Power Electronics and The Electric Revolution
Opportunities and Challenges

C Mark Johnson

POWER ELECTRONICS UK
Underpinning Research

University of Nottingham
UK | CHINA | MALAYSIA

Overview

- Evolution of UK Power Electronics Landscape
- The UK Industrial Strategy: Driving the Electric Revolution
- Sector Roadmaps: Growth Areas and Opportunities
- Overview of Technology Challenges
- High-frequency power conversion

UK Power Electronics Community

INDUSTRIAL STRATEGY

EPSRC
Pioneering research and skills

UK Research and Innovation

Innovate UK

KTN
the Knowledge Transfer Network

AEROSPACE TECHNOLOGY INSTITUTE

ADVANCED PROPULSION CENTRE UK

CATAPULT
Compound Semiconductor Applications

AGP
Aerospace Growth Partnership

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Automotive Challenge

automotive council UK

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POWER ELECTRONICS SPOKE

POWER ELECTRONICS UK

IET
The Institution of Engineering and Technology

AESIN
DRIVING PROGRESS
WE'RE CONNECTED

PEMD TPN
Power Electronics, Machines and Drives Technical and Professional Network

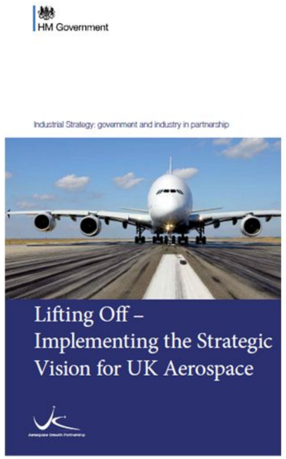
iMAPS

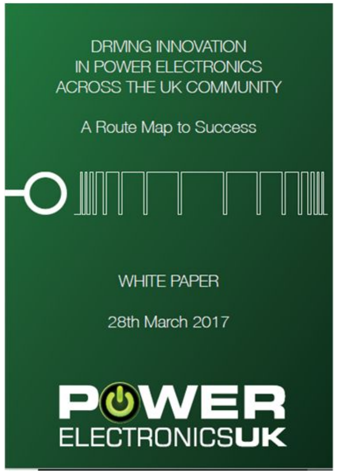
ECPE

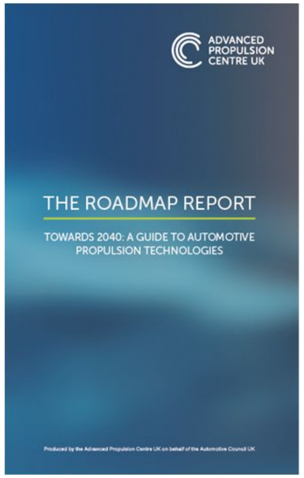
pels
IEEE POWER ELECTRONICS SOCIETY
Powering a Sustainable Future

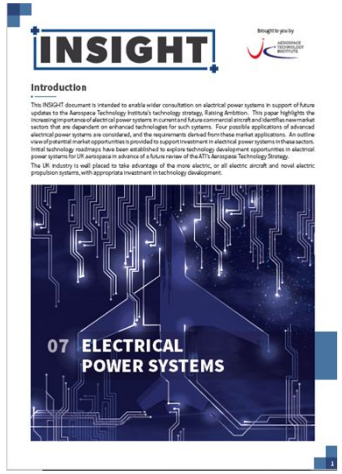
Key Reports and Initiatives

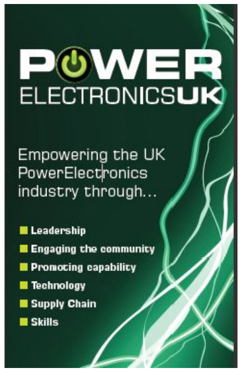
2011 **2013** **2014** **2015** **2016** **2017** **2018** **2019**











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POWER ELECTRONICSUK Automotive Challenge

INDUSTRIAL STRATEGY

Driving the Electric Revolution

Power Electronics: A Strategy for Success

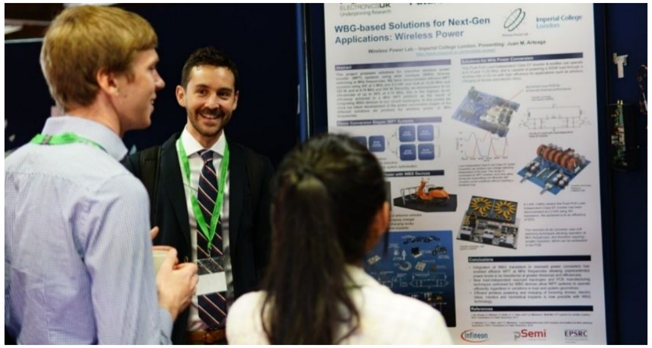
- Published October 2011
- Key Recommendations
  - Establish a National Forum to provide cohesion & representation
    - *PowerelectronicsUK*
  - UK to be an exemplar low-energy/low-carbon economy
  - Ensure UK remains at the forefront of innovative Power Electronics
  - Ensure a good supply of talented Power Electronics engineers
    - *EPSRC Centre for Doctoral Training*
  - Improve access and the exchange of leading technology
    - *EPSRC Centre for Power Electronics*

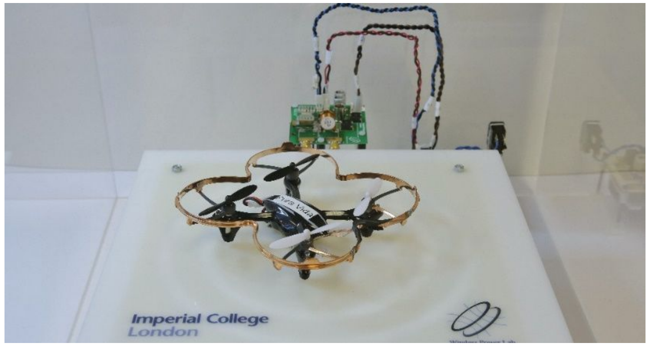
PowerelectronicsUK: April 2013

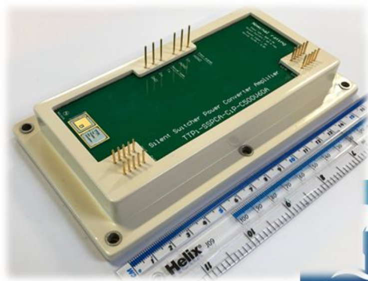
- PowerelectronicsUK acts to ensure that the UK is recognised as a world leader in power electronics, creating jobs, and attracting investment
- Provide leadership, guidance and co-ordination of key activities that support its ambition
- Act as a focal point for engagement and cohesion across all supporting bodies and stakeholders in the UK
- Act as a catalyst for growth in key markets of significant importance in the UK including Automotive, Aerospace, Energy, Industrial and Consumer.

EPSRC Centre for Power Electronics: July 2013

- The Centre is the UK's internationally recognised provider of world-leading, underpinning power electronics research, combining the UK’s best academic talent.
- Centre launched in July 2013
  - Hub based at University of Nottingham
  - 12 Core university partners plus 7 Associates
- Direct investment of **£23 million** over 7 years.
- Activities focus on:
  - Underpinning Research
  - Community Support
  - Impact and Growth.
- See www.powerelectronics.ac.uk for further details.







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Tranche 1 Core Research Themes

Tranche 1: 2013-2017

£8 million total funding

10 core university partners

Themes:

- Components
- Converters
- Devices
- Integrated Drives

University of Bristol, Newcastle University, University of Cambridge, University of Nottingham UK | CHINA | MALAYSIA, University of Greenwich, The University Of Sheffield., Imperial College London, University of Strathclyde, Manchester 1824 The University of Manchester, Warwick The University of Warwick

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Tranche 2 Core Research Themes

Tranche 2: 2017- 2020

£6 million total funding

10 university partners

Themes focus on wide band-gap power electronics:

- Switch Optimisation
- Virtual Prototyping
- Reliability & Health Management
- Heterogeneous Integration
- Converter Architectures

University of Bristol
Imperial College London
University of Cambridge
Manchester 1824 The University of Manchester
Coventry University
Newcastle University
Loughborough University
University of Nottingham UK | China | Malaysia
University of Greenwich
Warwick The University of Warwick

Centre for Doctoral Training

Every year UK industry needs more than 1,000 new engineers to drive the electric revolution in transport and energy

- Newcastle University and The University of Nottingham have joined forces to create a new generation of **UK power electronics and electric drives specialists and leaders**
- **4-year PhD programme**
- **Industry-led research projects**
- **Specialist skills training**
- **To find out more:** https://research.ncl.ac.uk/electric-propulsion/

Lifting Off – Strategic Vision for UK Aerospace

- Published March 2013
- Key Objectives:
  - Ensure UK remains Europe’s number one aerospace manufacturer
  - Support UK companies at all levels of the supply chain to broaden and diversify their global customer base
  - Provide long-term certainty and stability to encourage industry to develop the technologies for the next generation of aircraft in the UK
- *Led to formation of Aerospace Technology Institute*

Aerospace Technologies Institute

- The ATI sets the UK's aerospace technology strategy (Raising Ambition) to reflect the sector's vision and ambition.
- The ATI provides strategic oversight of the R&T pipeline and portfolio
- ATI is backed by a joint Government-industry commitment to invest £3.9 billion in R&T to 2026.
- Identifies global opportunities for UK organisations helping to connect the UK to the global sector
- https://www.ati.org.uk/

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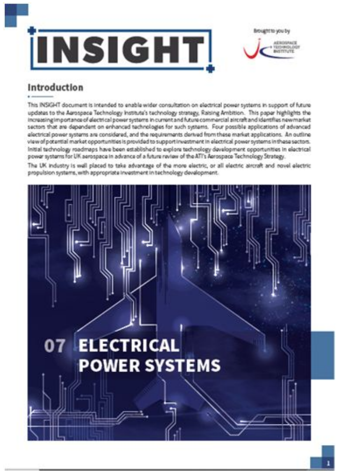

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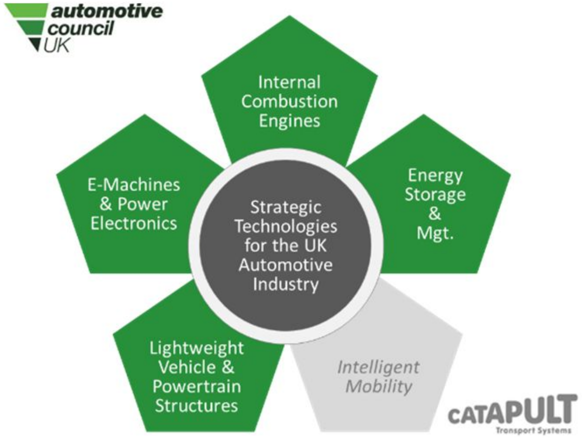
Driving Success: July 2013

