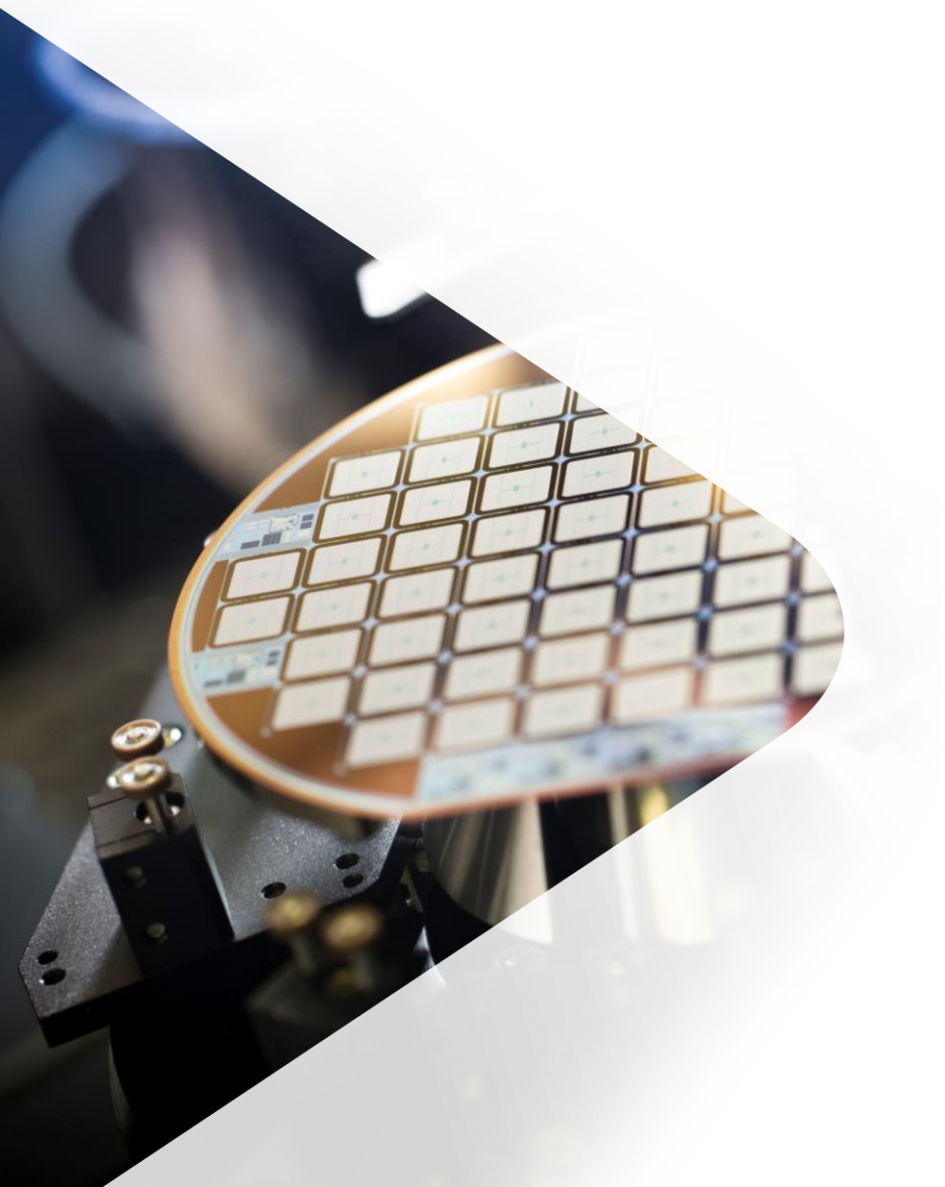
Power electronics insights report

February 2023

ADVANCED PROPULSION CENTRE UK | Accelerating Progress

The purpose of this report



- To stimulate power electronics manufacturing growth in the UK
- Join up the supply chain, bringing synergies to build compound semiconductor supplies for UK electric vehicle production
- Help select strategic projects in the UK that can increase innovation and supply resilience
- Identify strengths and gaps in the supply chain to focus industry and government efforts
- Provide recommendations to strengthen and build the UK's compound semiconductor supply chain

The basics of power electronics in electric vehicles

Power electronics are fundamental to electric vehicles. At the heart of these devices are semiconductors, commonly referred to as chips.

