Power Electronics Roadmap 2020

Narrative Report

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automotive council UK

ADVANCED PROPULSION CENTRE UK

Overview: Power Electronics

Power electronics play a crucial role in regulating voltage levels, controlling power flow to the electric traction motor and enabling a plug-in vehicle to charge from the electricity grid. With increasing electrification, power electronics will represent an ever-higher proportion of the value within each vehicle and a rapidly growing market opportunity.

The challenging requirements of the automotive sector are creating a demand for more power dense solutions, faster-switching semiconductors, improved reliability and higher temperature materials. These are needed to meet the differing demands for inverters which convert DC from the battery to AC to operate the motor, DC-DC converters which transform DC from the battery for use in different electronic systems around the vehicle, and for on-board chargers which convert AC from the grid to DC for charging the battery.

Semiconductors represent the highest cost item. Silicon, with its relatively low-cost and manufacturability will continue to play an important role in low voltage applications. For higher voltage applications, widespread adoption of SiC, a wide bandgap semiconductor is expected to continue, supported by advances in producing large, high-quality wafers at lower cost and innovative device designs. GaN, which is suited to applications where high switching frequencies are needed such as DC-DC converters is 2-3 years away, due to the challenges of manufacturing it cost effectively. Both of these materials will be essential to meeting the power density indicators for 2035, with further advances needed in cost effectiveness and device reliability for mass market adoption.

To realise the full potential of these materials, components around them need to be optimised to operate in high-temperature, high-frequency, and high-current environments. Innovation is needed in passive components, in PCBs, in sensor designs and in circuit architectures. Advanced control software and fault tolerant designs are required to deliver improved converter performance and long-term reliability. Standardisation and optimised architectures will benefit scale-up and bring down costs.

Finally, greater integration of all these elements is enabling smaller, lighter and ultimately cheaper designs, although this presents challenges for recyclability and environmental impact. These challenges must be addressed through new approaches including design for disassembly and efforts to create a truly circular economy for materials.

A full glossary is provided at the end of this report

Foreword and Acknowledgements

The APC would like to acknowledge the extensive support provided by industry and academia in development and publishing this roadmap.

We are grateful to the Automotive Council for entrusting us with the product and technology roadmaps refresh and their continued support.

This work has received significant support from BEIS (Department for Business, Energy and Industrial Strategy).

Neville Jackson
On behalf of the
UK Automotive Council

I am delighted to share the 2020 automotive propulsion technology roadmaps developed closely in collaboration with industry by the Advanced Propulsion Centre. These roadmaps define critical future targets and the most promising pathways to achieve a decarbonised and more sustainable future vehicle parc. They are an essential tool in developing a focused R&D agenda, particularly relevant for collaborative innovation.

The roadmaps build on the foundations of original UK Automotive Council roadmaps and developed further by the APC in 2017. These have been refreshed to reflect the urgency in transitioning to the UK target of net-zero emissions by 2050. The rate of change in propulsion technologies has accelerated rapidly in recent years; electrified vehicle adoption is on the rise, battery prices have come down faster than previously forecast, alternative zero-emission technologies like fuel cells are maturing at significant pace and clean fuels for combustion, including hydrogen, are emerging to replace existing fossil fuels.

However, there are significant challenges to overcome as the rate of change must increase further, requiring more intensive R&D and commercialisation that will deliver affordable products to market that are even more attractive for consumers. The 2020 technology roadmaps have been developed by industry expert surveys and panels, delivering a consensed view of future automotive propulsion targets, technologies and timescales.

Our aim with this report is to support the automotive sector with insights and a common technology focus to accelerate and deliver world-class solutions. The roadmaps are an important source of information in building collaborative R&D opportunities to address future mobility challenges, goods transport and off-highway vehicle research and development.

Prof Mark Johnson
Nottingham University,
APC Spoke for Power Electronics

Our 2020 power electronics roadmap reflects the ongoing global drive towards electrification, which has seen a dramatic acceleration in technology development accompanied by a more mature knowledge of application requirements and recognition of sustainability as a priority for the automotive industry.

I am very grateful to all those from the power electronics community who have engaged in the discussions, surveys and workshops.

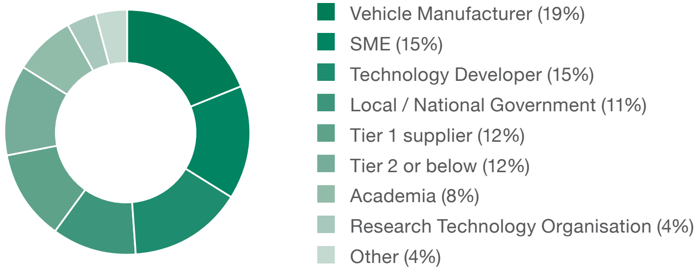
The main technology thrusts of semiconductors, components and converters remain from the 2017 roadmap. Enablers, in areas such as thermal management and manufacturing have been redistributed to provide more focus, whilst a new 'life cycle' theme emphasises the need for more sustainable development and an eventual move to a circular economy.

Finally, our understanding of commercial power electronics for vehicles and the greater maturity of the market has enabled us to give more precise performance indicators with a higher degree of confidence.

Insights from the 2020 Industry Experts Online Survey

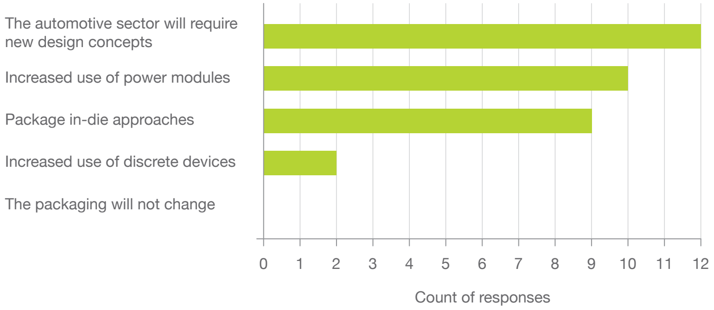
Trends towards high operating voltages of 1200V or more are evident in high power applications and significant changes are emerging in semiconductor packaging.

A spread of industry specialists responded to the online technology survey carried out in September 2020:



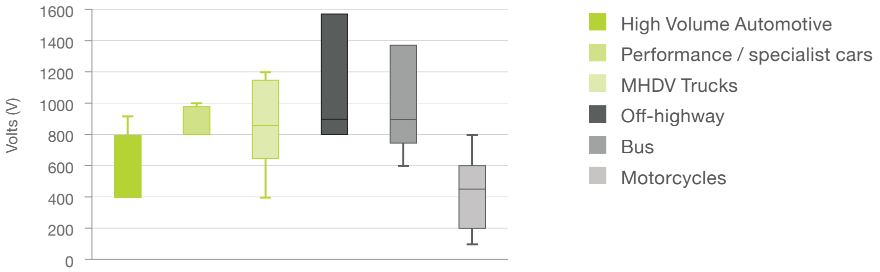
What is changing in semiconductor packaging?

Semiconductor packaging is changing rapidly to accommodate advancing WBG materials, increasing power demands, higher operating temperature and space constraints.



What are the typical maximum operating voltages across the automotive sector?

High operating voltages of 1200V and higher are appearing in heavy-duty and high performance vehicles.



What is the likely market share for SiC and GaN semiconductor materials?