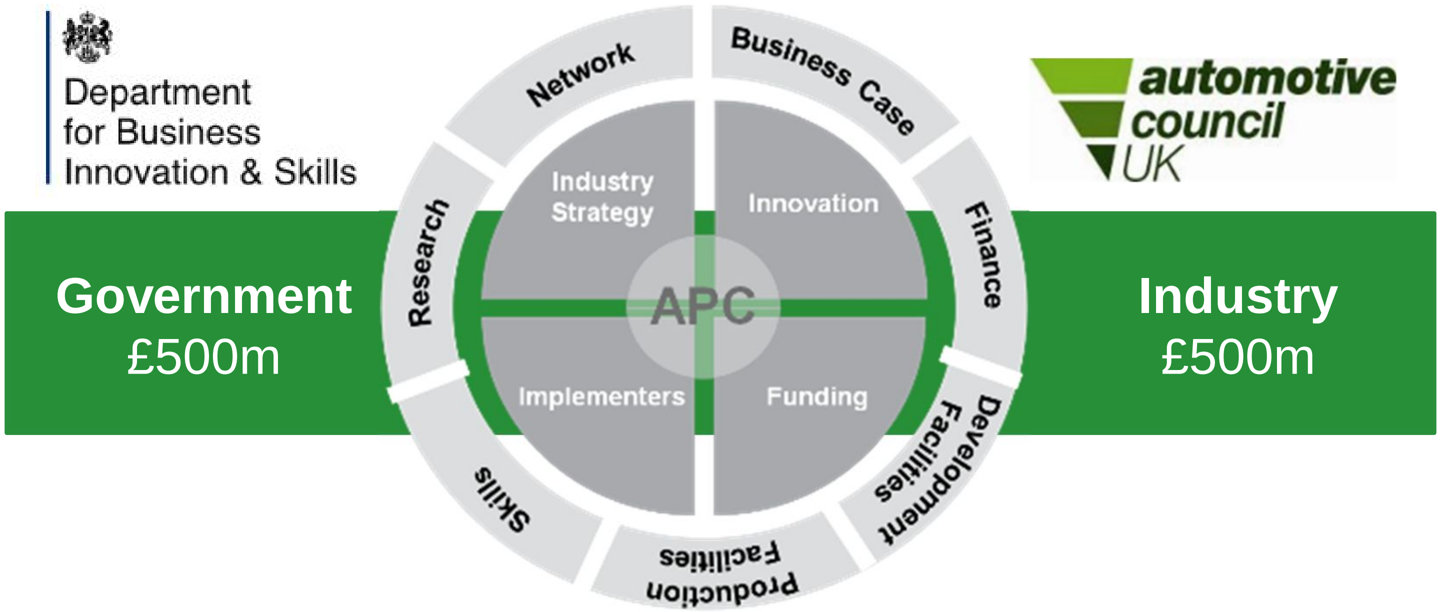
Power Electronics identified as one of 5 priority technologies



- Innovation & Technology
  - *Advanced Propulsion Centre (APC)*
  - *Spokes & Challenge Network*
- Enhancing supply chain competitiveness and growth
- Investing in people
- Business Environment enabling a competitive Automotive industry

Advanced Propulsion Centre

Founded in 2013, the Advanced Propulsion Centre is a 10 year co-investment partnership between government and industry



Building UK capability through the research, development and industrialisation of Low Carbon Propulsion Technologies

https://www.apcuk.co.uk/

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Driving the Electric Revolution

UK Research
and Innovation

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*'Driving the Electric Revolution will be the catalyst to building **£5bn more Power Electronics, Machines and Drives (PEMD) products in the UK by 2025**, encouraging industry across 7 sectors to invest and collaborate with academia to establish a PEMD supply Chain.'*

UK Research and Innovation

Policy/Wider Context

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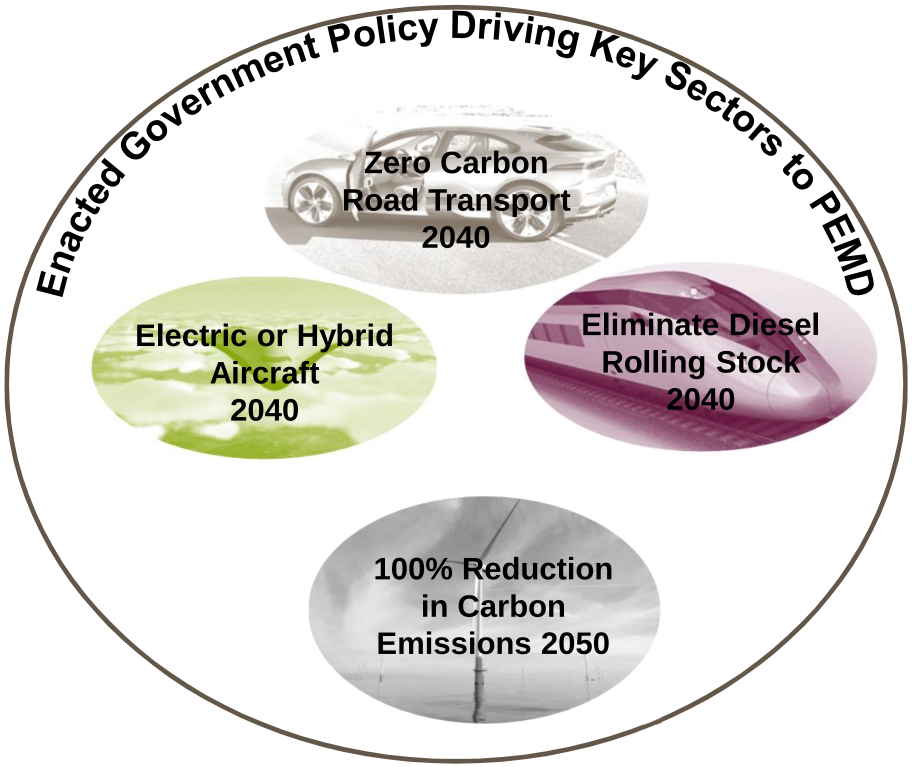
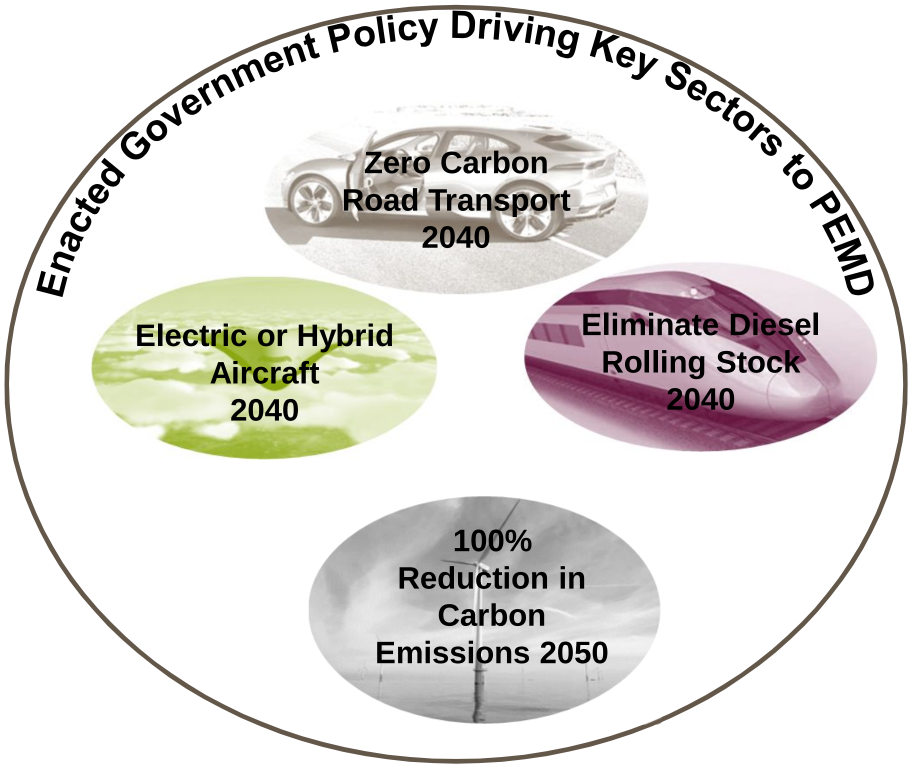


UK Research and Innovation

Policy/Wider Context



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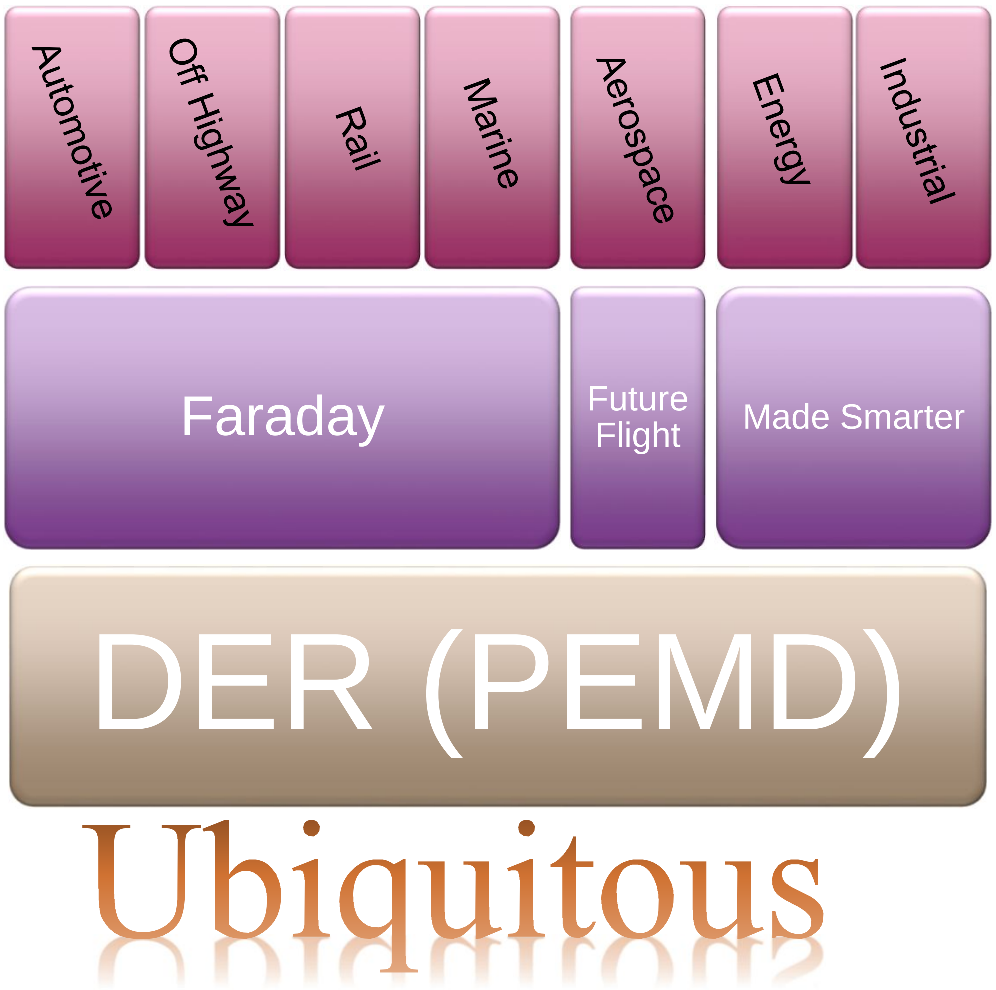

