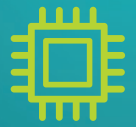


Power Electronics

Industry Challenges 2020-2035+

This document outlines the R&D challenges for Power Electronics across a diverse range of automotive applications. The industry challenges are intrinsically linked with the 2020 Automotive Council roadmaps and should be read in conjunction with the narrative report to provide a context and background to the rationale behind the challenges.

May 2021 | Version 1.0

ADVANCED PROPULSION CENTRE UK

An introduction to the industry challenge report

The industry challenges present the technical barriers to commercialising automotive powertrain technology in the short, medium and long term. Developed via a consensus process, this report highlights the most significant technology themes and specific R&D examples to springboard innovation. A list of recommendations on how this content can be taken forward by industry, academia and government is provided below:

Industry

- Review in-house R&D priorities against the industry consensus challenges provided in this report
- Provide guidance to companies wanting to transition into low-carbon automotive propulsion technologies
- Provide a sense-check for start-ups to help guide their technology focus

Academia

- Address the long-term scientific challenges that need to be overcome
- Align internal university research with the needs of the automotive industry
- Build a bridge with industry to execute and industrialise research

Government

- Understand the R&D challenges required to industrialise low-carbon propulsion technologies
- Identify R&D challenges that may require additional funding
- Understand the challenges facing different mobility sectors and adjust policy, strategy and funding support accordingly

A guide to reading the industry challenges

Technology Challenge

A Technology Challenge is a broad issue that OEMs and the supply chain face when commercialising technologies for the automotive industry.

Examples of research topics

Examples of research topics illustrate potential projects that could overcome the Technology Challenge. These are not intended to be an exhaustive list but a snapshot of areas captured in the industry engagement process.

Time horizon

The filled bar represents when research is likely to be completed. For example:

2020-2025 | 2025-2035 | 2030-2035+

Technology Challenge	Examples of research topics	Time Horizon	Cost effective, high volume	Power dense, high performance	High power, ultra-high efficiency
Efficient, rapid and accessible charging solutions	Efficient bi-directional charging to enable vehicle to grid and “battery as a service” business models.	2020-2025	●	●	○
	Designing inverter topologies so they can be used as efficient battery chargers that accept both AC and DC charging.		●	●	◒
	On-board charger / DC-DC converter topologies with higher switching frequencies (>100kHz) that achieve high load efficiency and reduce packaging space.		●	◒	●