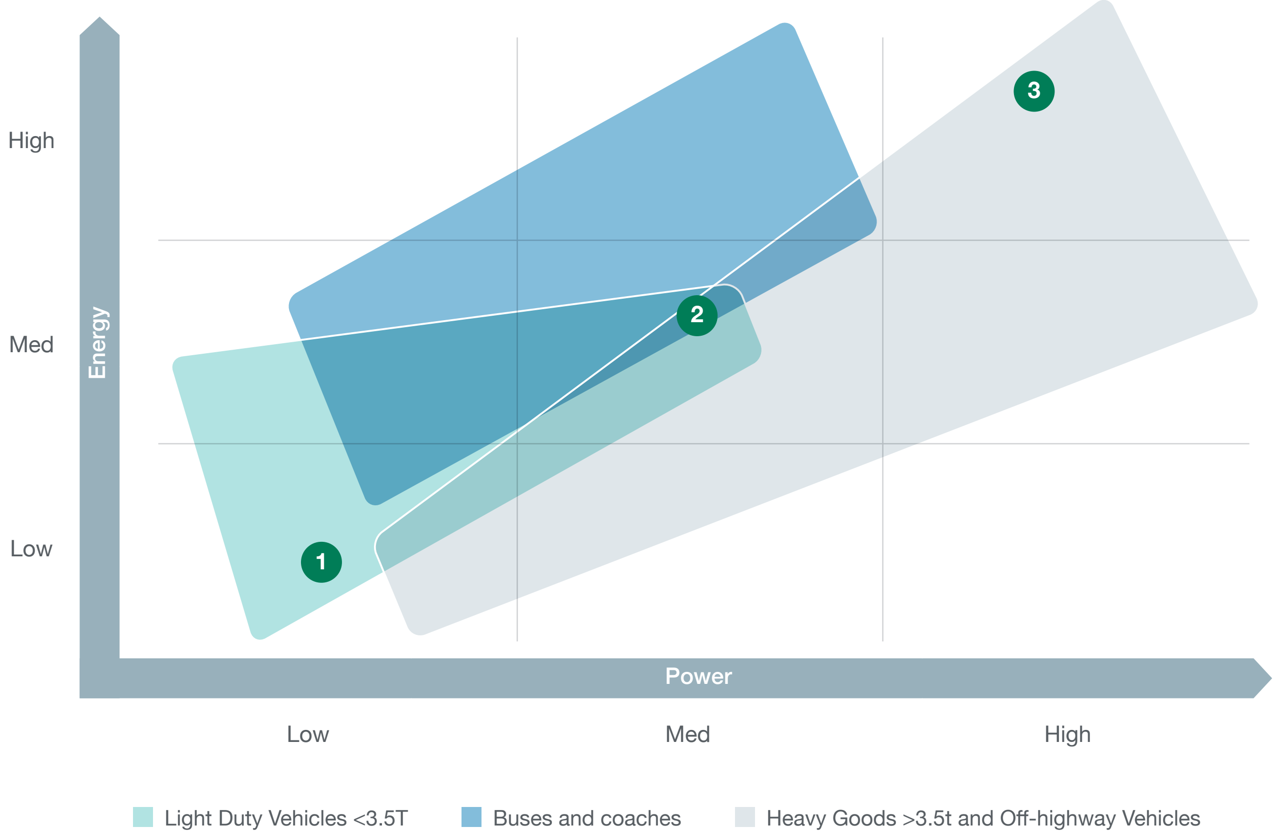
For higher voltage applications, widespread adoption of SiC is expected to increase as large, high-quality wafers are produced at lower cost. GaN, suited to applications where high switching frequencies are needed, follow a market increase a few years later.

SiC was expected to gain significant traction in the xEV market in the coming years with respondents claiming SiC could achieve 40-60% market penetration by 2035.

Perspectives on GaN were more cautious. Respondents believed mass market introduction would be at 2025 at the earliest and would achieve between 20-30% market share by 2035.

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 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).

Technology Indicators

Technology indicators for cost effective, high volume applications

Technology indicators that industry is likely to achieve in a mass-market competitive environment. All the cost and performance metrics are ambitious, but relate to the same technology.

		2020	2025	2035
Inverter Indicators	Cost ($/kW)	3.5	2	1.7
	Volumetric Power Density (kW/l)	17	25	35
	Gravimetric Power Density (kW/kg)	13	20	25
	WLTP Average Efficiency	93%	95%	97%

		2020	2025	2035
DC-DC Converter Indicators	Cost ($/kW)	50	40	35
	Volumetric Power Density (kW/l)	1.2	1.75	3
	Gravimetric Power Density (kW/kg)	0.75	1.2	2.5
	Peak Efficiency	95%	96%	97%

		2020	2025	2035
Single Phase, On-Board Charger Indicators	Cost ($/kW)	80	65	50
	Volumetric Power Density (kW/l)	0.5	1	1.5
	Gravimetric Power Density (kW/kg)	0.8	1.2	1.75
	Peak Efficiency	93%	95%	97%

The below table represents the indicator specifications used for the roadmap. These are for reference only, and do not reflect a target spec.

Inverter Indicators Spec	2020	2025	2035
Peak Power	100kW	100kW	100kW
Continuous Power	50kW	50kW	70kW
Input voltage (min)	250V	250V	500V
Input voltage (nominal)	400V	400V	800V
Output current (max)	450A rms	450A rms	225A rms
Coolant inlet temperature	65°C	65°C	65°C
Production volume	>100k	>100k	>200k

DC-DC Indicators Spec[1]	2020	2025	2035
Peak Power	3kW	3kW	4kW[2]
Continuous Power	3kW	3kW	4kW
Input / output voltage (nominal)	400V	400V	800V
Output / input voltage (nominal)	12V	12V	12V
Coolant inlet temperature	65°C	65°C	65°C
Production volume	>100k	>100k	>200k

OBC Indicators Spec[3]	2020	2025	2035
Peak Power	6.6kW	6.6kW	6.6kW
Continuous Power	6.6kW	6.6kW	6.6kW
Input / output voltage (nominal)	190/270V AC 45-60Hz	190/270V AC 45-60Hz	190/270V AC 45-60Hz
Output / input voltage (nominal)	400V	400V	750V
Coolant inlet temperature	65°C	65°C	65°C
Production volume	>100k	>100k	>200k

[1] Unidirectional power flow and galvanic isolation assumed
[2] Assumes increasing MaaS / infotainment functionality
[3] Bidirectional power flow and galvanic isolation assumed

Technology Indicators
In 2020, these replace targets in the roadmaps, providing a direction of travel and an approach to measuring best-in-class performance for this technology.

Technology indicators for cost effective, high volume applications

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Inverters
Inverters convert the DC provided by the on-board battery pack to AC that is suitable for operating the electric motor.

DC-DC Converters
DC-DC Converters transform fixed DC input voltage to a controllable DC output voltage for lower power ancillaries such as infotainment, lighting and ADAS features.

On-Board Chargers
On-Board Chargers convert alternating current from the electrical grid (mains AC) to DC suitable for recharging the battery pack.

2020 indicators reflect evidence given from industry on the best-in-class numbers for cost effective, high volume applications

Cost: Significant cost reductions are achievable through economies of scale. For the targets listed above, reducing cost is of paramount importance to support the uptake of electric vehicles.

Power Density: Power density is important to minimise weight and free up packaging space. Power density improvements are more limited in DC-DC converters and on-board chargers. This is because the converters are more complex, involving additional magnetic components and multiple conversion stages to realise galvanic isolation.

Efficiency: Inverters are typically being integrated with electric motors and transmissions. Efficiency targets are therefore represented as a WLTP average efficiency number to reflect that the inverter must work efficiently as part of a vehicle powertrain. Given the more limited operating points, peak efficiencies are suitable for DC-DC converters and on-board chargers.

Inverters
Inverters for cost-effective, high-volume applications will typically have lower peak and continuous power ratings. The nominal input voltage will be around 400V in the next 5–10 years, until 800V systems come down in cost. Cooling inlet temperature is based on what is currently an industry standard and harmonised with the electric motor.

DC-DC Converters
DC-DC Converters will typically remain at 3kW, which is enough to deal with the ancillary demands. In the long term, it is anticipated this could rise with enhanced infotainment, ADAS and CAV features. Hence 4 kW DC-DC converters are expected by 2035.

On-Board Chargers
On-board Chargers (OBCs). Chargers for cost-effective, high-volume applications are assumed to be moving to the industry standard of 6.6kW. Input voltage reflects the power delivery network for the UK, although in European markets three-phase OBCs could be introduced.