UK Research and Innovation

Policy/Wider Context

Pull is from end users

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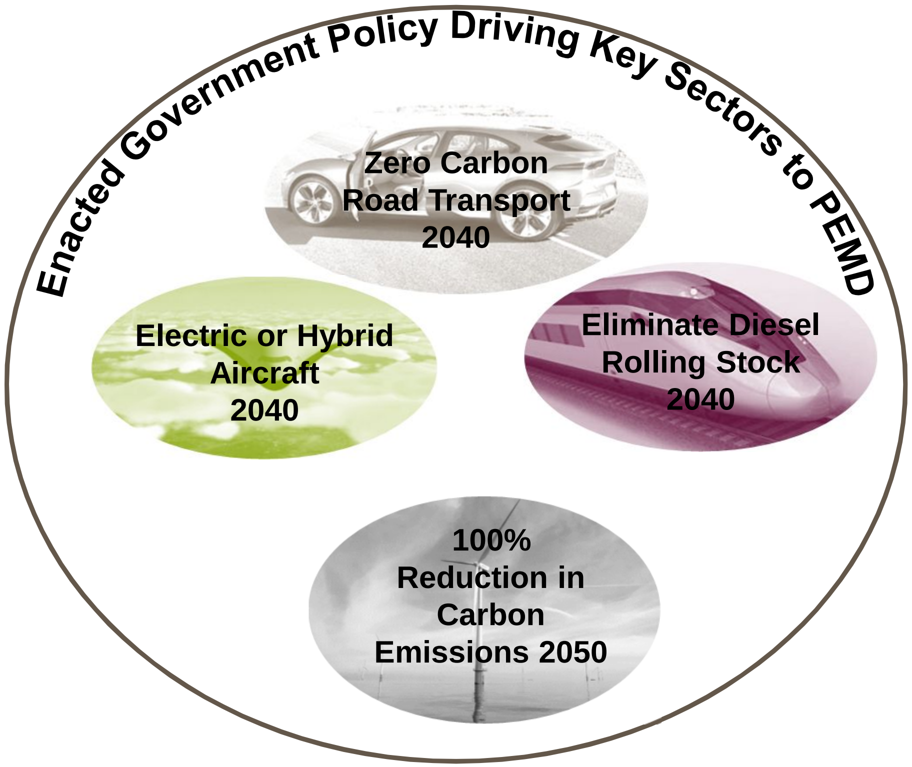

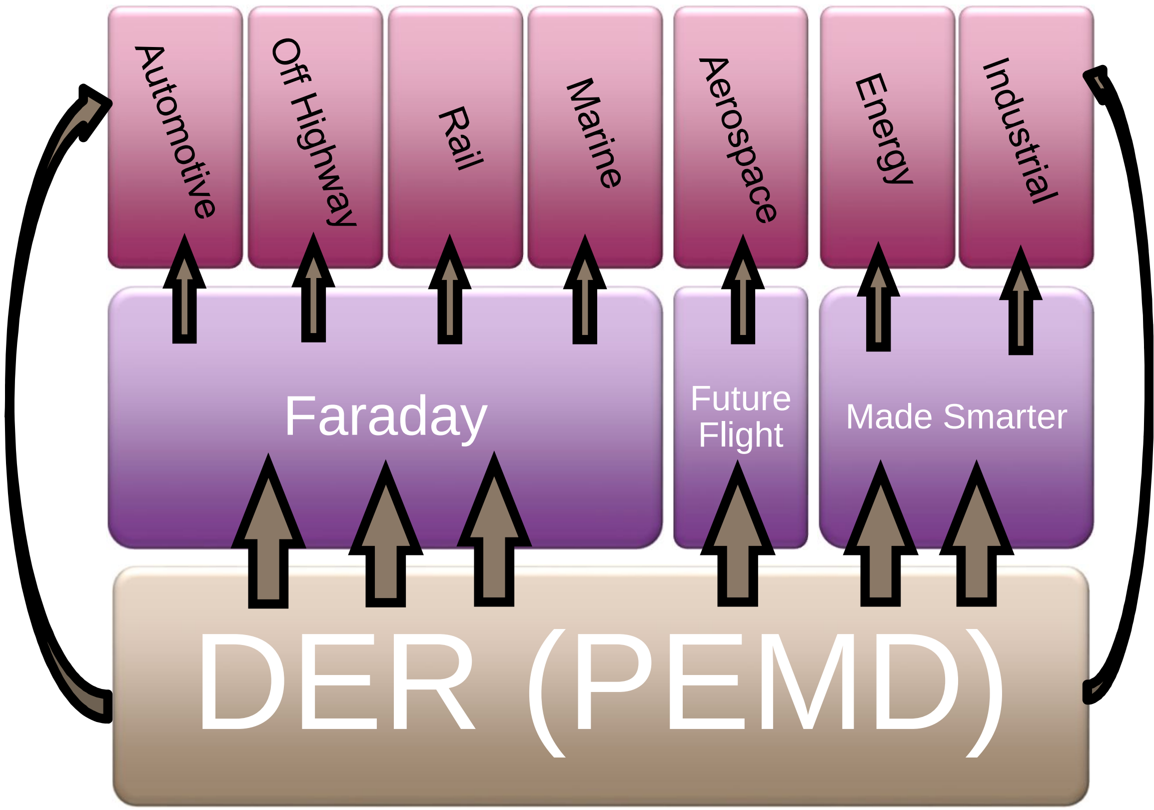

Ubiquitous

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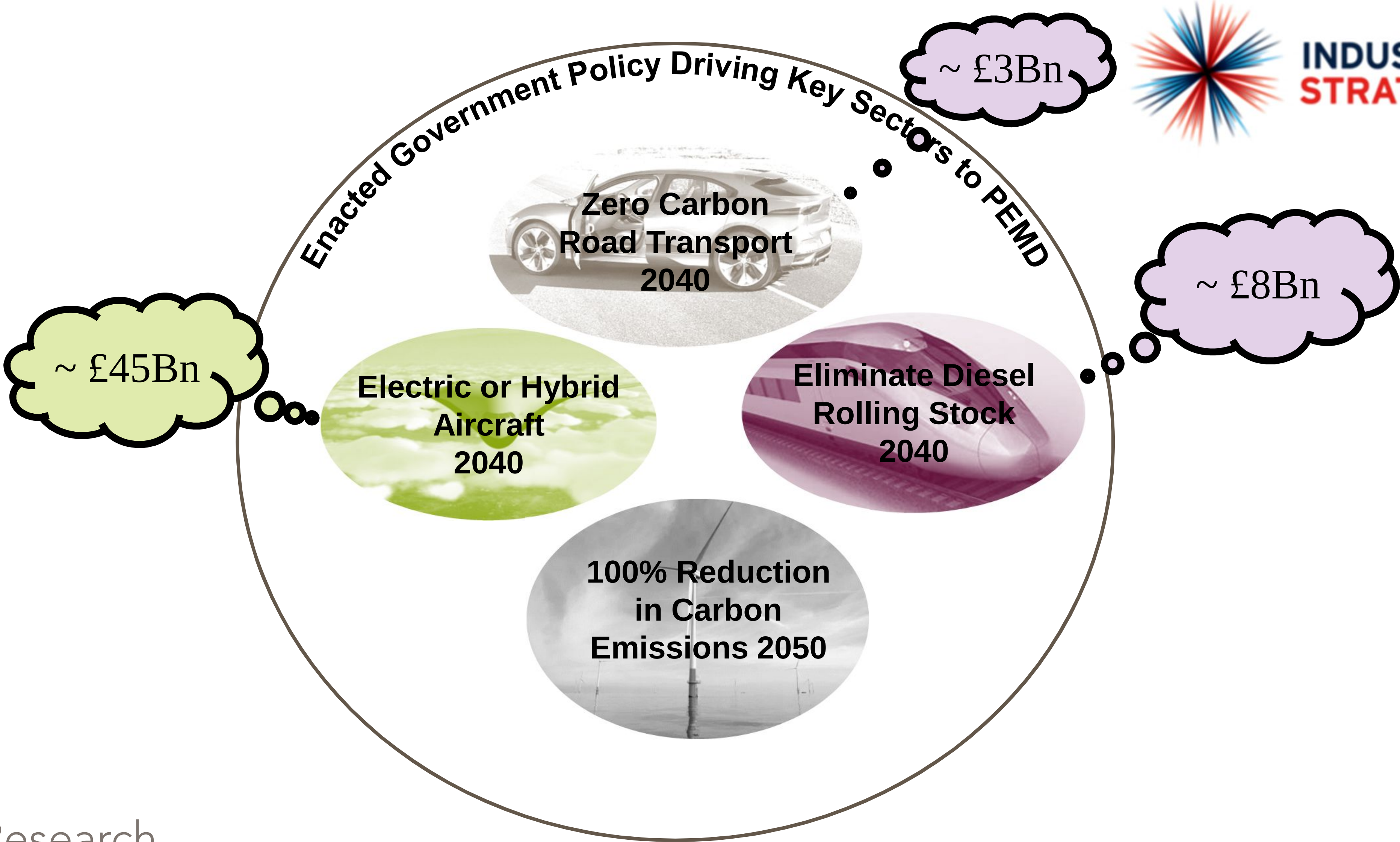