Attributes and vehicle applications

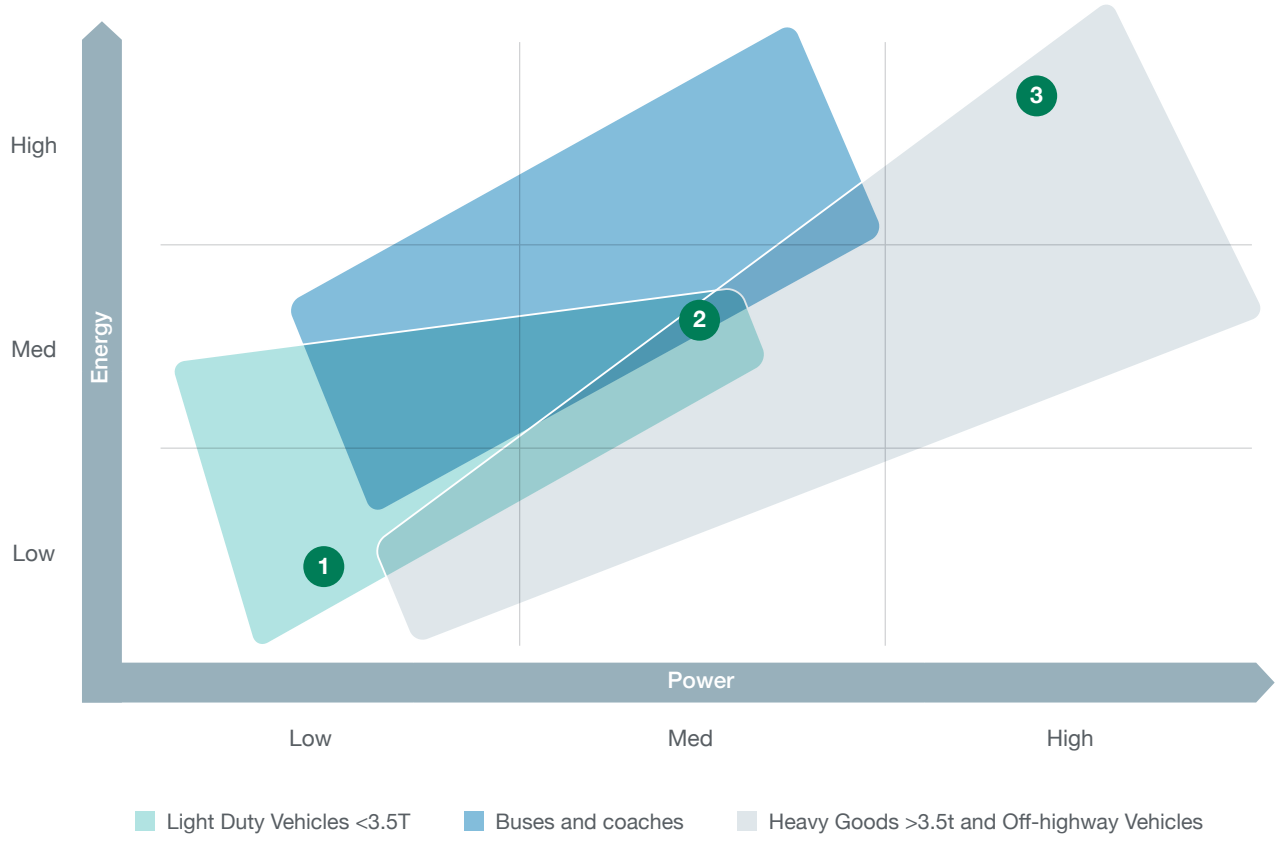
The columns refer to the different attributes or vehicle applications related to each technology theme. The dots represent how relevant overcoming this topic would be to each application area. The three attributes are explained in more depth in the following pages.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Attributes and vehicle applications

Energy-power spectrum across applications

Propulsion systems are tailored to specific power and energy demands, based on their use case and duty cycle. The graph below presents an outline of principle mass-market products.



The 2020 roadmap provides values for (1) Cost effective, high volume indicators.

Values for (2) Power dense, high performance and (3) High power, ultra-high efficiency applications will be developed with industry in due course.

1 Cost effective, high volume orientated:

Achieving economies of scale at a low cost is paramount for these products. Applications include high volume passenger car and delivery vans (majority 400V).

2 Power dense, high performance orientated

High power densities are required with cost a less decisive factor. Applications include performance passenger cars, buses and some medium duty vehicles (800V prevalent).

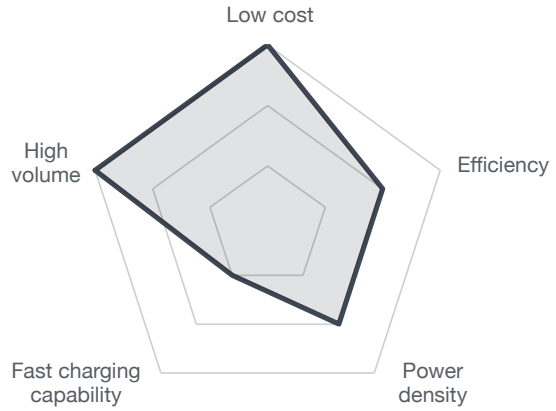
3 High power, ultra high efficiency orientated

High power densities and reliability are needed for these applications but efficiency is key to maximise energy use. Applications include 44 tonne trucks and large, off-highway vehicles (700-1,200V).

Attributes and vehicle applications – typical performance characteristics

The purpose of the radar plots is to demonstrate the attributes industry prioritise across this technology. Each attribute is ranked from 1-3 to show the varying emphasis per application. Note: the plots are not constructed using absolute values.