The below table represents the indicator specifications used for the roadmap. These are for reference only, and do not reflect a target spec.

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Roadmap 2020

Power Electronics

Technology Roadmap

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

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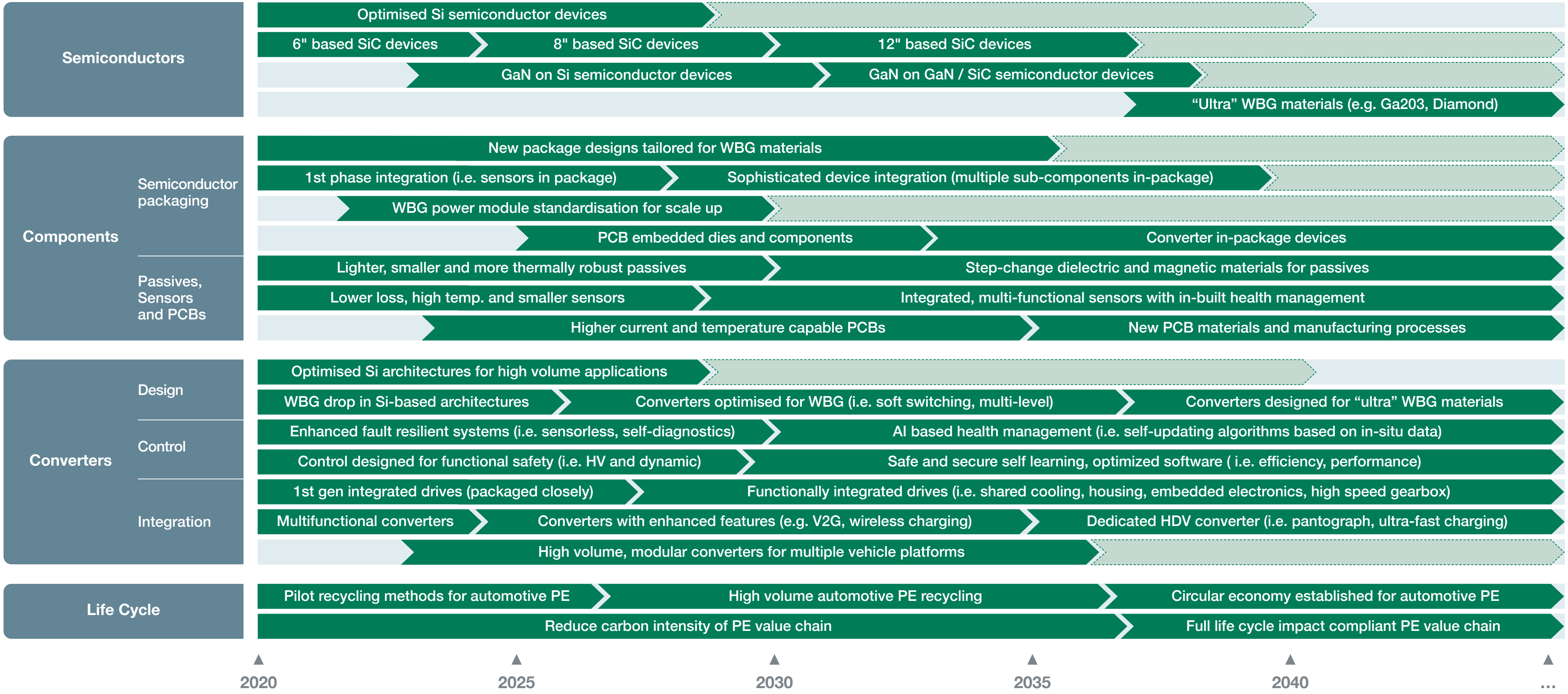
This roadmap represents a snapshot-in-time view of the global automotive industry propulsion technology forecast for mass market adoption. Specific application-tailored technologies will vary from region to region.

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*



Semiconductors
- Optimised Si semiconductor devices
- 6" based SiC devices → 8" based SiC devices → 12" based SiC devices
- GaN on Si semiconductor devices → GaN on GaN / SiC semiconductor devices
- "Ultra" WBG materials (e.g. Ga203, Diamond)

Components

Semiconductor packaging
- New package designs tailored for WBG materials
- 1st phase integration (i.e. sensors in package) → Sophisticated device integration (multiple sub-components in-package)
- WBG power module standardisation for scale up
- PCB embedded dies and components → Converter in-package devices

Passives, Sensors and PCBs
- Lighter, smaller and more thermally robust passives → Step-change dielectric and magnetic materials for passives
- Lower loss, high temp. and smaller sensors → Integrated, multi-functional sensors with in-built health management
- Higher current and temperature capable PCBs → New PCB materials and manufacturing processes

Converters

Design
- Optimised Si architectures for high volume applications
- WBG drop in Si-based architectures → Converters optimised for WBG (i.e. soft switching, multi-level) → Converters designed for "ultra" WBG materials

Control
- Enhanced fault resilient systems (i.e. sensorless, self-diagnostics) → AI based health management (i.e. self-updating algorithms based on in-situ data)
- Control designed for functional safety (i.e. HV and dynamic) → Safe and secure self learning, optimized software (i.e. efficiency, performance)

Integration
- 1st gen integrated drives (packaged closely) → Functionally integrated drives (i.e. shared cooling, housing, embedded electronics, high speed gearbox)
- Multifunctional converters → Converters with enhanced features (e.g. V2G, wireless charging) → Dedicated HDV converter (i.e. pantograph, ultra-fast charging)
- High volume, modular converters for multiple vehicle platforms

Life Cycle
- Pilot recycling methods for automotive PE → High volume automotive PE recycling → Circular economy established for automotive PE
- Reduce carbon intensity of PE value chain → Full life cycle impact compliant PE value chain

Primary Technology Themes

Semiconductors

Semiconductors represent the highest-cost item in automotive power electronics. They affect the innovation trajectories of all other areas of the power electronics roadmap. Continuous improvement of Si-based semiconductors and the maturity of wide bandgap (WBG) semiconductors are communicated in this section.

Components

- Semiconductor packaging
- Passives, Sensors and PCBs

Components:

New **semiconductor packaging** concepts will emerge to optimise the performance of wide bandgap semiconductors. Two parallel trends are presented: specialised packaging for tailored performance and power module standardisation for high volumes.

Passives, Sensors and PCBs are components with promising innovation potential in the automotive sector. New materials and manufacturing routes need to be developed to deliver high operating temperatures and lower losses at higher voltages.

Converters

- Design
- Control
- Integration

Converters:

Converter designs that harness the increased performance of wide bandgaps are needed, especially for more high-performance applications. Incremental improvement in existing architectures to reduce costs in high-volume applications are also required.

Control software will mature to enhance reliability, performance and safety. As the vehicle and powertrain becomes increasingly integrated and connected, enhanced control strategies will be developed.