Semiconductors

Semiconductors are needed for a wide range of applications on a vehicle, ranging from the entertainment system to power-steering. Crucially, they are an integral part of any electrified powertrain, supplying and controlling the current and voltage throughout the drive system. The devices needed for microelectronics are very different to those for power electronics.

IGBTs

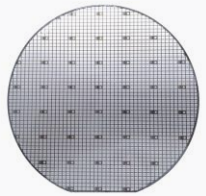
IGBTs (insulated-gate bipolar transistor) and MOSFETs (metal–oxide semiconductor field effect transistor) are critical devices that provide the ability to control current and operate at high-switching frequencies.

Wafers

The IGBT and MOSFET devices start off life as a thin Silicon (Si) or Silicon Carbide (SiC) wafer, 6” to 8” in diameter. Using an epitaxial layering process, materials are deposited on the base wafer substrate to produce epi-wafers that can have electronics fabricated onto their surface.

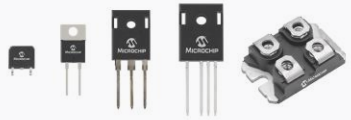
Wafer fab, power modules and inverters

The individual die (blocks of semiconductor material within the wafer) are separated and made into discrete devices or power modules which are then used to produce inverters. This involves several electrical, electronics, and mechanical assembly steps, adding further value to the product.