1



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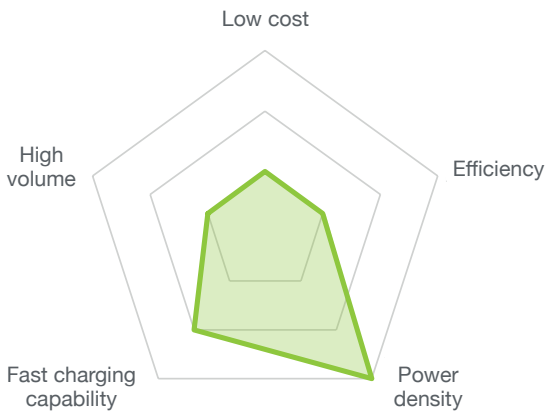

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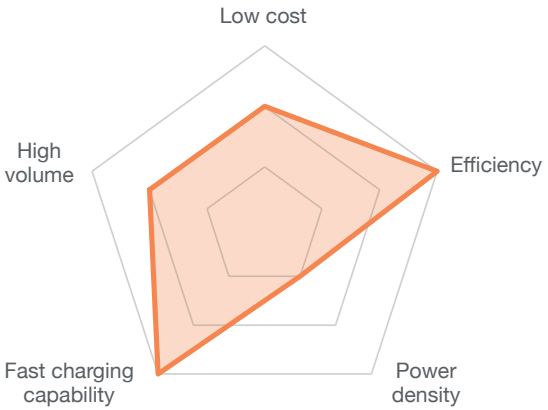

1 **Cost effective, high volume orientated:**

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Power Electronics

Technology challenges and research topics

Technology challenges for power electronics

The technology challenges listed here represent the highest priority R&D themes that industry and academia regard as critical for innovation.

Efficient, rapid and accessible charging solutions See challenge	Scaling up the wide-bandgap manufacturing See challenge
Improving inverter performance See challenge	Reduce the life cycle impact of power electronics, from production to end-of-life See challenge
Manufacturing methods to enable economies of scale or better performance See challenge	Leveraging advanced data to enhance modelling and simulation techniques See challenge
Enhancing low voltage systems for hybrids and new urban mobility vehicles See challenge	Accelerated, high-fidelity testing and validation capability See challenge
Advanced software and control techniques to optimise converter performance See challenge	

The above challenges are not listed in a prioritised order. They represent all the themes industry and academia regard as critical for innovation.

Power electronics – technology challenges and research topics (1/7)

The research topics listed below predominately focus on **Converter Integration** and **Converter Design** sections of the power electronics technology roadmap with linkages to the **Semiconductor Packaging, Passives, Sensors and PCBs** sections as well.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	Cost effective, high volume	Power dense, high performance	High power, ultra-high efficiency
Efficient, rapid and accessible charging solutions	Efficient bi-directional charging to enable vehicle to grid and “battery as a service” business models.	2020-2025	●	●	○
	Designing inverters that can accept efficient battery chargers with both AC and DC charging.		●	●	◒
	On-board charger / DC-DC converter topologies with higher switching frequencies (>100kHz) that achieve high load efficiency and reduce packaging space.		●	◒	●
	Enhanced thermal management for AC chargers (e.g., immersion cooling or advanced liquid cooling plates) to enable efficient fast charging (<50kW).		◒	●	◒
	Wide-bandgap enabled charger topologies with ultra-high switching frequencies (>1MHz) and optimised passives (e.g., smaller inductors) and active components.	2025-2035	◒	●	●
	Developing automotive quality passives, microcontrollers, sensors and gate drives to operate alongside semiconductors rated at 1200V and above.		○	◒	●
	Converters that deliver rapid (50-100kW) and ultra-rapid (100-500kW) wireless power transfer to enable opportunity charging.	2030-2035+	○	◒	●

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Power electronics – technology challenges and research topics (2/7)

The research topics listed below predominately focus on **Semiconductor Packaging and Passives, Sensors and PCBs** sections of the power electronics technology roadmap with linkages to the **Converter Design and Converter Integration** sections as well.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	Cost effective, high volume	Power dense, high performance	High power, ultra-high efficiency
Improving inverter performance	SiC power module packaging materials and assembly processes for >200C capability including tolerance of wide temperature range cycling and power cycling with rapid transients (e.g. sintered packaging).	2020-2025	●	●	●
	Advanced dielectric and magnetic materials to enable passives to work with SiC semiconductors (i.e., higher temperatures, high frequency, increased energy storage capability).	2025-2035	◒	●	●
	Enhanced thermal management for inverters (e.g., immersion cooling or advanced liquid cooling plates) to reduce stress during peak acceleration / regeneration events.		◒	●	●
	Printed circuit board (PCB) with enhanced current handling and temperature capability.		◒	●	●
	Package designs and assembly processes to realise ultra-high power-density converters with adaptable geometry/3D layout including fully-integrated solutions e.g. based on die-embedding.	2030-2035+	◒	●	◒
	New inverter integration concepts to achieve a step change in packaging space and weight (i.e., converter in package, die embedded in PCBs or dies with integrated sensing and gate drives).		◒	●	◒