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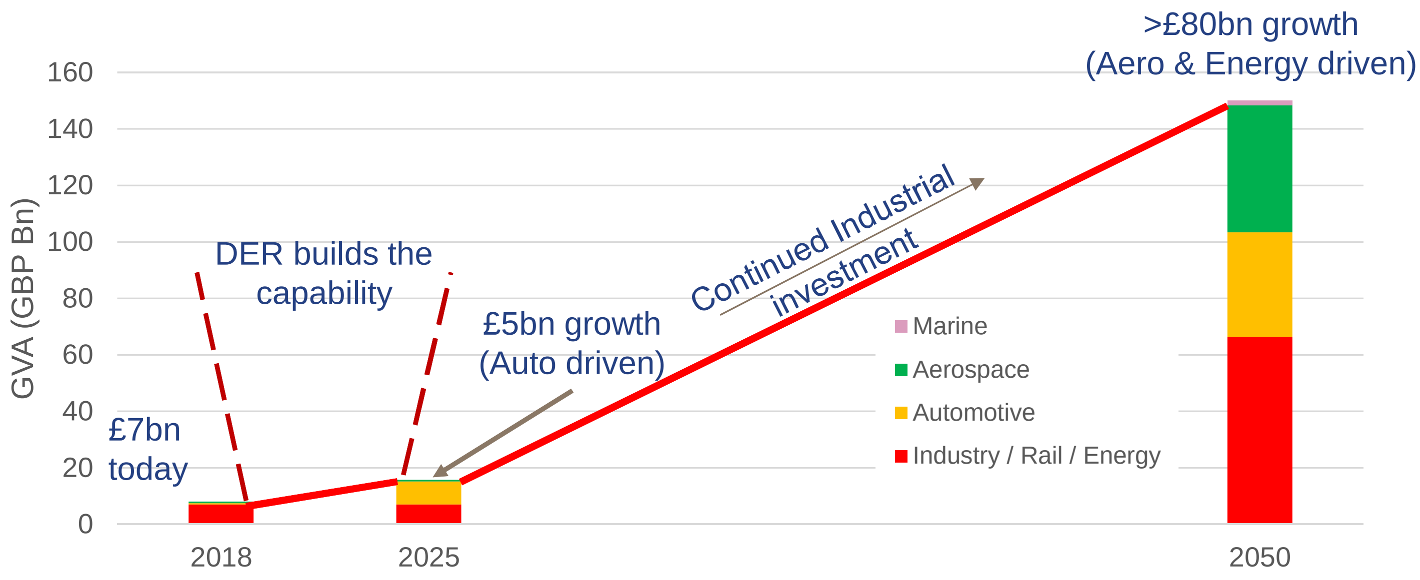
UK Research and Innovation



Why Now?

Transition from ICE accelerating – **Hybrids, Pure EVs, Decarbonisation**

International competition is strong – but **still no clear winners emerging**

UK skills, research base and industry collaboration attractive to investors while race continues…

Growth in Existing Markets → **Development of New Product / Process** → **Development of New Markets**

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- There is a global race in progress now, examples:

- US: $70M DoE Investment in wide bandgap power electronics

- Japan: £35M Super-Cluster program for Silicon Carbide (SiC) and Gallium Nitride (GaN) power electronics to save 30TWh of grid efficiency losses.

- In April 2019, the UK lost a £400m GVA + 500 job E machine project to Japan/Korea because we couldn’t demonstrate a supply chain

So what are we doing about it?

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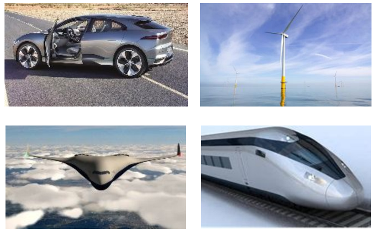
Enhancing UK strengths to lead the world

Focused across all Sectors

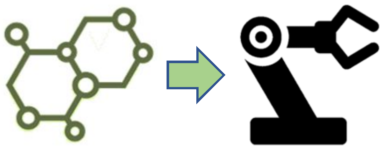


Maximise productivity

Enable cross fertilisation

Secure sufficient capacity

Materials to Manufacturing



Covering full PEMD lifecycle from new materials to manufacturing

Driving innovation beyond our international competitors

Supply Chain Development

Build new supply chain to support increase in electrification demand

Build UK SME's into credible Tier 1s and Tier 2s

Developing World Leading Facilities

Prototyping and Scale-Up

Consolidating international leadership in UK academic base

Training and Skills

Meeting industry requirements for PEMD specialists

Retraining, technical and dedicated PEMD degree programmes

Driving the Electric Revolution - Projected Delivery (£80m)

Focused across all Sectors	Materials to Manufacturing	Supply Chain Development	Developing World Leading Facilities	Training and Skills

IN SCOPE

Industrialisation Centres utilising **existing clusters of UK expertise and infrastructure**:

- Each **focussed around specific problem spaces** (for example advanced manufacturing processes)
- R&D and **Fast Start** projects within the centres
- Incorporating **co-located, cross-sector research, equipment** and **training**

High Efficiency, High Volume Supply Chains delivering cross sector high volume UK supply chains:

- Hard **focus on 2025 target to build £5Bn additional PEMD products**, 40% local content
- Engage supply chain organisations to develop innovative and differentiated production methods optimising productivity.

Low Volume, High Value Supply Chains and Tier N development longer term, **niche markets, SME growth**:

- Design and development of **flexible low/medium volume manufacturing facilities** and supply chains
- Delivery of cost effective toolkits for production control, business improvement supplier network development

OPTIONAL

OUTSIDE ISCF: Alignment of existing funding and loan programmes (£122m, £85m industry, 125M loans), **delivering further strategic benefit**:

- **Alignment to existing CR&D funding programmes** (OLEV, APC, ATI, Network Rail etc), delivering a single cross-sector strategy
- Potential **for SME loan programme** to allow UK Tier N supply chain scale up to **achieve increase to 60% local content**

\+ =

Driving the electric revolution objectives

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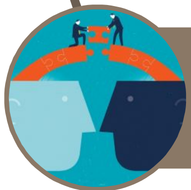
Objective 1

- To leverage the UK's world leading research capability in PEMD to help industry create the supply chains necessary to manufacture the PEMD products the world needs



Objective 2

- To identify gaps in the supply chains and help industry fill them. **Filling these generates enormous leverage downstream**

Objective 3

- To ensure cooperation and collaboration so we don't duplicate effort, waste time and can reuse solutions across the 7 sectors.

Objective 4

- We help fill the skills gap by retraining, upskilling and repurposing engineers from traditional internal combustion businesses into PEMD supply chains.

2050 Targets

£3Bn in World Leading research

60% UK PEMD content and £10Bn FDI, £500M fast start benefits by 2025

£80Bn and deliver 100% EVs and >90% decarbonisation via PEMD

Increase skilled jobs by 10k and retrain 10k fossil fuel based jobs

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Challenge Timeline

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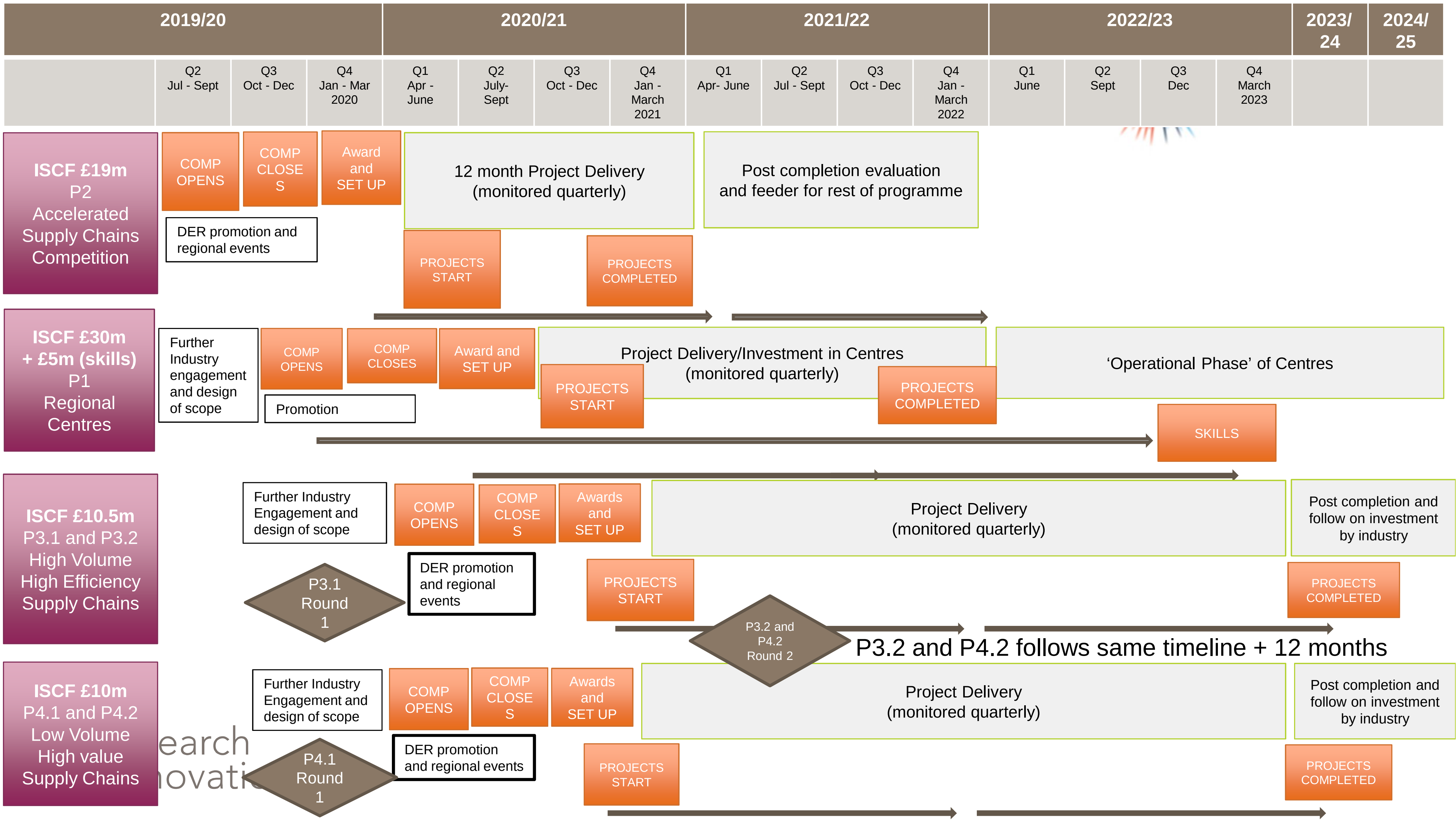
2019/20
2020/21
2021/22
2022/23
2023/24
2024/25
Q2 Jul - Sept
Q3 Oct - Dec
Q4 Jan - Mar 2020
Q1 Apr - June
Q2 July-Sept
Q3 Oct - Dec
Q4 Jan - March 2021
Q1 Apr- June
Q2 Jul - Sept
Q3 Oct - Dec
Q4 Jan - March 2022
Q1 June
Q2 Sept
Q3 Dec
Q4 March 2023
ISCF £19m P2 Accelerated Supply Chains Competition
COMP OPENS
COMP CLOSES
Award and SET UP
12 month Project Delivery (monitored quarterly)
Post completion evaluation and feeder for rest of programme
DER promotion and regional events
PROJECTS START
PROJECTS COMPLETED
ISCF £30m + £5m (skills) P1 Regional Centres
Further Industry engagement and design of scope
COMP OPENS
COMP CLOSES
Award and SET UP
Promotion
Project Delivery/Investment in Centres (monitored quarterly)
PROJECTS START
PROJECTS COMPLETED
'Operational Phase' of Centres
SKILLS
ISCF £10.5m P3.1 and P3.2 High Volume High Efficiency Supply Chains
Further Industry Engagement and design of scope
COMP OPENS
COMP CLOSES
Awards and SET UP
Project Delivery (monitored quarterly)
Post completion and follow on investment by industry
P3.1 Round 1
DER promotion and regional events
PROJECTS START
PROJECTS COMPLETED
P3.2 and P4.2 Round 2
P3.2 and P4.2 follows same timeline + 12 months
ISCF £10m P4.1 and P4.2 Low Volume High value Supply Chains
Further Industry Engagement and design of scope
COMP OPENS
COMP CLOSES
Awards and SET UP
Project Delivery (monitored quarterly)
Post completion and follow on investment by industry
P4.1 Round 1
DER promotion and regional events
PROJECTS START
PROJECTS COMPLETED

