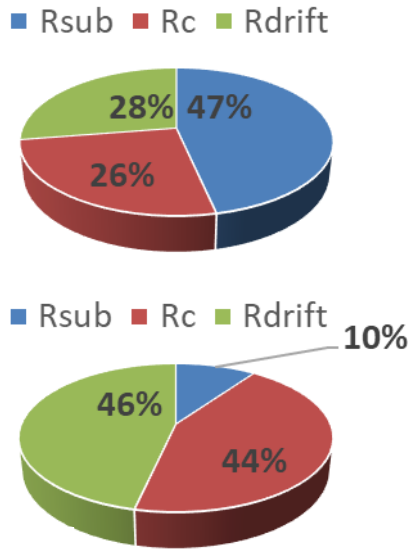

courtesy of SOITEC

## Value proposition

- High increase of number of producible wafers
- Maximize substrate value
- Device feature size reduction / RDSon improvement
- Copy & paste of MOSFET process flow
- Acceleration of the path to 200mm transition

**Experimental data on 650V SiC diode**




$\Delta R$ @ RT = 33mOhm*mm$^2$



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# Vertically integrating for supply chain robustness

**Raw material → SiC ingots & substrates → SiC dice manufacturing → discrete/module design & manufacture → Finished products**

## Norrköping SiC substrate R&D plant

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

## Catania new integrated SiC plant

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

* targeting > 40% substrate in-sourcing by 2024

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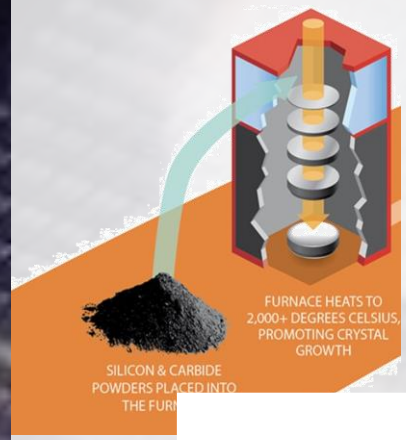
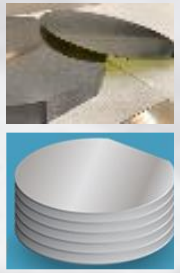
# Vertical integration, from powder to final product

## Substrate technology

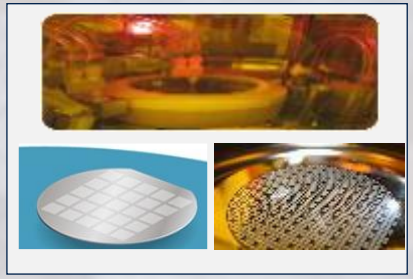


**SiC ingot**

**Wafer Slicing & polishing**

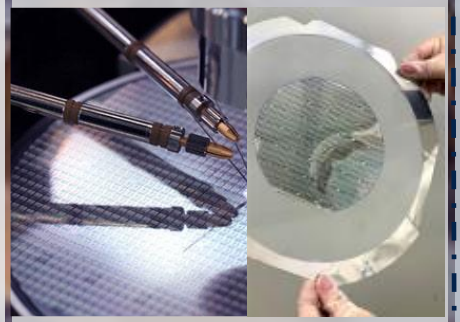
## Front-end technology



**Epitaxy**

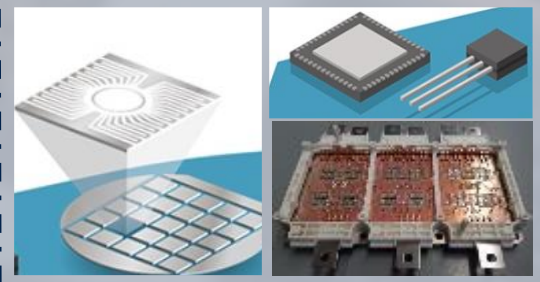
**Device fabrication lithography, deposition, etching, thermal treatment metallization, etc.**

## Testing



**Wafer testing (Electrical Wafer sorting) & wafer level burning**

## Back-end technology (assembly)



**Dicing (singulation)**

**Packaging**

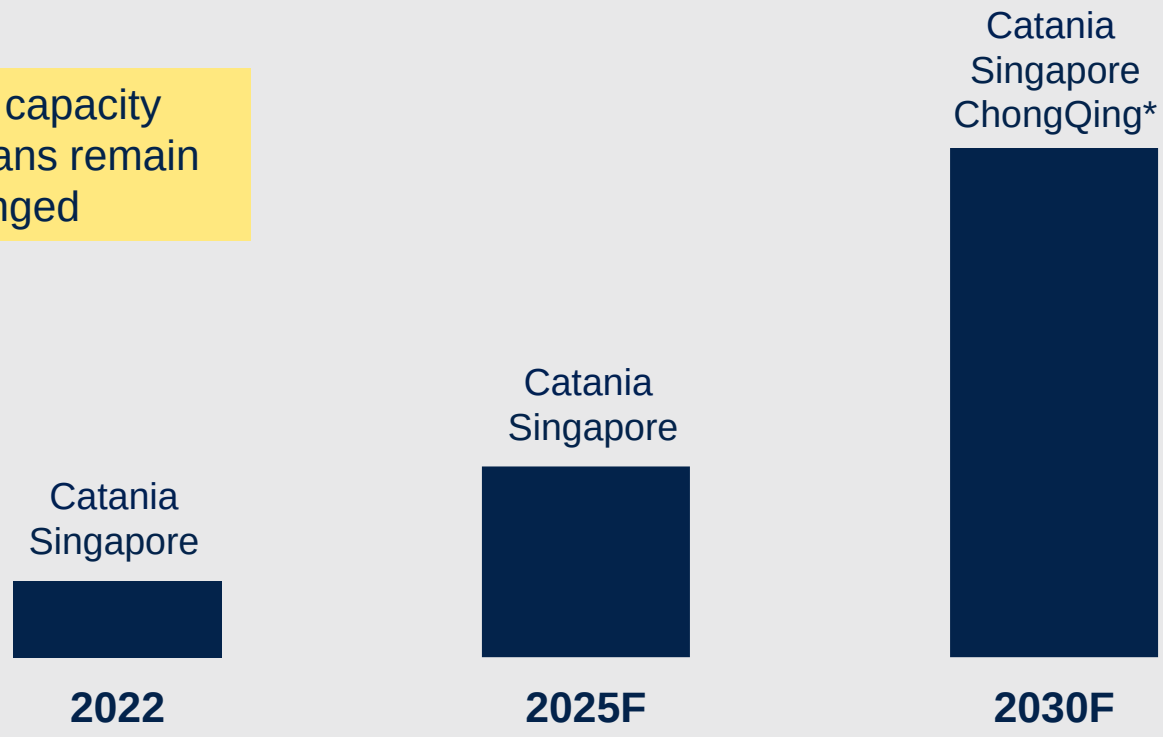
# Expansion of silicon carbide manufacturing capacity






## SiC device manufacturing capacity growth

2022-2025 capacity expansion plans remain unchanged




Supported by corresponding investments in back-end capacity
in Bouskoura and Shenzhen and ramp of internal substrate manufacturing in Catania

* Dedicated JV with Sanan in China to address the local market

# Takeaways

Silicon carbide is key in **power conversion efficiency**

**Demand for SiC** is growing quickly due to its extensive use in electric vehicle subsystems.

Investment in a **vertically integrated** approach essential to improve output and address market needs

Continued development of the technology node to improve power density

ST SiC MOSFET technology is **state-of-the-art and best positioned** to support the growth today

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