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Power electronics – technology challenges and research topics (3/7)

The research topics listed below predominately focus on **Semiconductors and Semiconductor Packaging** sections of the power electronics technology roadmap with linkages to the **Converter Design and Converter Integration** sections as well.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	Cost effective, high volume	Power dense, high performance	High power, ultra-high efficiency
Manufacturing methods to enable economies of scale or better performance	Standardised wide-bandgap power modules across different power ranges to enable economies of scale.	2020-2025	●	◒	◒
	Reconfigurable converters – Inverter, DC-DC, on-board charger (OBC) combinations.		●	●	●
	Advanced manufacturing techniques (i.e., ALM) for converters / power modules to maximise performance (i.e., better heat sinks, optimised packaging).	2030-2035+	◒	●	◒
Enhancing low voltage systems for hybrids and new urban mobility vehicles	Continued improvement of Si device designs: Insulated-gate Bipolar Transistor (IGBT), Metal-Oxide Semiconductor Field Effect Transistors (MOSFETs), Power Integrated Circuits (ICs).	2020-2025	●	◒	◒
	Low cost gallium nitride (GaN) based converter designs for micro-mobility solutions.	2025-2035	●	○	○

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Power electronics – technology challenges and research topics (4/7)

The research topics listed below predominately focus on the **Converter Control** section of the power electronics technology roadmap with linkages to the **Semiconductor Packaging and Passives, Sensors and PCBs** sections as well.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	Cost effective, high volume	Power dense, high performance	High power, ultra-high efficiency
Advanced software and control techniques to optimise converter performance	Software and control for converters utilising high-frequency (>150kHz) and ultra high (>1MHz) switching and advanced topologies.	2020-2025	◒	●	●
	Improved sensor technology (e.g., low-cost current sensing with wide bandwidth; high temperature sensors; low loss sensors).		●	●	●
	Condition and load-adaptive control algorithms.	2025-2035	●	●	●
	In-service condition monitoring and health management for converters.		●	●	●
	Alternative approaches for sensing e.g., embedded and/or wireless sensors; sensorless methods.		◒	●	◒
	Integrated, direct optical control / drive power devices.	2030-2035+	◒	●	◒

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Power electronics – technology challenges and research topics (5/7)

The research topics listed below focus on the **Semiconductor** section of the power electronics technology roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	Cost effective, high volume	Power dense, high performance	High power, ultra-high efficiency
Scaling up the wide-bandgap manufacturing	Identifying commonality in Si and wide-bandgap device manufacturing and adjusting processes to create reduced cost manufacturing capability for wide-bandgap devices.	2020-2025	●	●	●
	High volume manufacturing techniques to scale up ingot and epitaxy processes for 8" SiC supply.		●	◒	◒
	Improve GaN-on-Si epitaxy processes to increase yield rates and enable GaN based semiconductors to be used for automotive.		●	●	●
	Investigate the feasibility and marginal benefit of transitioning to 12" silicon carbide (SiC) substrates.	2025-2035	●	◒	◒
	Large-area, low-cost GaN substrates and vertical GaN devices.		●	●	●
	Manufacturing methods that enable diamond and Gallium Oxide based power semiconductor materials to enter the automotive sector.	2030-2035+	◒	●	●

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Power electronics – technology challenges and research topics (6/7)

The research topics listed below focus on the **Life Cycle** section of the power electronics technology roadmap.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	Cost effective, high volume	Power dense, high performance	High power, ultra-high efficiency
Reduce the life cycle impact of power electronics, from production to end-of-life	Replace harmful chemicals (e.g. lead) from power electronics assembly processes.	2025-2035	●	●	●
	Develop recycling processes to recover high-value materials from power electronics devices in a cost effective, clean, safe and energy efficient manner.				
	Multi-physics reliability prediction tools on shared platform to facilitate industry collaboration.				
	Improve extraction and refining processes for reduced environmental impact and higher use of renewable energy. Optimise life cycle assessment (LCA) impact.				
	Improvements in life extension and end of life (EOL) technologies for the re-use of materials.	2030-2035+			
	In-built tracking and monitoring to follow power electronics components through the value chain.				
	Holistic, through-life, predictive design tools for enhanced sustainability.				