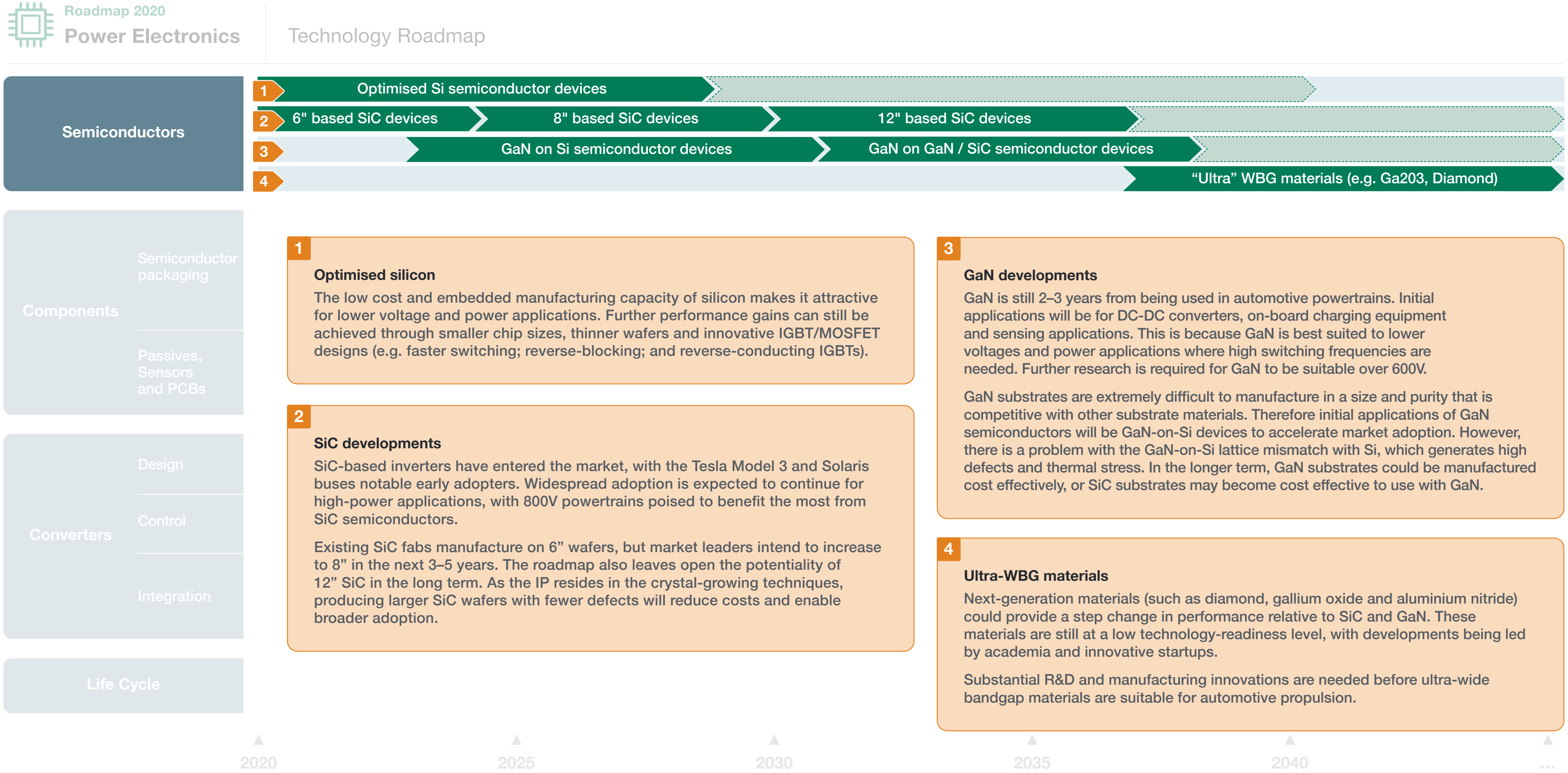
Integrating power electronics more effectively reduces cost and saves space. Potential innovation routes include integrating electronics with motors and transmissions, as well as developing multifunctional or modular converter architectures.

Life Cycle

Life cycle includes the carbon intensity, environmental impact, resource consumption and recyclability of the power electronics value chain. Only by improving all of these elements can electric vehicles be a truly sustainable solution.

Semiconductors

The adoption of wide bandgap materials, which deliver a step change in performance compared to silicon, will gather pace as manufacturing quality improves.



1

Optimised silicon

The low cost and embedded manufacturing capacity of silicon makes it attractive for lower voltage and power applications. Further performance gains can still be achieved through smaller chip sizes, thinner wafers and innovative IGBT/MOSFET designs (e.g. faster switching; reverse-blocking; and reverse-conducting IGBTs).

2

SiC developments

SiC-based inverters have entered the market, with the Tesla Model 3 and Solaris buses notable early adopters. Widespread adoption is expected to continue for high-power applications, with 800V powertrains poised to benefit the most from SiC semiconductors.

Existing SiC fabs manufacture on 6" wafers, but market leaders intend to increase to 8" in the next 3–5 years. The roadmap also leaves open the potentiality of 12" SiC in the long term. As the IP resides in the crystal-growing techniques, producing larger SiC wafers with fewer defects will reduce costs and enable broader adoption.

3

GaN developments

GaN is still 2–3 years from being used in automotive powertrains. Initial applications will be for DC-DC converters, on-board charging equipment and sensing applications. This is because GaN is best suited to lower voltages and power applications where high switching frequencies are needed. Further research is required for GaN to be suitable over 600V.

GaN substrates are extremely difficult to manufacture in a size and purity that is competitive with other substrate materials. Therefore initial applications of GaN semiconductors will be GaN-on-Si devices to accelerate market adoption. However, there is a problem with the GaN-on-Si lattice mismatch with Si, which generates high defects and thermal stress. In the longer term, GaN substrates could be manufactured cost effectively, or SiC substrates may become cost effective to use with GaN.

4

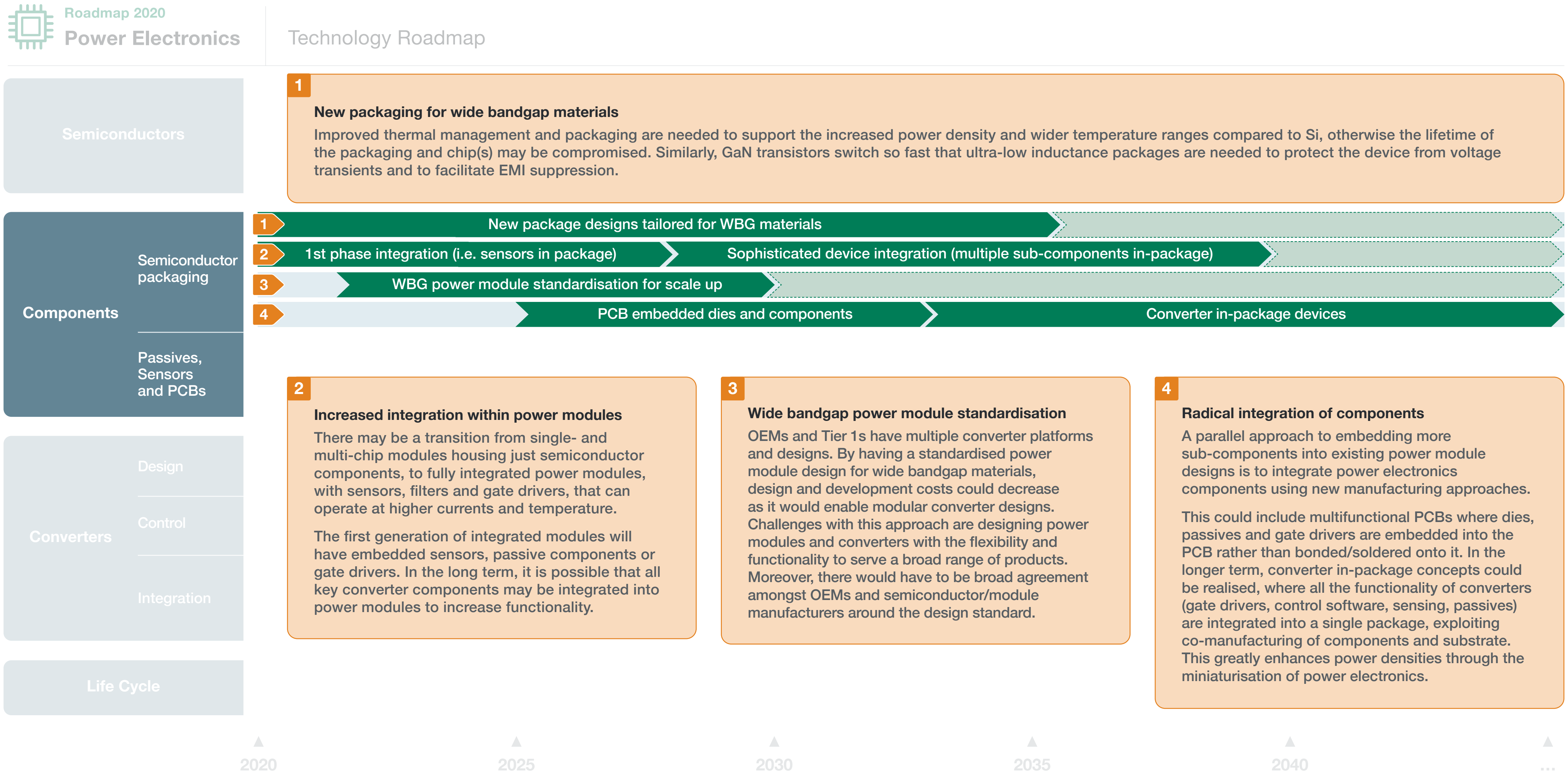
Ultra-WBG materials

Next-generation materials (such as diamond, gallium oxide and aluminium nitride) could provide a step change in performance relative to SiC and GaN. These materials are still at a low technology-readiness level, with developments being led by academia and innovative startups.