Technology Roadmaps

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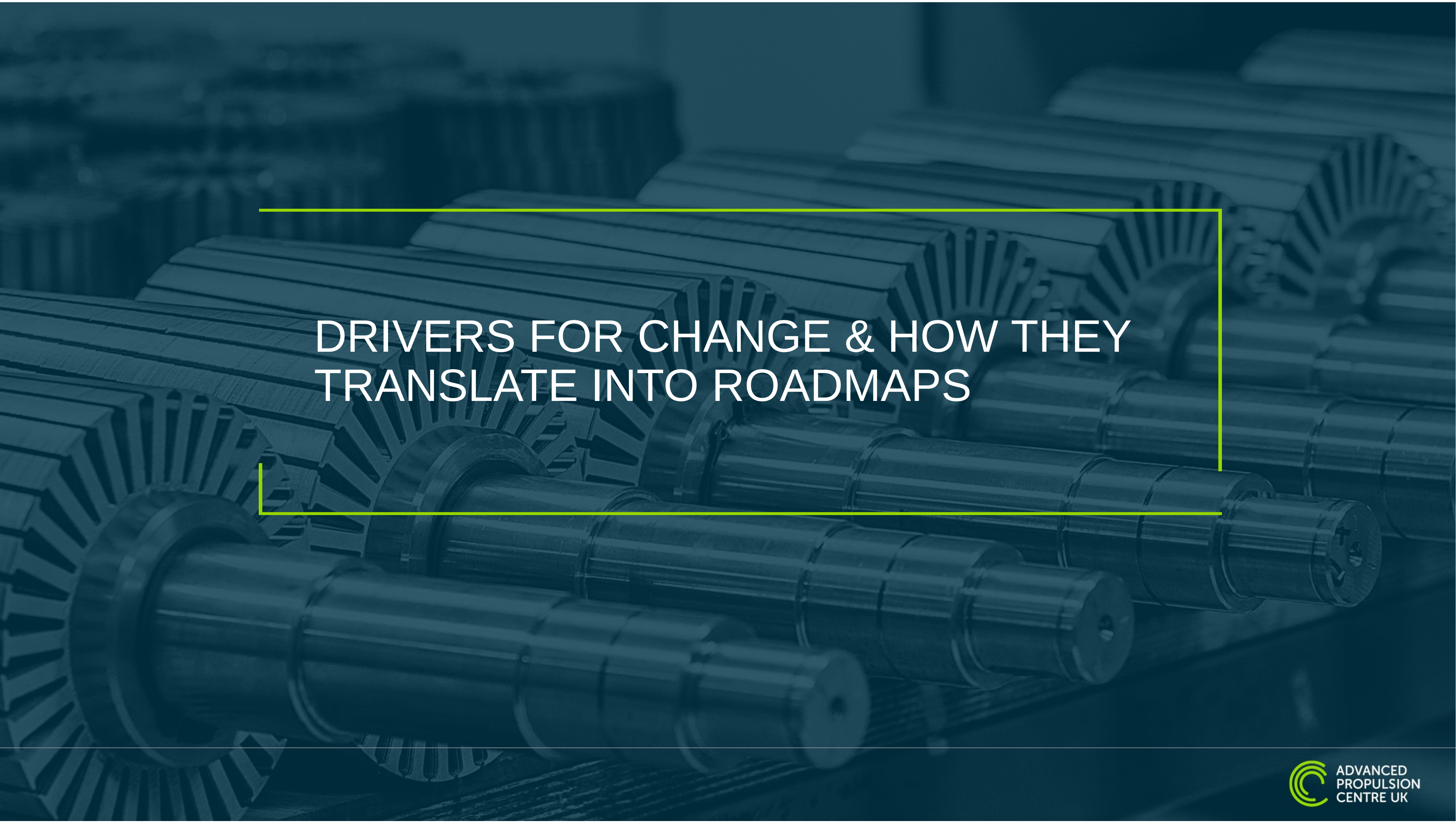
Sector Technology Roadmaps

- Sector Technology Roadmaps provide a vision of:
  - **WHY** new technology is needed:
    - Market drivers, legislation, business trends, consumer preferences, etc., which impact the need for new technology
  - **WHEN** each new technology step is needed in the market-place:
    - And by implication when product development, advanced engineering and fundamental research, etc., have to be started in order to be ready
  - **WHAT** new technology best meets these needs:
    - Generally based on a subjective analysis of what may offer the best cost/benefit and potential evolutionary steps based on **current** knowledge

- Roadmaps are a useful tool to communicate a future vision and to identify key future focus areas
- Consensus roadmaps are particularly useful in communicating a common vision and identifying specific industry challenges