SiC fabricated wafer

Clas-SiC Ltd



SiC discrete MOSFET and power module

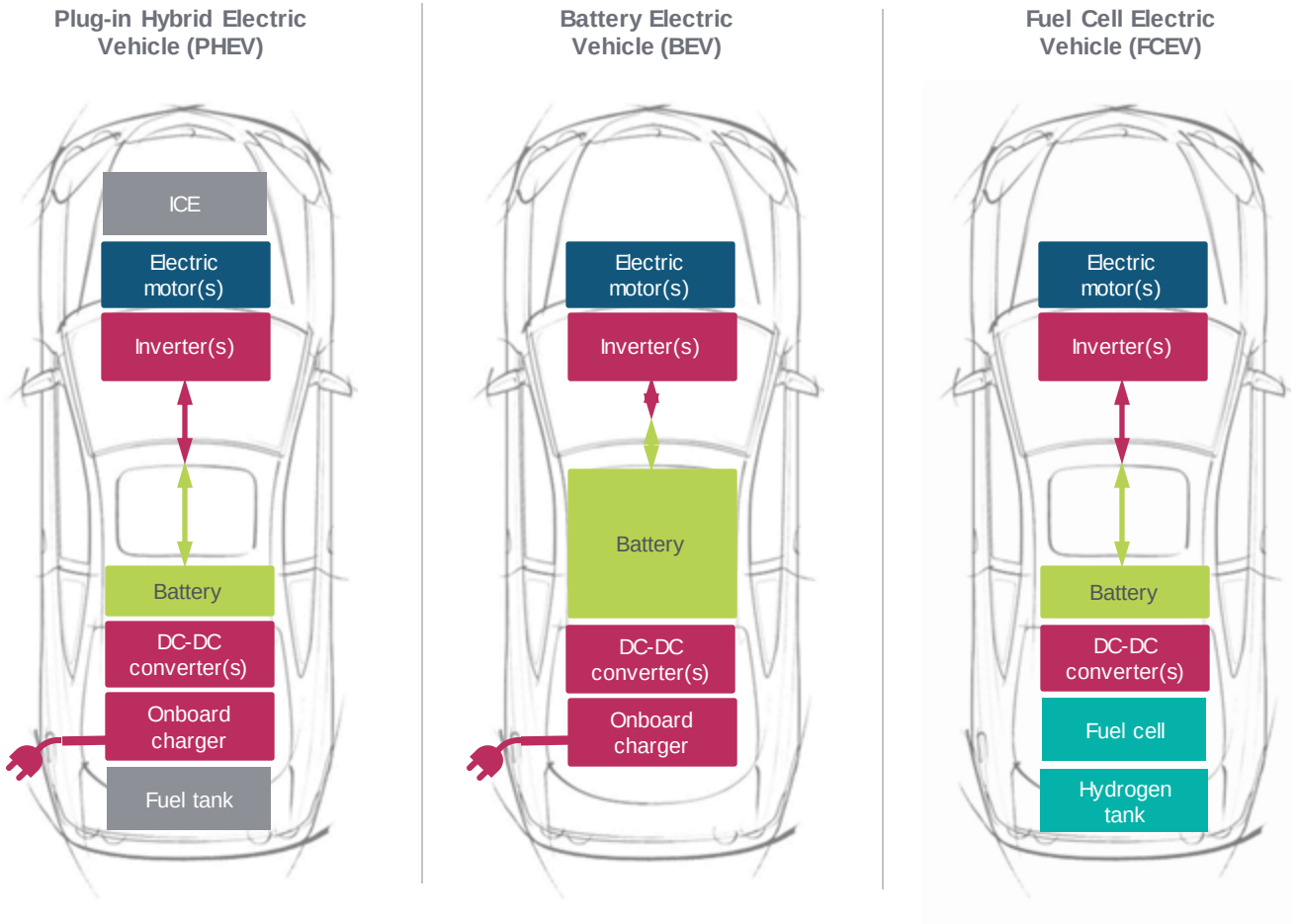
Microchip Technology Caldicot Ltd

IPG5 800 V SiC inverter

McLaren Applied Ltd

Power electronics onboard electric vehicles

There are three main power electronic components onboard battery electric vehicles; an inverter, a DC-DC converter and an onboard charger (OBC).



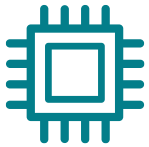
- An inverter converts DC power from the vehicle's battery to AC power to drive the electric motor. These high-power devices (30-400 kW) are either standalone or integrated with the electric motor into an electric drive unit (EDU).
- A DC-DC converter on a BEV or PHEV decreases (steps-down) voltage from the high-voltage battery, e.g., 400-800 V, to low voltages as needed by the vehicle's auxiliary systems. These are typically low-power devices (3-7 kW). Note: high-power converters are needed for FCEVs.
- OBCs take AC power from the electrical grid and convert it to DC for storage on the vehicle's battery. These are typically rated at 3-23 kW.

Silicon carbide (SiC)

Silicon carbide (SiC) is the front-runner for future electric vehicle power distribution, control and supply management

Insights

- SiC MOSFETs offer huge potentials for power electronic systems due to their reduced conduction and switching losses and work efficiently at higher operating temperatures
- By operating at higher switching frequencies and voltages of 800 V +, SiC provides a compounding effect from improved power conversion efficiencies of 5-15% and significant weight savings to the electric motor, cabling and the cooling system