Substantial R&D and manufacturing innovations are needed before ultra-wide bandgap materials are suitable for automotive propulsion.

Components

Higher performing packaging for wide bandgap semiconductors can be achieved through new designs and greater integration of components, while greater standardisation of power modules supports cost-effective scale-up.



1

New packaging for wide bandgap materials

Improved thermal management and packaging are needed to support the increased power density and wider temperature ranges compared to Si, otherwise the lifetime of the packaging and chip(s) may be compromised. Similarly, GaN transistors switch so fast that ultra-low inductance packages are needed to protect the device from voltage transients and to facilitate EMI suppression.

2

Increased integration within power modules

There may be a transition from single- and multi-chip modules housing just semiconductor components, to fully integrated power modules, with sensors, filters and gate drivers, that can operate at higher currents and temperature.

The first generation of integrated modules will have embedded sensors, passive components or gate drivers. In the long term, it is possible that all key converter components may be integrated into power modules to increase functionality.

3

Wide bandgap power module standardisation

OEMs and Tier 1s have multiple converter platforms and designs. By having a standardised power module design for wide bandgap materials, design and development costs could decrease as it would enable modular converter designs. Challenges with this approach are designing power modules and converters with the flexibility and functionality to serve a broad range of products. Moreover, there would have to be broad agreement amongst OEMs and semiconductor/module manufacturers around the design standard.

4

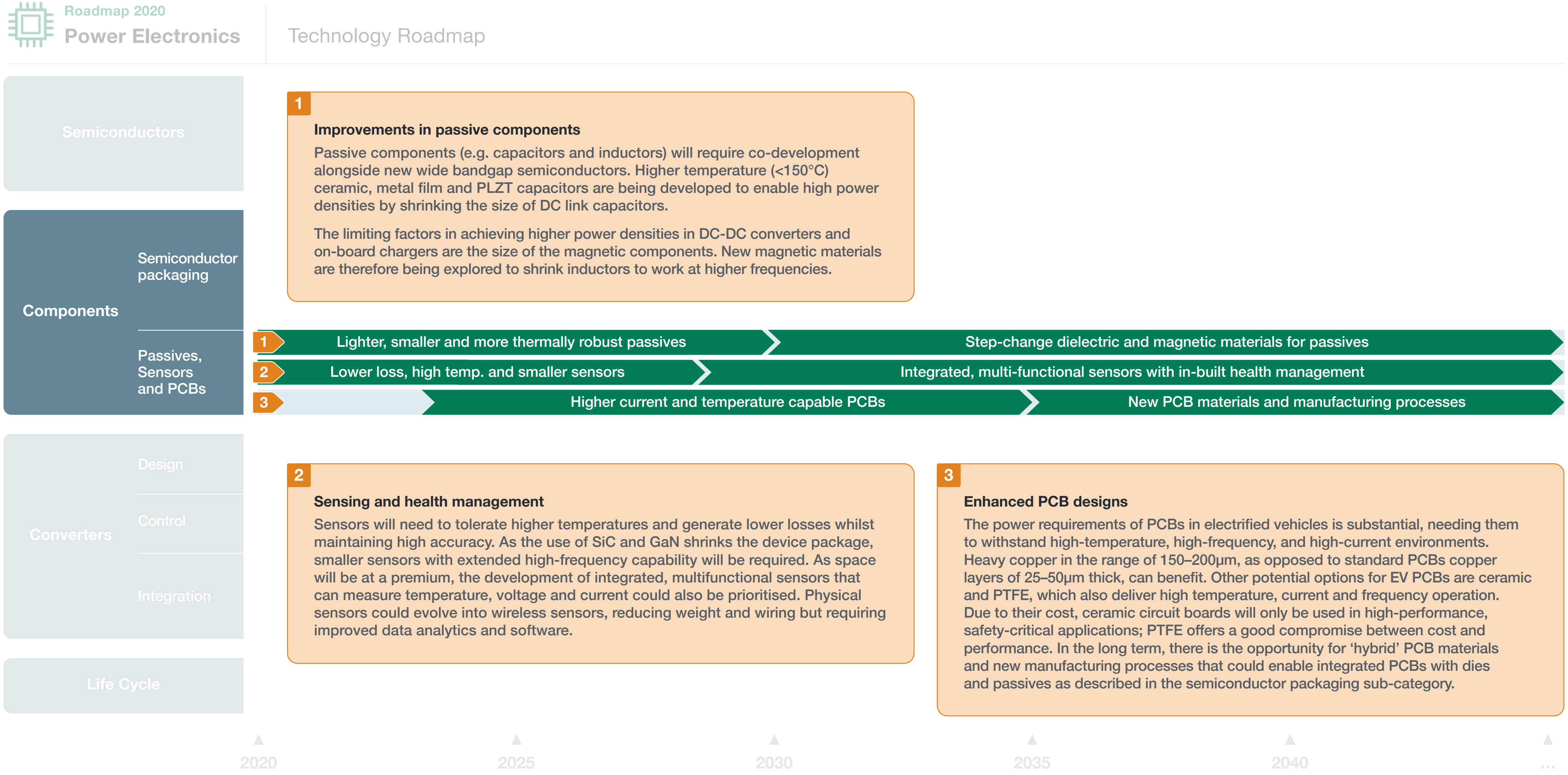
Radical integration of components

A parallel approach to embedding more sub-components into existing power module designs is to integrate power electronics components using new manufacturing approaches.

This could include multifunctional PCBs where dies, passives and gate drivers are embedded into the PCB rather than bonded/soldered onto it. In the longer term, converter in-package concepts could be realised, where all the functionality of converters (gate drivers, control software, sensing, passives) are integrated into a single package, exploiting co-manufacturing of components and substrate. This greatly enhances power densities through the miniaturisation of power electronics.

Components

New, more compact passive components, magnetic materials and PCB materials are needed to withstand high-temperature, high-frequency, and high-current environments.



Roadmap 2020
Power Electronics

Technology Roadmap

Semiconductors

Components
- Semiconductor packaging
- Passives, Sensors and PCBs

Converters
- Design
- Control
- Integration

Life Cycle

1

Improvements in passive components

Passive components (e.g. capacitors and inductors) will require co-development alongside new wide bandgap semiconductors. Higher temperature (<150°C) ceramic, metal film and PLZT capacitors are being developed to enable high power densities by shrinking the size of DC link capacitors.

The limiting factors in achieving higher power densities in DC-DC converters and on-board chargers are the size of the magnetic components. New magnetic materials are therefore being explored to shrink inductors to work at higher frequencies.