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Power electronics – technology challenges and research topics (7/7)

The research topics listed below are cross cutting challenges and apply to all areas of the **Power Electronics Technology Roadmap**.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	Cost effective, high volume	Power dense, high performance	High power, ultra-high efficiency
Leveraging advanced data to enhance modelling and simulation techniques	Improved reliability models for WBG devices.	2020-2025	●	●	●
	Leveraging in-situ data to enhance next generation product design.	2025-2035			
	Multi-domain virtual prototyping environment for converters (electrical, thermal, mechanical, reliability).				
	Develop a better understanding of duty cycles for urban mobility, e.g. CAV, last mile delivery vehicles, to define design requirement and support cost, weight, performance, noise vibration harshness (NVH) optimisation for future vehicles.				
Accelerated, high-fidelity testing and validation capability	Testing procedures for semiconductor device reliability and performance targeted at automotive power applications (especially for SiC and GaN).	2020-2025	●	●	●
	Improved accelerated test methods and non-destructive evaluation/validation for PE components and packaging.				

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Integrated Drives

Technology challenges and research topics

Technology challenges for integrated drives

Integrated motor-drive systems combine an electric motor and a drive unit at the very least, and most commonly a power electronics system. The technology challenges listed here represent the highest priority R&D themes that industry and academia regard as critical for innovation.

These research challenges are across multiple disciplines, including:

- Transmissions / driveline components
- Electric motors
- Power electronics
- Control systems
- Lightweight materials and design
- Packaging and integration
- Modular construction, assembly and disassembly

Lightweight, high performance integrated electrical drive units	See challenge
Managing noise, vibration and harshness	See challenge
Enhancing the efficiency of electric drive units	See challenge
Integrated thermal management for electrification propulsion systems	See challenge
Assembly and disassembly solutions for integrated drives, serviceability and fault avoidance	See challenge
Control systems capable of electrified system health management, correction and telemetry	See challenge

The above challenges are not listed in a prioritised order. They represent all the themes industry and academia regard as critical for innovation.

Integrated drives – technology challenges and research topics (1/3)

Cross-cutting research topics for **Integrated Drives** that relate to the **Electric Motors** and **Power Electronics** roadmaps.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	Cost effective, high volume	Power dense, high performance	High power, ultra-high efficiency
Lightweight, high performance integrated electrical drive units	Cost effective processes to produce thin walled, integrated housings for motors, power electronics and transmissions with embedded cooling channels.	2020-2025	●	●	●
	Improved multi-physics simulation to drive EDU design optimisation and component integration to deliver low cost, high performance and reliable driveline, e-motors and power electronics systems which leads to cooling, NVH, power density, efficiency, cost attributes etc being optimised.	2025-2035	●	●	●
	Enhanced converter architectures, designs and assembly processes to facilitate integration of power electronics inside the motor (e.g., on the endplate or stator iron).		◒	●	◒
	Multi-material casing and housing solutions to reduce weight and maintain structural integrity (i.e., metal matrix composites in rotors, composite housings).		◒	●	◒
Managing noise, vibration and harshness	Skewing motors and adjusting electronics to offset NVH without compromising efficiency or increasing costs significantly.	2020-2025	●	●	●
	NVH mitigation techniques for switched reluctance machines	2020-2035	◒	◒	●
	Materials and packaging techniques to protect electronics against vibration and mechanical stress from the motor and transmission	2025-2035	●	●	●
	Electrical isolation of power electronics and windings to reduce electrical interference and harmonics		●	●	●

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Integrated drives – technology challenges and research topics (2/3)