DRIVERS FOR CHANGE & HOW THEY TRANSLATE INTO ROADMAPS

ADVANCED PROPULSION CENTRE UK

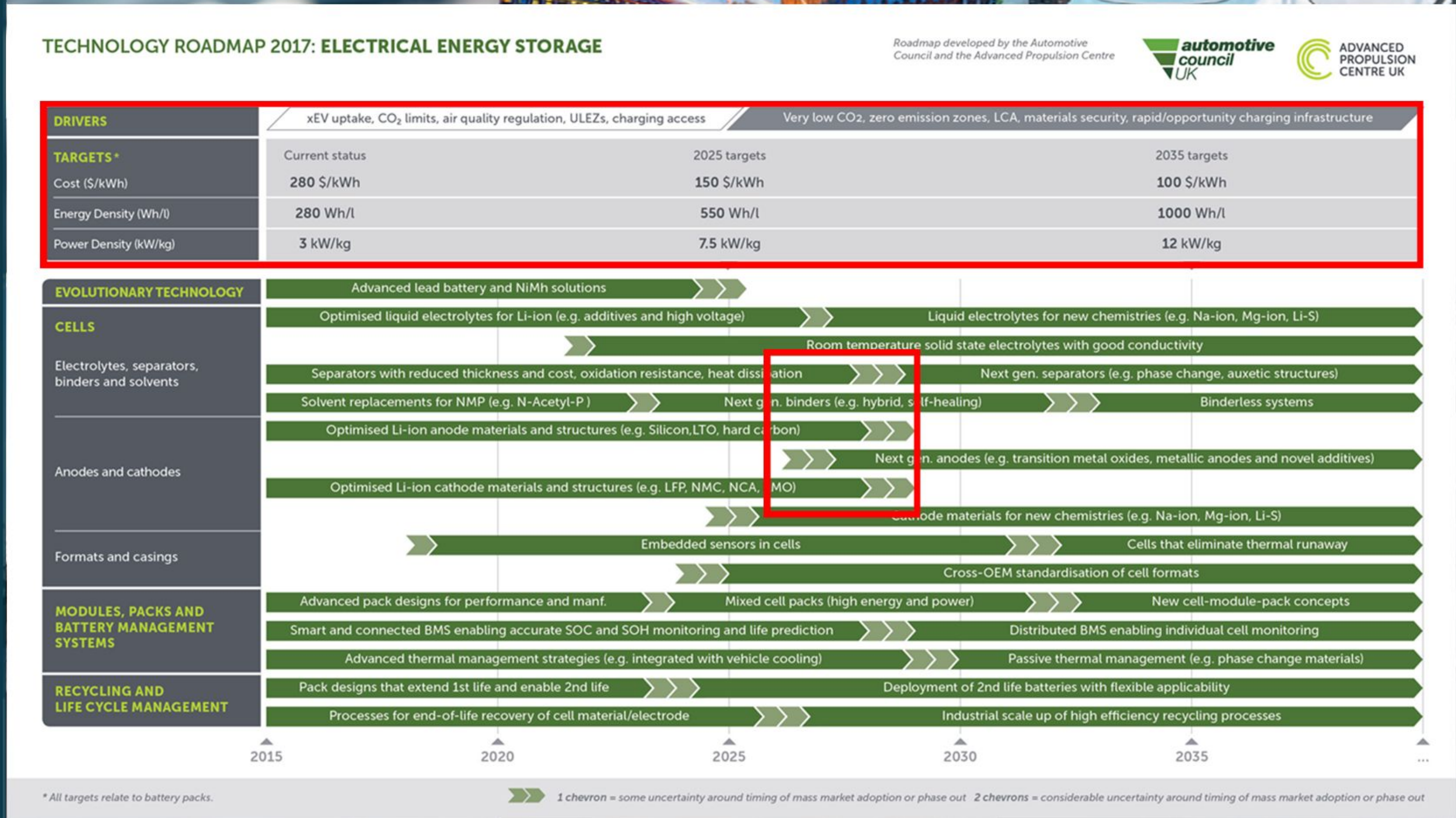
TO MEET THESE TARGETS SIG

KEY TRENDS AND DRIVERS

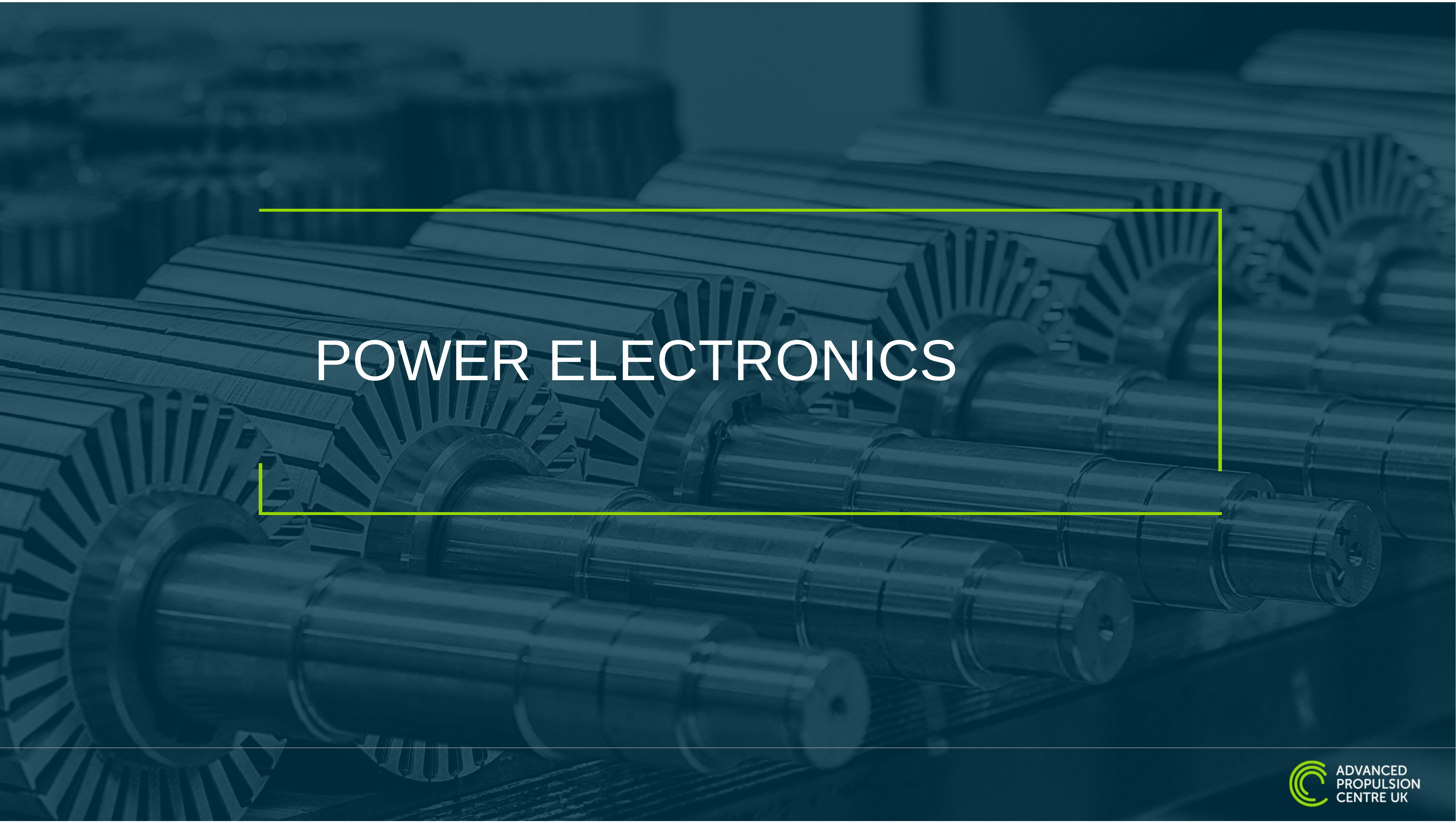
The roadmaps identify how key trends could influence powertrain development

The automotive sector needs to consider how its interacts with the energy system, how business models will evolve to accommodate MaaS and the impact of autonomy on powertrains

As time progresses certain trends, such as life cycle regulation, will exert more influence on future powertrain development

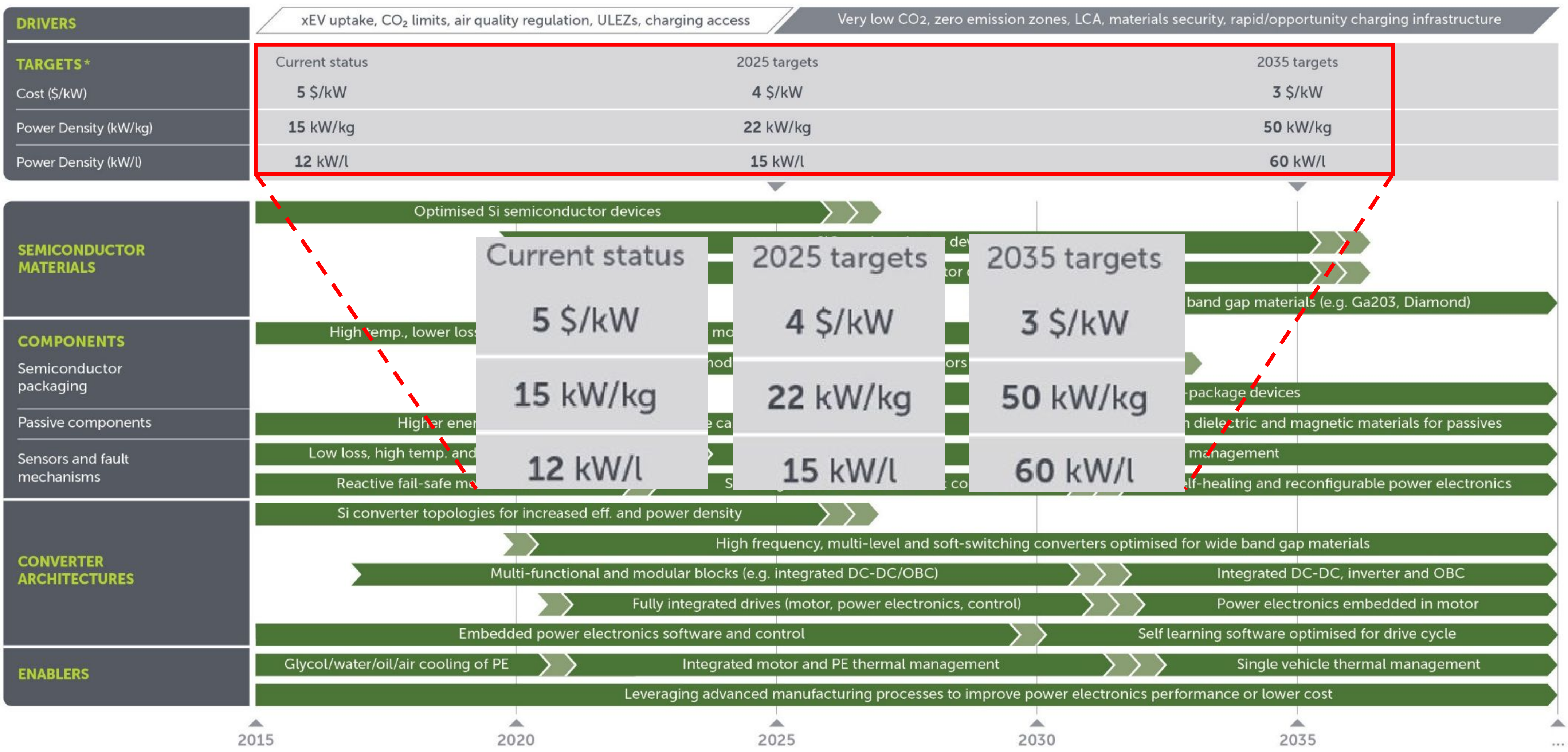


POWER ELECTRONICS



TECHNOLOGY ROADMAP 2017: **POWER ELECTRONICS**

Roadmap developed by the Automotive Council and the Advanced Propulsion Centre



** All targets relate to an EV passenger car traction inverter*

***1 chevron** = some uncertainty around timing of mass market adoption or phase out **2 chevrons** = considerable uncertainty around timing of mass market adoption or phase out*

TECHNOLOGY ROADMAP 2017: **POWER ELECTRONICS**

Roadmap developed by the Automotive Council and the Advanced Propulsion Centre

automotive council UK

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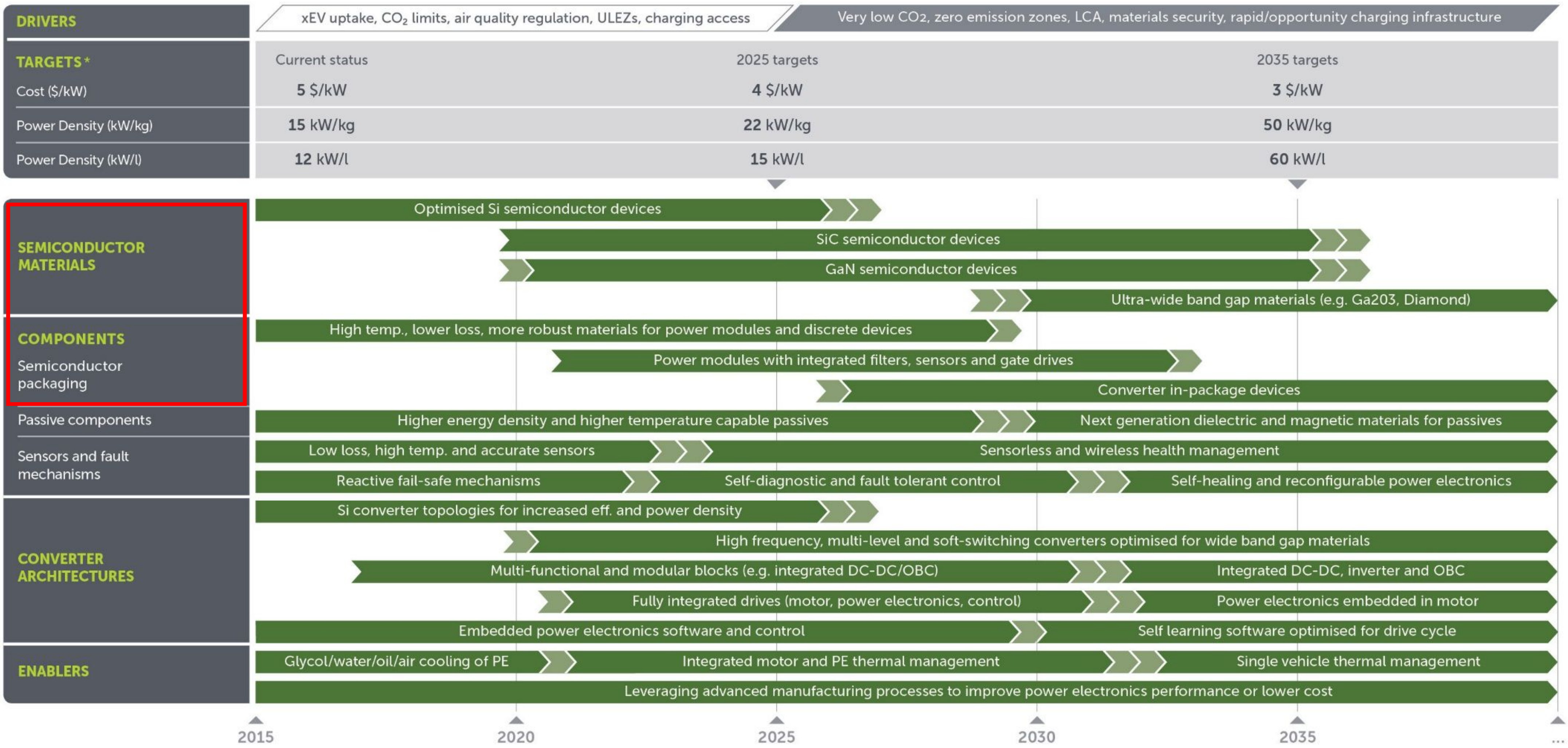