1 Lighter, smaller and more thermally robust passives → Step-change dielectric and magnetic materials for passives

2 Lower loss, high temp. and smaller sensors → Integrated, multi-functional sensors with in-built health management

3 Higher current and temperature capable PCBs → New PCB materials and manufacturing processes

2

Sensing and health management

Sensors will need to tolerate higher temperatures and generate lower losses whilst maintaining high accuracy. As the use of SiC and GaN shrinks the device package, smaller sensors with extended high-frequency capability will be required. As space will be at a premium, the development of integrated, multifunctional sensors that can measure temperature, voltage and current could also be prioritised. Physical sensors could evolve into wireless sensors, reducing weight and wiring but requiring improved data analytics and software.

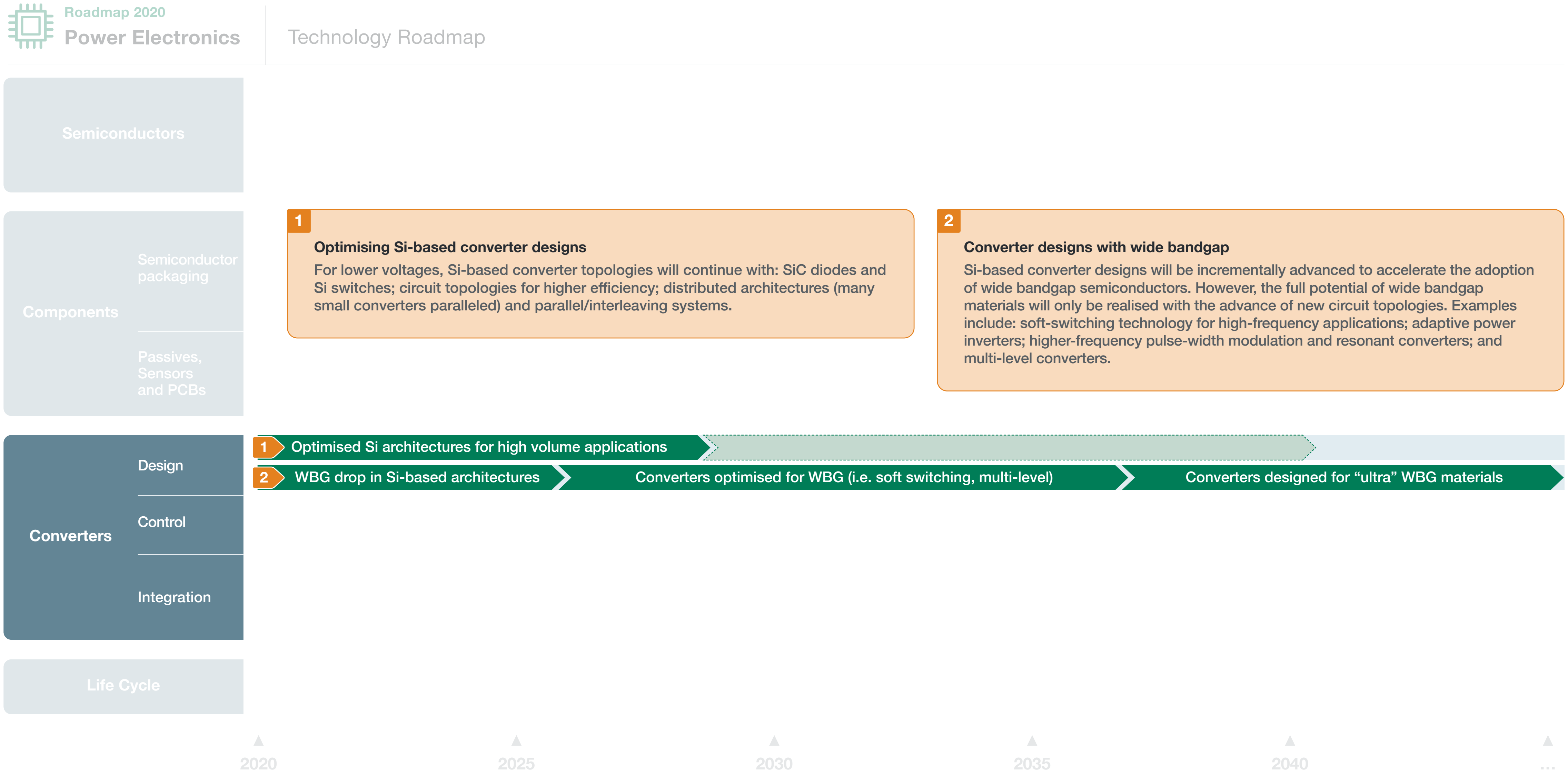
3

Enhanced PCB designs

The power requirements of PCBs in electrified vehicles is substantial, needing them to withstand high-temperature, high-frequency, and high-current environments. Heavy copper in the range of 150–200µm, as opposed to standard PCBs copper layers of 25–50µm thick, can benefit. Other potential options for EV PCBs are ceramic and PTFE, which also deliver high temperature, current and frequency operation. Due to their cost, ceramic circuit boards will only be used in high-performance, safety-critical applications; PTFE offers a good compromise between cost and performance. In the long term, there is the opportunity for 'hybrid' PCB materials and new manufacturing processes that could enable integrated PCBs with dies and passives as described in the semiconductor packaging sub-category.

Converters

Advanced converter architectures, beyond Si-based designs are needed to fully benefit from wide bandgap semiconductors.



Roadmap 2020
Power Electronics

Technology Roadmap

Semiconductors

Components
- Semiconductor packaging
- Passives, Sensors and PCBs

1

Optimising Si-based converter designs

For lower voltages, Si-based converter topologies will continue with: SiC diodes and Si switches; circuit topologies for higher efficiency; distributed architectures (many small converters paralleled) and parallel/interleaving systems.

2

Converter designs with wide bandgap

Si-based converter designs will be incrementally advanced to accelerate the adoption of wide bandgap semiconductors. However, the full potential of wide bandgap materials will only be realised with the advance of new circuit topologies. Examples include: soft-switching technology for high-frequency applications; adaptive power inverters; higher-frequency pulse-width modulation and resonant converters; and multi-level converters.

Converters
- Design
- Control
- Integration

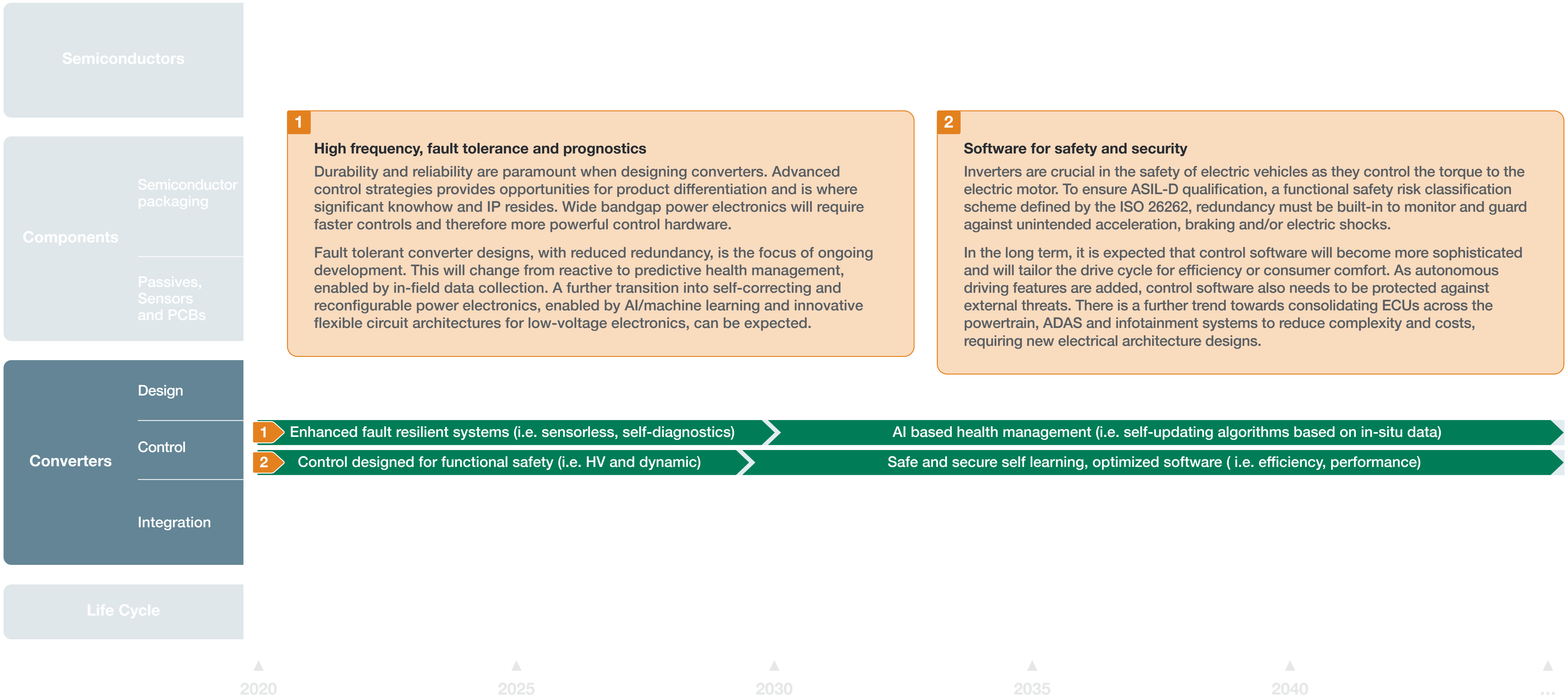
1 Optimised Si architectures for high volume applications