Cross-cutting research topics for **Integrated Drives** that relate to the **Electric Motors** and **Power Electronics** roadmaps.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	Cost effective, high volume	Power dense, high performance	High power, ultra-high efficiency
Enhancing the efficiency of electric drive units	High speed bearings and e-axles co-developed alongside electric motors and transmissions.	2020-2025	◒	●	●
	Advanced bearings materials to minimise losses (e.g., ceramic, air, magnetic).	2025-2035	◒	●	●
	Integration of wide-bandgap (WBG) power electronics into EDUs to improve system reliability and reduce cost as WBG is expected to make e-machines smaller, faster, and more efficient.		●	●	●
	E-machine topologies / use of materials for improved high-speed performance (i.e.. exploiting the WBG capability)		◒	●	●
Integrated thermal management for electrification propulsion systems	Techniques to thermally, mechanically and electrically isolate the motor from the power electronics to reduce semiconductor failure rates.	2020-2025	●	●	●
	Integration of thermal systems within the electric drivetrain, including; advances in phase change materials and heat management across the complete vehicle.	2025-2035	◒	●	◒
	Single cooling loops for motors, power electronics and battery packs.		●	●	●

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Integrated drives – technology challenges and research topics (3/3)

Cross-cutting research topics for **Integrated Drives** that relate to the **Electric Motors** and **Power Electronics** roadmaps.

Technology Challenge See all challenges	Examples of research topics	Time Horizon	Cost effective, high volume	Power dense, high performance	High power, ultra-high efficiency
Assembly and disassembly solutions for integrated drives, serviceability and fault avoidance	Modular inverters for segmented and integrated drives with multiple motor types.	2020-2025	●	○	◒
	Modular and flexible approach to EDU component integration, taking libraries of power electronics, e-motors, cooling systems, insulation and drivelines to develop a configuration-to-specification approach.	2025-2035	●	●	●
	Reversible joints and modular parts to ease serviceability and aid mechanical separation of key components for recycling.		●	●	●
	Package architecture and assembly processes to facilitate integration of power electronics inside the motor by co-manufacturing within the stator, rotor or housing.		◒	●	◒
	Additive layer manufacturing of high performance, functionally integrated drives that achieve a step change in power density	2030-2035+	○	●	◒
Control systems capable of electrified system health management, correction and telemetry	EDU level master control system to maximise transmission, electric motor and power electronics efficiency.	2020-2025	●	●	●
	Sophisticated torque vectoring and control systems to enable efficient hub motor solutions.	2025-2035	●	●	◒
	Integrated, predictive state of health systems enabling preventive maintenance		●	●	●

Notes: The examples of research topics are intended to provide topics emerging from industry workshops while developing the roadmaps. These are not a complete and exhaustive list and make no reference to priorities within R&D.