Silicon carbide market penetration

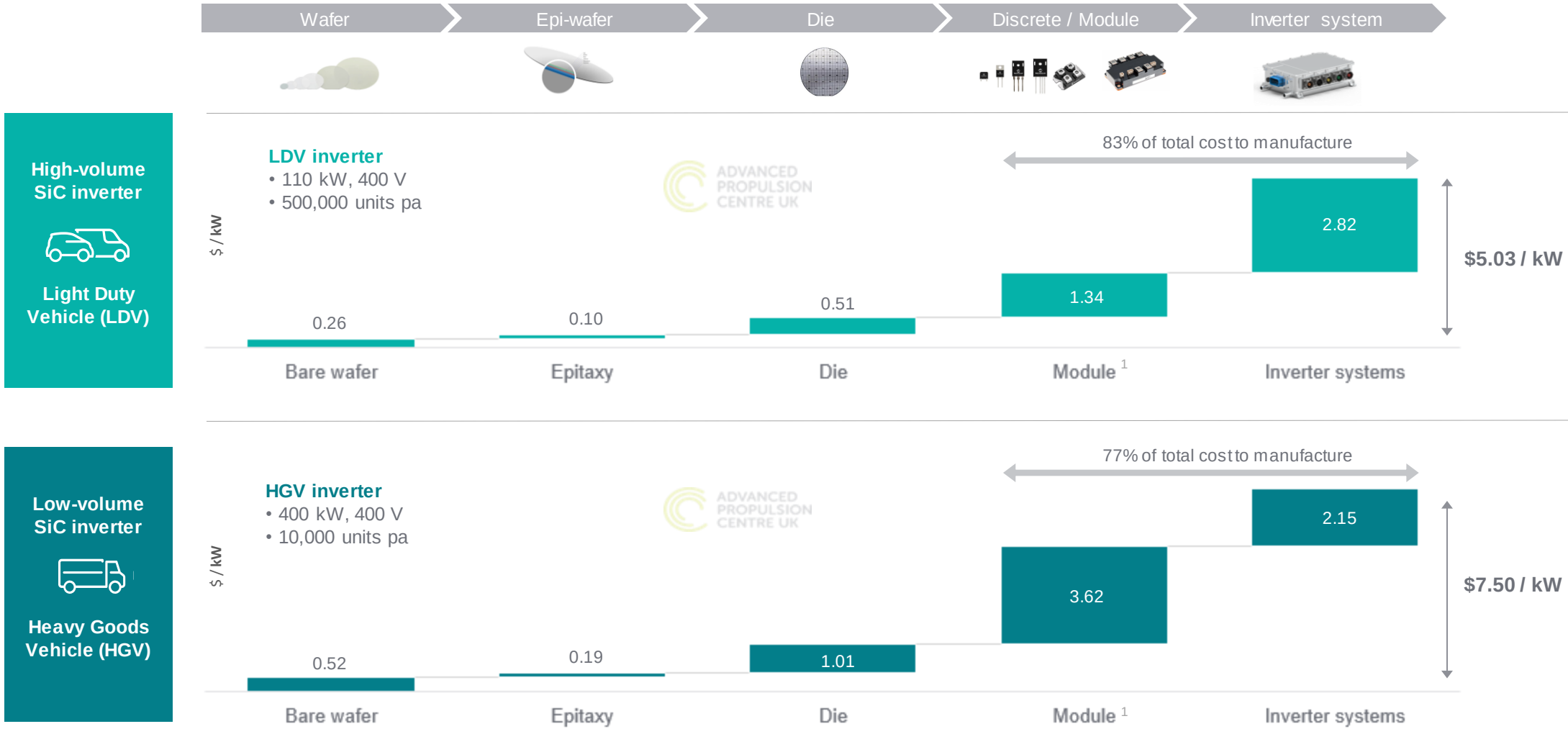
SiC wafer demand and market penetration for light duty vehicles

- SiC-based inverters are expected to dominate the market by 2030, reaching 30-50% market penetration by 2025
- Europe will need between 600,000 - 800,000 SiC wafers by 2030
- UK would need a supply of 80,000 SiC wafers annually by 2030 to support locally-produced electric vehicles

Read more about this in our Q3 2022 demand report

There are high-value opportunities across the value chain. For example, in passive components, DC-link capacitors, inductive devices, packaging, test & development.

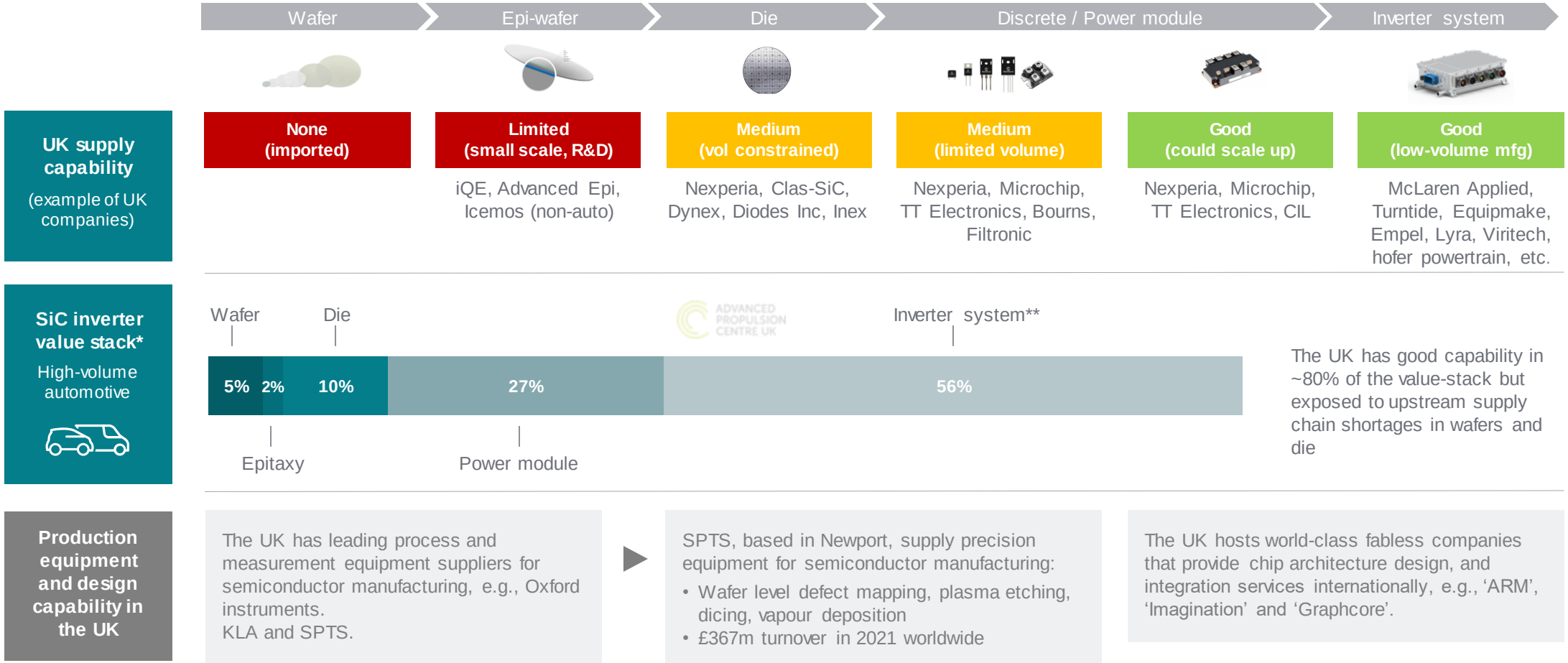
Calculated cost-stack for low-volume and high-volume SiC inverters