2 WBG drop in Si-based architectures → Converters optimised for WBG (i.e. soft switching, multi-level) → Converters designed for “ultra” WBG materials

Life Cycle

Converters

Advanced control software and fault tolerant design together with self-diagnosis and self-correction can deliver greater durability, reliability and safety.



1

High frequency, fault tolerance and prognostics

Durability and reliability are paramount when designing converters. Advanced control strategies provides opportunities for product differentiation and is where significant knowhow and IP resides. Wide bandgap power electronics will require faster controls and therefore more powerful control hardware.

Fault tolerant converter designs, with reduced redundancy, is the focus of ongoing development. This will change from reactive to predictive health management, enabled by in-field data collection. A further transition into self-correcting and reconfigurable power electronics, enabled by AI/machine learning and innovative flexible circuit architectures for low-voltage electronics, can be expected.

2

Software for safety and security

Inverters are crucial in the safety of electric vehicles as they control the torque to the electric motor. To ensure ASIL-D qualification, a functional safety risk classification scheme defined by the ISO 26262, redundancy must be built-in to monitor and guard against unintended acceleration, braking and/or electric shocks.

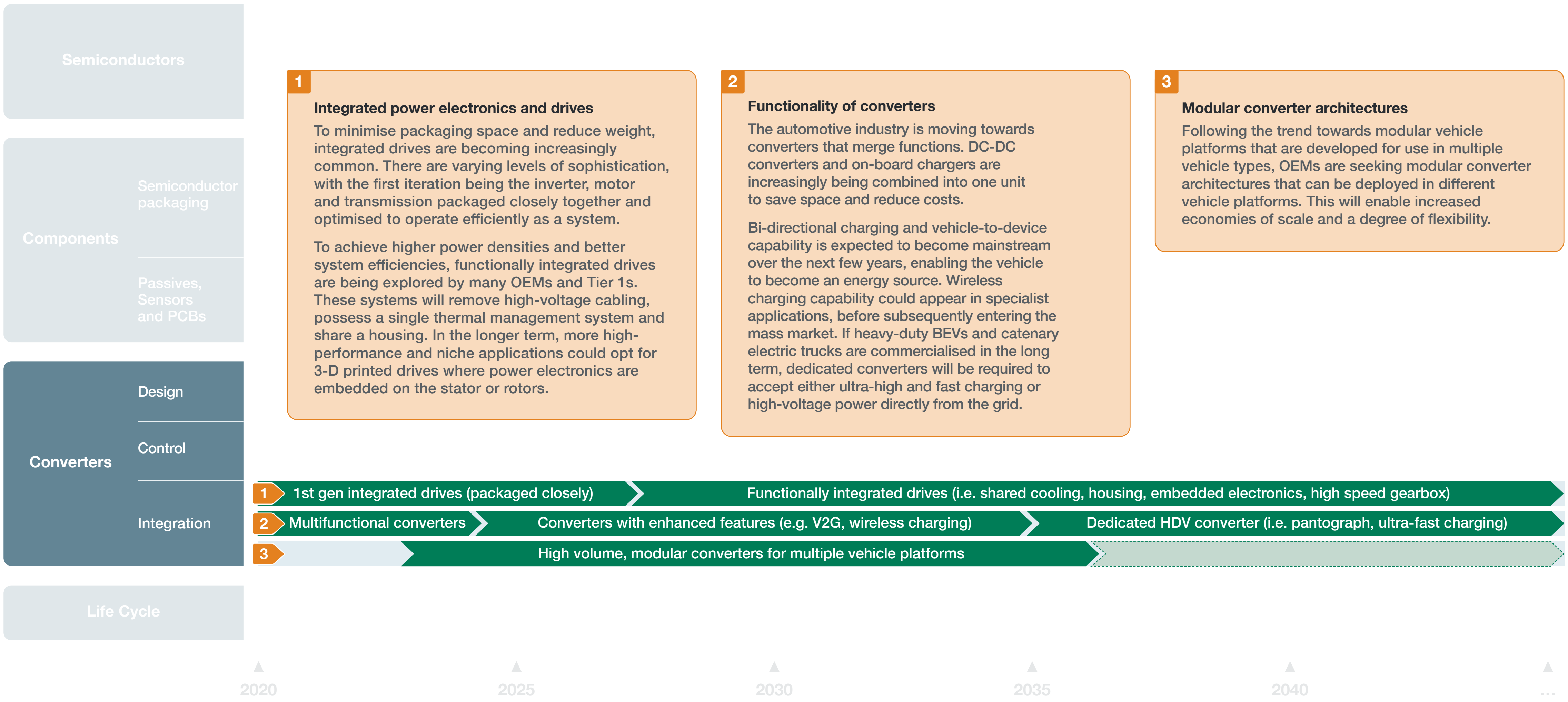
In the long term, it is expected that control software will become more sophisticated and will tailor the drive cycle for efficiency or consumer comfort. As autonomous driving features are added, control software also needs to be protected against external threats. There is a further trend towards consolidating ECUs across the powertrain, ADAS and infotainment systems to reduce complexity and costs, requiring new electrical architecture designs.

Converters

Greater integration of functions within drives, coupled with modular architectures can deliver smaller, lighter and cheaper designs.

Roadmap 2020
Power Electronics

Technology Roadmap



Semiconductors

Components

Semiconductor packaging

Passives, Sensors and PCBs

Converters

Design

Control

Integration

Life Cycle

1

Integrated power electronics and drives

To minimise packaging space and reduce weight, integrated drives are becoming increasingly common. There are varying levels of sophistication, with the first iteration being the inverter, motor and transmission packaged closely together and optimised to operate efficiently as a system.

To achieve higher power densities and better system efficiencies, functionally integrated drives are being explored by many OEMs and Tier 1s. These systems will remove high-voltage cabling, possess a single thermal management system and share a housing. In the longer term, more high-performance and niche applications could opt for 3-D printed drives where power electronics are embedded on the stator or rotors.

2

Functionality of converters

The automotive industry is moving towards converters that merge functions. DC-DC converters and on-board chargers are increasingly being combined into one unit to save space and reduce costs.

Bi-directional charging and vehicle-to-device capability is expected to become mainstream over the next few years, enabling the vehicle to become an energy source. Wireless charging capability could appear in specialist applications, before subsequently entering the mass market. If heavy-duty BEVs and catenary electric trucks are commercialised in the long term, dedicated converters will be required to accept either ultra-high and fast charging or high-voltage power directly from the grid.