○ Not relevant ◒ Somewhat relevant ● Very relevant

Technology roadmaps

Roadmap 2020

Power Electronics

Technology Roadmap

Technology indicators for 2020-2035 can be seen on page 2

automotive council UK

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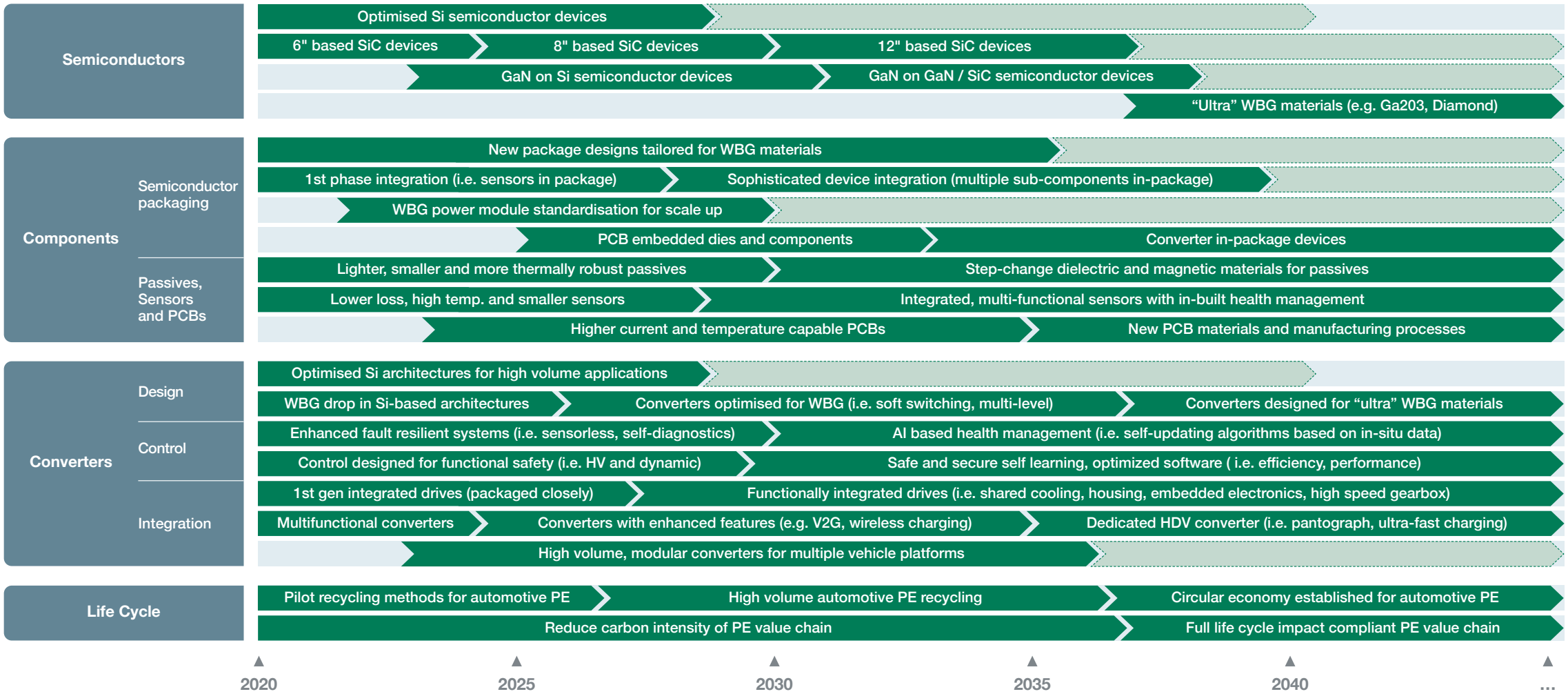
This roadmap represents a snapshot-in-time view of the global automotive industry propulsion technology forecast for mass market adoption. Specific application-tailored technologies will vary from region to region.

Dark bar: *Technology is in a mass market application. Significant innovation is expected in this time frame*

Transition: *Transitions do not mean a phase out from market but a change of R&D emphasis*

Dotted line bar: *Market Mature – technology has reached maturity. Likely to remain in mass market until it fades out where it's superseded*



Changing powertrain technology options across a range vehicle applications in the short, medium and long term

	Short Term (2020-2025)	Medium Term (2025-2035)	Long Term (2035+)
LDV 	Significant growth in vehicle electrification, to be supported by higher battery energy density, faster charging and lower costs.	Mature battery electric vehicle platforms achieving cost parity with conventional ICE and an increasing number of PEM fuel cell vehicles for long range journeys.	New battery chemistries, based on access to raw materials, LCA focus and low-energy production. Mature fuel cell applications with associated hydrogen infrastructure.
HGV and OH 	Focussed propulsion selection tailored to vehicle type, duty cycle and use case aiming for net-zero carbon emissions; optimised for TCO.	Growth in fuel cells for heavy goods vehicles together with maturing net-zero combustion engines and more efficient BEV platforms.	Emerging catenary transport for certain heavy goods vehicles with collaborative support and infrastructure from government.
Bus and Coach 	Operator specific actions to increase electrification and PEM fuel cells fleet migration.	Mature BEV and fuel cell platforms designed with second use, higher utilisation and increased economic return.	Tailored public transport solutions, new vehicle types and route management for customised journeys.
All vehicle types 	Continued innovation in thermal propulsion systems achieving decarbonisation through net-zero fuels		
	Increasing LCA focus across all activities to deliver environmentally sustainable manufacturing and products		

LDV: Light Duty Vehicle
ICE: Internal Combustion Engine
HGV: Heavy Goods Vehicle
LCA: Life Cycle Assessment
OH: Off-highway
TCO: Total cost of ownership
BEV: Battery Electric Vehicle
PEM: Proton Exchange Membrane

Appendix

Background to the industry challenge report

The opportunities for industry research (and academic)

This report aims to bring industrial research to market-readiness faster, with a fresh approach to R&D challenges, directly linked to the technology roadmaps published by the Advanced Propulsion Centre (APC) on behalf of the Automotive Council UK in 2020.