Credits to: Exawatt SiC and GaN inverter cost-stack study for the APC, Dec 2022

Module[1] prices are based on market selling price tracked by Exawatt minus estimated low-volume die costs. HGV module prices are higher due to low-volume economics and niche product specification.

The UK has supply chain capability in power modules and inverter systems but is exposed to upstream material supply shortages



* **Credits to:** Exawatt SiC and GaN inverter cost-stack study for the APC, Dec 2022.

** Inverter system includes: circuit board, ICs, microcontroller, sensors, resistors, capacitors, magnetic devices, DC-link capacitor, terminals, HV and LV connectors, bus bars, plastic injection moulding parts, cooling system, cabling, environmental management, aluminium die-cast case, sealing, electronic manufacturing, housing assembly, validation testing.

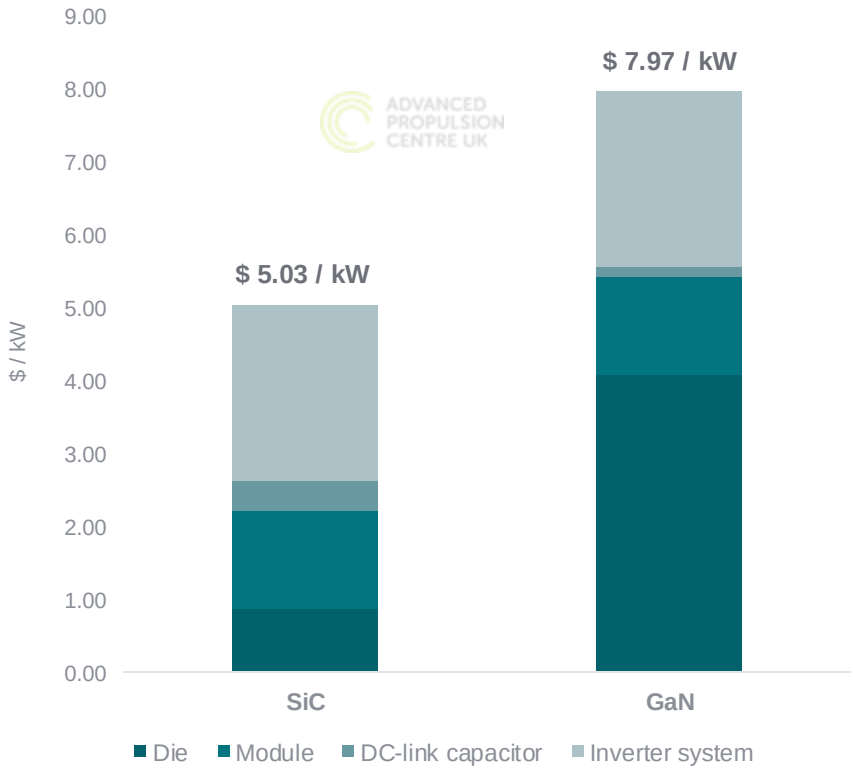
NB: mfg refers to manufacturing

SiC adoption for mass-market automotive applications is accelerating whilst GaN is maturing