3

Modular converter architectures

Following the trend towards modular vehicle platforms that are developed for use in multiple vehicle types, OEMs are seeking modular converter architectures that can be deployed in different vehicle platforms. This will enable increased economies of scale and a degree of flexibility.

1 1st gen integrated drives (packaged closely) → Functionally integrated drives (i.e. shared cooling, housing, embedded electronics, high speed gearbox)

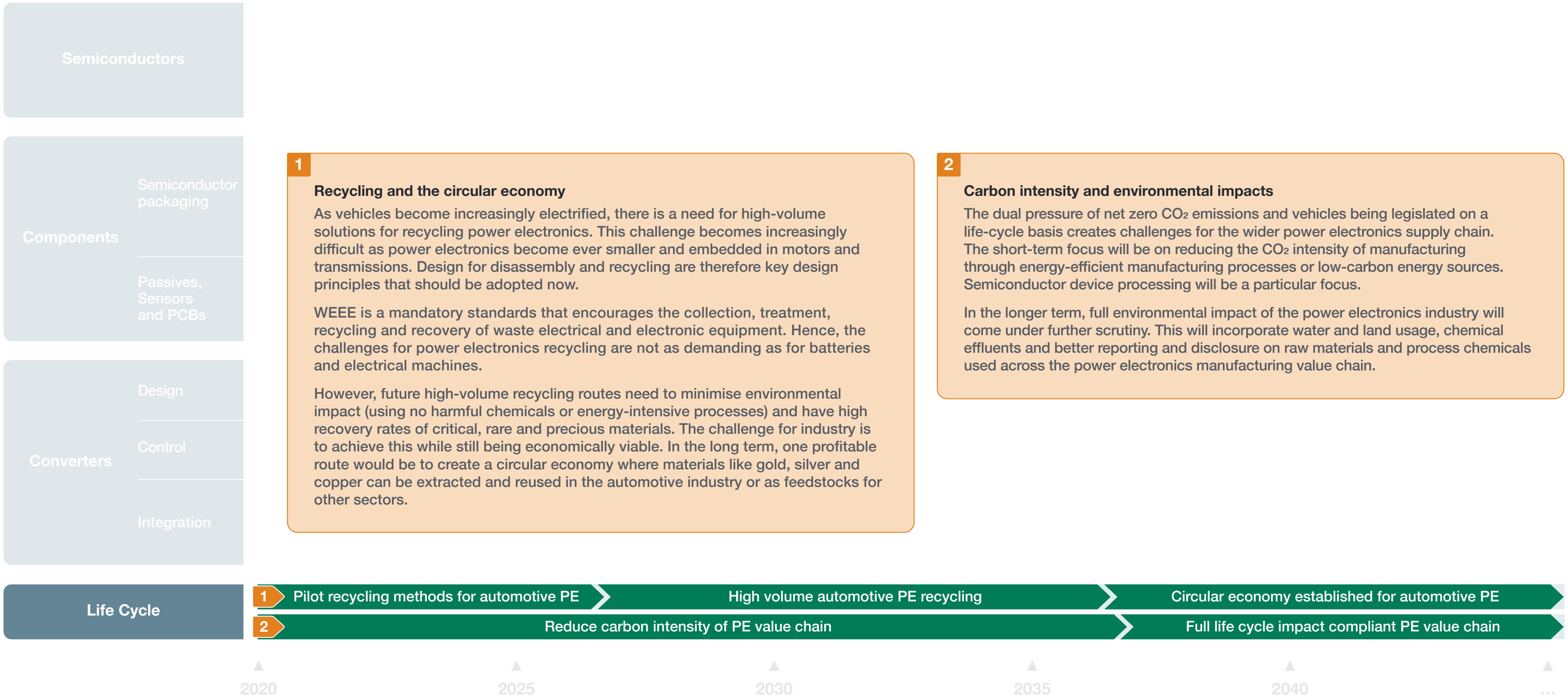
2 Multifunctional converters → Converters with enhanced features (e.g. V2G, wireless charging) → Dedicated HDV converter (i.e. pantograph, ultra-fast charging)

3 High volume, modular converters for multiple vehicle platforms

Life Cycle

New approaches, such as design for disassembly and creating a circular economy for precious materials, will be needed to address the long-term environmental responsibilities of the power electronics industry.

Roadmap 2020
Power Electronics Technology Roadmap



1

Recycling and the circular economy

As vehicles become increasingly electrified, there is a need for high-volume solutions for recycling power electronics. This challenge becomes increasingly difficult as power electronics become ever smaller and embedded in motors and transmissions. Design for disassembly and recycling are therefore key design principles that should be adopted now.

WEEE is a mandatory standards that encourages the collection, treatment, recycling and recovery of waste electrical and electronic equipment. Hence, the challenges for power electronics recycling are not as demanding as for batteries and electrical machines.

However, future high-volume recycling routes need to minimise environmental impact (using no harmful chemicals or energy-intensive processes) and have high recovery rates of critical, rare and precious materials. The challenge for industry is to achieve this while still being economically viable. In the long term, one profitable route would be to create a circular economy where materials like gold, silver and copper can be extracted and reused in the automotive industry or as feedstocks for other sectors.

2

Carbon intensity and environmental impacts

The dual pressure of net zero CO_2 emissions and vehicles being legislated on a life-cycle basis creates challenges for the wider power electronics supply chain. The short-term focus will be on reducing the CO_2 intensity of manufacturing through energy-efficient manufacturing processes or low-carbon energy sources. Semiconductor device processing will be a particular focus.

In the longer term, full environmental impact of the power electronics industry will come under further scrutiny. This will incorporate water and land usage, chemical effluents and better reporting and disclosure on raw materials and process chemicals used across the power electronics manufacturing value chain.

Glossary

Abbreviation	Explanation
ADAS	Advanced driver-assistance systems use sensors, cameras and advanced computing to support the driver.
ASIL-D	Automotive Safety Integrity Level is a risk classification scheme defined by ISO 26262. Level D defines the highest integrity requirements on the product.
Bandgap	The energy needed to excite electrons from a material's valence band into the conduction band. Wide bandgap (WBG) materials with larger bandgaps such as SiC and GaN can withstand higher voltages and temperatures than silicon.
CAVs	Connected and autonomous vehicles is an umbrella term to capture the varying levels of autonomy and technologies relating to self-driving vehicles.
GaN	Gallium nitride is a wide bandgap semiconductor material and a potential replacement for silicon.
IGBT	An insulated-gate bipolar transistor is an efficient and fast power electronic switch.
MOSFET	A metal-oxide semiconductor field-effect transistor is a device which can amplify and switch electronic signals.
PCB	A printed circuit board provides support and electrical connection to electronic components. Virtually all electronic devices use one.
PLZT	A dielectric-layer material formed of a lead-lanthanum-zirconium-titanate
PTFE	Polytetrafluoroethylene is a synthetic fluoropolymer consisting of carbon and fluorine atoms which is hydrophobic, and has a very low coefficient of friction. Teflon is perhaps the best known brand name.
SiC	Silicon carbide is a wide bandgap semiconductor material and a potential replacement for silicon.
WEEE	The European Waste Electrical and Electronic Equipment Directive applies to a wide range of electronic and electrical products.
WLTP	The world harmonised light-duty vehicles test procedure is a global standard for establishing the fuel consumption, pollutant levels and CO_2 emissions of IC and hybrid cars and the range of fully electric vehicles.

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This is an industry consensus roadmap facilitated by the APC

Summary of engagements during the 2020 roadmap refresh

Spread of companies that participated in the refresh

109 industry organisations participated in Workshops and Interviews

38 additional industry organisations participated via the Online Survey

Total engagements 147 Industry Organisations

A global view with international participation

Austria
Belgium
England
Germany
Netherlands
Scotland
Singapore
Sweden
Switzerland
United States
Wales
Japan