For electrification technologies (Electrical Energy Storage, Electric Machines and Power Electronics) the challenges are matched to cost and performance metrics related to electrified powertrains. The Thermal Propulsion System, Lightweight Vehicles and Powertrain Structures and Fuel Cell technology challenges are matched to the relevant product types; light duty, heavy goods and off-highway and bus and coach.

Separate challenges are provided for integrated electric drives within the Electric Machines and Power Electronics reports.

All technology solutions will need a balanced selection from the challenges, specific to each application, and require careful management of their trade-offs.

Industry and academia working together

The report provides a common platform for industry and academia to collaborate in a drive to overcome technology challenges and advance net-zero propulsion systems. Many topics involve fundamental research that can later be industrialised into market-ready products.

Links to the Automotive Council Roadmaps

The industry challenges have been developed to support the net-zero Automotive Council roadmaps published by the APC in November 2020.

The roadmaps and the Industry Challenges report can be used by organisations and institutions to prioritise their research objectives to meet their technology goals.

Developing the industry challenges

Data collection, engagements and validation

The data analysed and shaped into the Industry Challenges report came from several sources:

Roadmap survey responses

We received a total of 130 responses from different types of organisations such as; vehicle manufacturers, SMEs, technology developers, engineering consultancies and service providers, Tier 1, Tier 2 or below, academia, local/national government and research technology organisations. Whilst around 60% of the respondents were UK-based, contributions were also received from Germany, USA, Japan, China, Belgium, and Sweden.

APC competitions insights

Information has been gathered from the APC competitions where specific technical challenges have been highlighted.

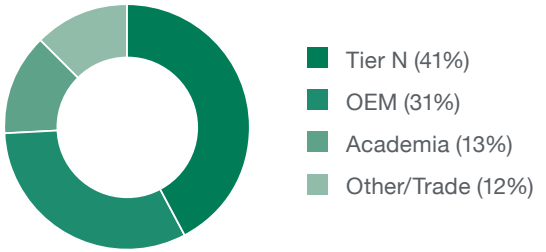
APC Spoke specialists

Data compiled from the survey responses and insights were validated through the APC Spokes. Where necessary more input was provided to fill in specific gaps. The 2017-2018 research challenges were reviewed to include the relevant ones into the new industry challenges list.

Industry workshops

Six events were held, one for each technology area: Electrical Machines, Power Electronics, Electrical Energy Storage, Thermal Propulsion Systems, Fuel Cells and Lightweighting. Industry experts provided feedback on technology challenges and details of research topics for each technology relevant to the product types (Light-duty Vehicles, Heavy Goods Vehicles and Off-Highway, Bus and Coach). A split by organisation type attending the industry challenges workshops is shown below.

Organisation types at the industry workshops



The APC approach to defining the industry challenges

In order to provide a well-informed industry and academia-led propulsion technology list of research challenges that informs and mobilise innovation in propulsion technologies, the APC approached the work as follows:

August 2020 — April 2021

Roadmap workshops and online survey

This was completed prior to the industry challenges workstream and fed into the technology roadmap development - a precursor to the industry challenges.

Our online survey collected data from a wide range of stakeholders by asking experts for specific challenges. These have been analysed according to the main technology themes.

Updated technology roadmaps

These were launched at LCV2020, followed by supporting narrative reports for each technology roadmap detailing context, background data and insights that fed into updated technology roadmaps.

APC Spokes challenges (Academia)

A fresh eyes review of the 2017-2018 research challenges by the APC Spokes provided an up-to-date list for the current report.

Further research topics were added from the roadmap workshops output.

Industry workshops and consensus (Industry)

Six industry workshops were run with roadmaps experts to develop, validate and further populate the examples of the research list.

A draft of the Industry Challenges was provided for comment in order to gather final consensus from the workshop groups.

Industry Challenges published

The report is ready and available to download from the APC website.

www.apcuk.co.uk/technology-roadmaps

Find all the technology roadmaps and industry challenges at

www.apcuk.co.uk/technology-roadmaps

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