Insights

- GaN-on-Si is the most mature technology for high-volume automotive applications, suited for voltages up to 650 V
- GaN devices, at high voltages (650 V +) and high currents (50 A +), are likely to remain more expensive than equivalent SiC devices, despite the lower cost of the silicon substrate
- As GaN mass-production technics improve, the low die yields arising from low current density – a consequence of the lateral device architecture – will continue to make costs challenging
- SiC power device manufacturing revenue is expected to grow at a CAGR of 34% from $1.09 bn in 2021 to $6.3 bn in 2027*, strongly driven by automotive applications. Leading suppliers include; STMicroelectronics, Infineon, Wolfspeed, ROHM, onsemi and Mitsubishi Electric.
- APC's survey of experts in the power electronics industry forecasts a 40-60% penetration of SiC devices for automotive applications by 2035. SiC-based inverters are expected to have the leading market share by 2030.

Modelled costs for high-volume inverters (110 kW, 400 V)



* Source: Yole Développement, Power SiC 2022 Report

Definitions: GaN (Gallium Nitride), CAGR (Compounded Annual Growth Rate)

Credits to: Exawatt SiC and GaN inverter cost stack study for the APC, Dec 2022

Recent SiC investments and strategic partnerships (Q4 2022)

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Insights

- Increased global investments in SiC manufacturing
- More vehicle platforms emerging with 800 V + architectures
- Large multinational suppliers are vertically integrating

Oct 2022
Jaguar Land Rover partners with Wolfspeed for supply of silicon carbide semiconductor technology on next generation electric vehicles. Expected on Range Rover models from 2024.

Nov 2022
BorgWarner to invest $500 million in Wolfspeed, securing up to $650 million in annual capacity of silicon carbide devices.

Nov 2022
Infineon and Stellantis agree a Memorandum of Understanding securing a multi-year delivery deal for silicon carbide chips.

- As of June 2022, companies producing vehicles on an 800 V + platform include Porsche, Hyundai, BYD, Kia, GAC, Lucid, Geely and GM. Tesla, the first adopter of SiC inverters, is likely to introduce 800 V platforms in future models.
- Despite the global shortage, 2021 was a record year for worldwide sales of semiconductors exceeding $550 billion (according to KPMG), a 25.6% increase over 2020. Major semiconductor suppliers are ‘sold out’ to the end of 2023.
- onsemi and VW Group cement strategic collaboration on a platform SiC traction motor inverter solution, Business Wire, Jan 2023.

Source: Public domain press releases and news bulletins

The APC is funding strategic projects to build and strengthen power electronics manufacturing in the UK

APC 12: McLaren Applied – ESCAPE

- Building a secure UK end-to-end power electronic supply chain capable of competing globally
- Aligning the UK SiC supply chain to be capable of the end-to-end supply of materials and parts to support UK power electronics manufacturing
- Total project value £19.5 million, with £9.7 million funded through the APC

Project consortium

McLaren Applied (lead partner)
University of Warwick
Clas-sic Wafer Fab
Compound Semiconductor Centre
Lyra Electronics
Microchip Technology
MaxPower Semiconductor
Techworkshub
Tribus-D
Turbo Power Systems
Exawatt
Compound Semiconductor Applications Catapult

APC 15: BMW – @FutureBEV

- New standardised inverter utilising 800 V SiC power modules
- Improving efficiency
- Fast charging capability
- Developing UK 800 V battery supply chain
- Total project value £30 million, with £15 million funded through the APC

Project consortium

BMW (lead partner)
Compound Semi-conductor Applications - Catapult
Custom Interconnect Ltd
Lyra Electronics
University of Warwick

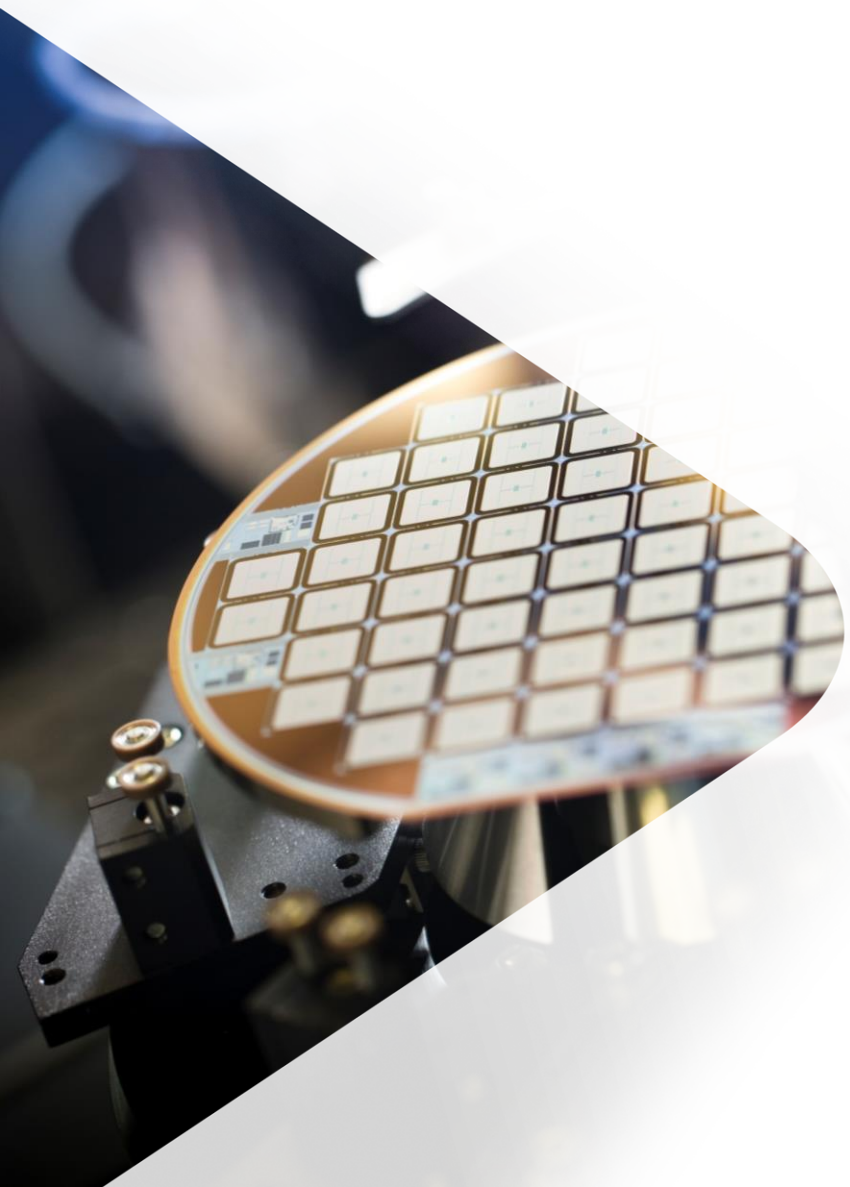
Conclusions and insights

Increasing local semiconductor and inverter production for high-power vehicles (luxury, performance, SUVs and HGVs), will future-proof automotive manufacturing in the UK

Insights

- The UK is lacking an end-to-end semiconductor supply chain for power semiconductors. Wafers and epi-wafers are currently imported.
- Wafer production in the UK will find it difficult to compete with established multinational players without strategic support from UK government
- Based on 2020 production estimates, the number of inverters needed by UK-based manufacturers totaled ~170,000 units, primarily imported
- By 2035, ~2.3 million inverters will be needed for cars and vans manufactured in the UK per annum, with the vast majority of inverters being high-powered, high-voltage BEV inverters

Key recommendations



Building the UK's compound semiconductor supply chain

- The UK should focus on strengthening its SiC compound semiconductor supply chains for locally-produced high-performance and high-power vehicles
- Industrialising advanced die packaging can give the UK the edge in accessing high-value markets in discrete and power module devices
- Assembly and manufacturing inverters and converter systems hold 30-50% of the total power electronics value in the supply chain. UK Tier 1s can leverage strengths in differentiated products to increase local production for domestic and export markets
- Encouraging foreign direct investments in SiC and GaN technologies will allow the UK to consolidate and expand its significant footprint in vehicle manufacturing
- A lack of upstream wafer substrate manufacturing exposes the UK to supply shocks and downstream production constraints. More emphasis should be given to R&D projects that can create viable technologies for semiconductor material growth in the UK

Contact APC for further information

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