** All targets relate to an EV passenger car traction inverter*

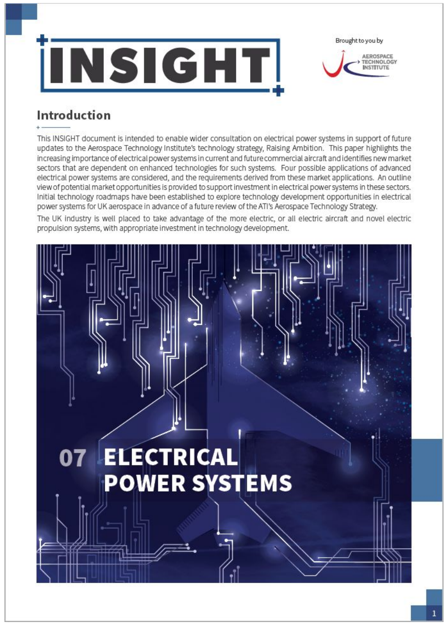
***1 chevron** = some uncertainty around timing of mass market adoption or phase out* ***2 chevrons** = considerable uncertainty around timing of mass market adoption or phase out*

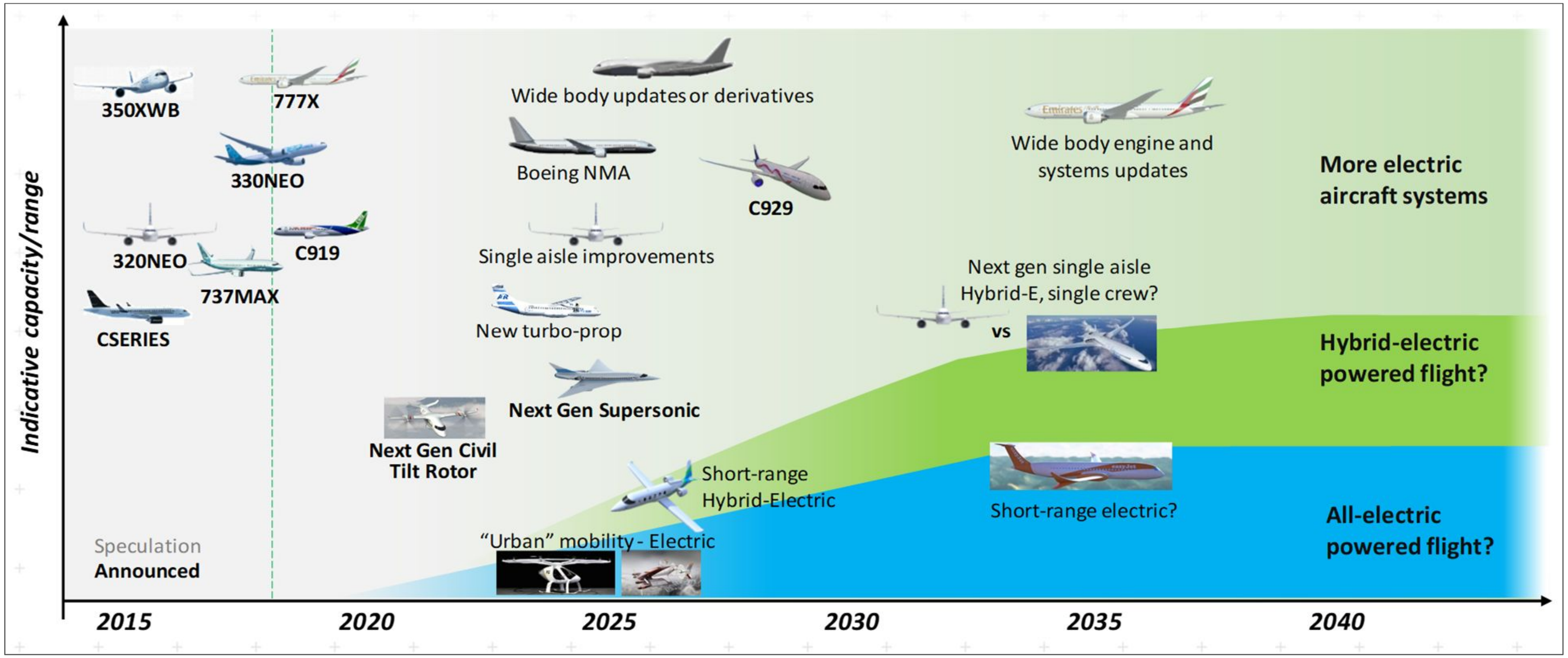
WIDE BAND GAP DEVICES AND THE IMPORTANCE OF INTEGRATING THEM SUCCESSFULLY INTO THE POWERTRAIN IS A CONSISTENT R&D THEME

Research Challenge	SHORT TERM (5-7 years to mass market)	MEDIUM TERM (7-15 years to mass market)	LONG TERM (10-20 years to mass market)
1 Improved power semiconductor materials and devices	• Continued improvement of Si device designs: IGBTs, MOSFETs, Power ICs • Reducing cost and improving quality of SiC and GaN epitaxy and substrates • Alternative substrate materials e.g. GaN and SiC on Si • Identifying commonality in Si and wide band gap device manufacturing and adjusting processes to create reduced cost manufacturing capability for wide band gap devices	• SiC and GaN devices with enhanced reliability operating to >250°C • SiC on Si substrate scale-up and reduced cost • GaN Power ICs • GaN devices with improved stability	• Cost effective, higher voltage >1500V GaN and SiC • Large area, low-cost GaN substrates • GaN vertical devices • Diamond & Gallium Oxide materials and device processes • Exploring new materials and/or devices that radically improve breakdown fields, thermal conductivity & electron velocity of semiconductors
2 Improved power semiconductor packaging technology	• Development of standard interfaces to allow multisourcing-manufacturers • Embedded chip and planar interconnect for low-inductance • High reliability joining and interconnect technologies • Modules with integrated passive components • Low-cost integrated cooling (e.g. double sided cooling for flip chip) • Materials and assembly processes for wide temperature range cycling and power cycling with rapid transients	• Integration of gate drives, filters, controls and sensors • Embedded power and control elements • Integrated EMI suppression • Converter-in-package for increased power density • Materials and assembly processes for 250°C capability including wide temperature range cycling and power cycling with rapid transients	• Easy to design and manufacture power modules with elementary bricks, pre-packaged chips • High volume, low-cost manufacturing platform • 3D integrated hetrogenous assemblies • Low-cost substrate & laminate materials with low CTE (<16ppm) and high thermal conductivity (>20W/(mK)) • Reconfigurable, multi-functional Converter-in-Package • Materials and assembly processes for >250°C capability including wide temperature range cycling and power cycling with rapid transients

Electrification in Aerospace

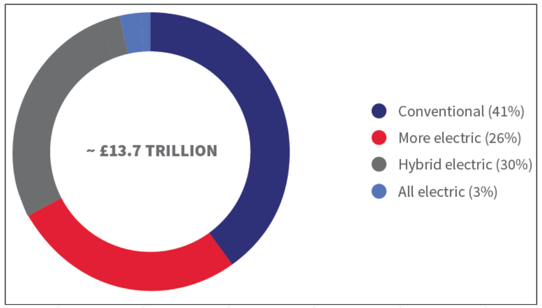
Electrical Power Systems





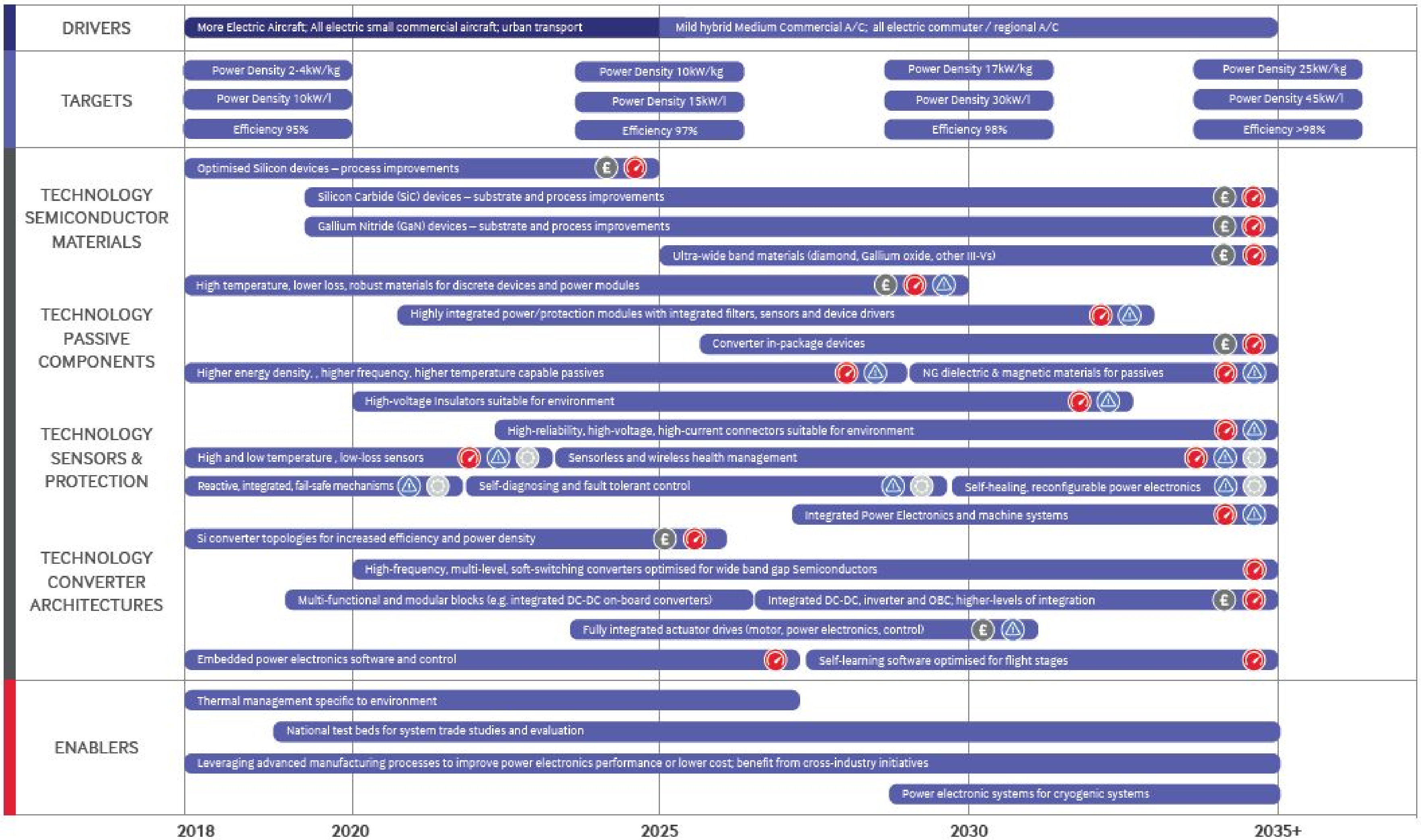
Electrification in aerospace is driven by innovative technology and enables:

- Continued evolutionary development and market growth of More Electric Aircraft
- Disruptive development and market introduction of electric and hybrid aircraft creating new market opportunities



ATI EPS Roadmap summary

	2025	2030	2035	Technologies					Enablers		
Drivers	More Electric Aircraft All electric UAT	Mild Hybrid Single Aisle a/c Hybrid sub-regional a/c	Mild Hybrid Wide Body a/c All electric sub-regional								
Architecture & Interconnects	Energy density 250 kWh/l Power density 10 kW/kg Operating voltage 540V	Energy density 1 MWh/l Power density 20 kW/kg Operating voltage 3kV	Energy density >1 MWh/l Power density 25 kW/kg Operating voltage >3kV	Conductors / Insulation	Connectors	Cabling Design	System Architecture		Improved cable assembly & installation.	Testing methods	Concepts for reuse and recycling
Electrical Energy Storage	Power density 5 kWh/kg Energy density 200 Wh/kg Discharge rate 8C	Power density 7.5 kWh/kg Energy density 300 Wh/kg Charge rate 12C	Power density 10 kWh/kg Energy density 500 Wh/kg Charge / Discharge rate 15C	Cells (Electrolytes, seperators, binders, solvents, anodes, cathodes, formats & casings)	Packs and battery management	Recycling & life cycle management	Super capacitors	Fuel cells	National test beds for system trade studies and evaluation	Cross sector leverage	
Electrical Machines	Power density 7.5 kW/kg Power density 30 kW/l Efficiency 93% Machine power 500kW	Power density 12 kW/kg Power density 40 kW/l Efficiency 96% Machine power 2MW	Power density 20 kW/kg Power density 50 kW/l Efficiency >96% Machine power >5MW	Windings / Insulation	Soft Magnetics	Machine Architecture	Machine Integration	High performance manufacturing & materials	National test beds for system trade studies and evaluation	Machine vs. power electronics optimisation	Cross sector leverage
Power Electronics	**Power density 10 kW/kg Power density 15 kW/l Efficiency 97%**	**Power density 17 kW/kg Power density 30 kW/l Efficiency 98%**	**Power density 25 kW/kg Power density 45 kW/l Efficiency >98%**	**Semiconductor materials**	**Passive components**	**Sensors & protection**	**Converter architectures**	**High performance manufacturing & materials**	**National test beds for system trade studies and evaluation**	**Machine vs. power electronics optimisation**	**Thermal management**



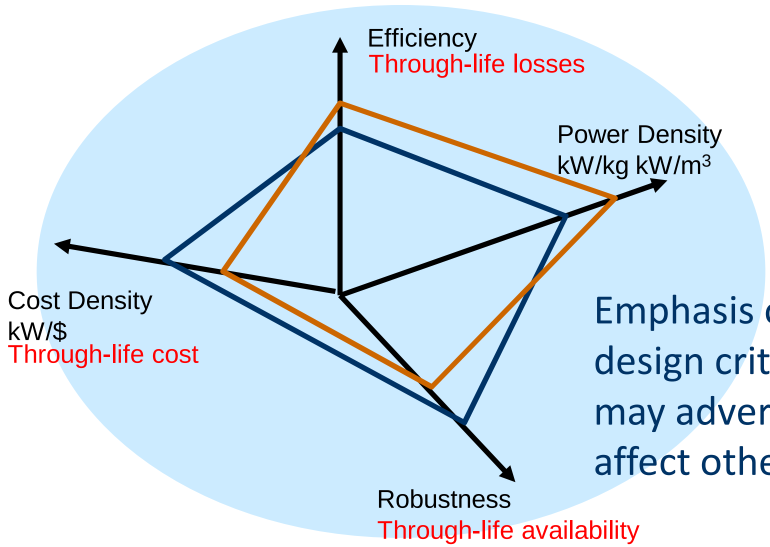
Technology Road Map 2018: Power Electronics

Whole Aircraft Attributes: Cost: | Operational needs & flexibility: | Fuel efficiency: | Passenger experience: | Safety: | Environment:

Challenges for Power Electronics

Challenges for Power Electronics

- Reduced costs (BoM, manufacturing, O&M, recycling)
- Increased efficiency (reduced losses through life)
- Increased power density (reduced volume, reduced mass)
- Ease of use (plug and go, modular solutions, simplified thermal management, negligible EMI, load/source integration)
- Environmental tolerance (higher temperature, extreme temperature range, vibration & shock)
- Skills!



Emphasis of one design criterion may adversely affect others

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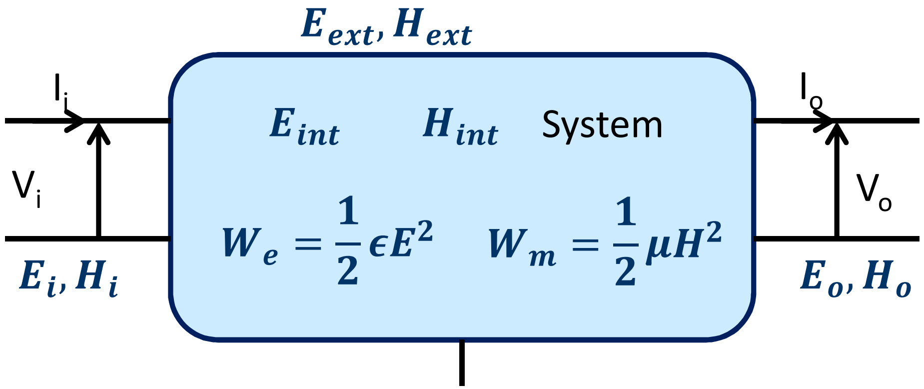
Opportunities for High Frequency Power Electronics

- Silicon, Silicon Carbide and Gallium Nitride have potential to operate at MHz frequencies
- Increased efficiency
  - Use of majority carrier devices (FETs/Schottky diodes) at higher voltages reduces switching and on-stage losses compared to Si bipolar
- Increased switching speeds
  - Smaller passive component requirements
  - Reduced filter sizes
  - More power dense converters
  - True sinusoidal outputs from inverters
  - Reduced bill of materials

Impact of Fast Switching



- All circuit elements generate electromagnetic fields, intentional (e.g. in capacitors and inductors) and unintentional ("stray" fields)
- Changing electromagnetic fields inside the system lead to non-ideal behaviour: parasitic components and cross-coupling
- Electromagnetic fields will be generated outside the system, leading to unintentional Electromagnetic Interference (EMI)

> *Faster switching produces greater rates of change of voltage/current – EMI suppression becomes more challenging*

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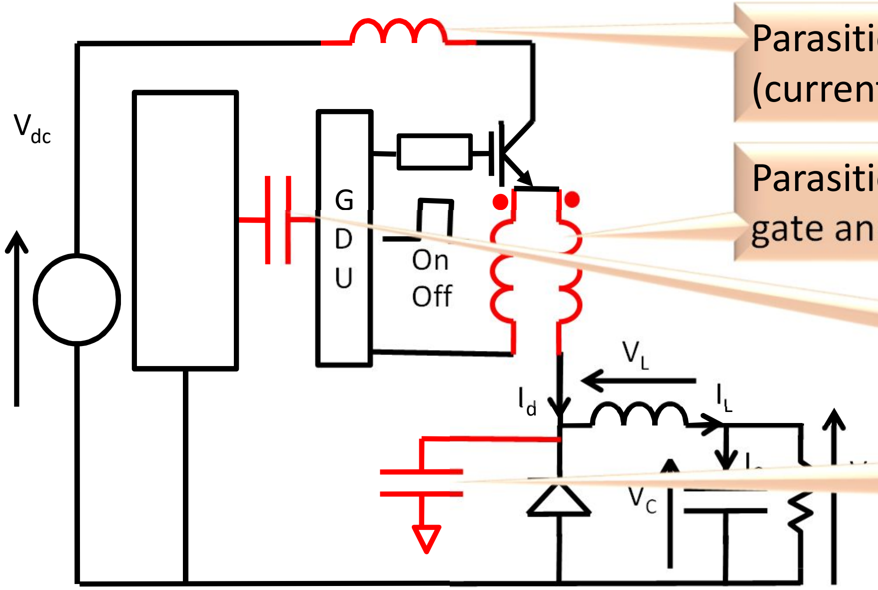
Common Effects of Parasitic Components



Parasitic inductance due to interconnections (current producing magnetic field)

Parasitic coupling/shared path inductance between gate and power circuits

Parasitic capacitance between gate drive and control electronics

Parasitic capacitance to "ground" through heatsink (power module substrate acts as a dielectric)

- Spurious oscillations resulting from:
  - Resonance of parasitic inductance with switch and diode capacitance
  - Common-mode currents circulating in the "ground" loop
  - False/oscillatory gating due to coupling of gate and drain circuits
  - Common-mode dv/dt induced feedthrough to control electronics from gate drive

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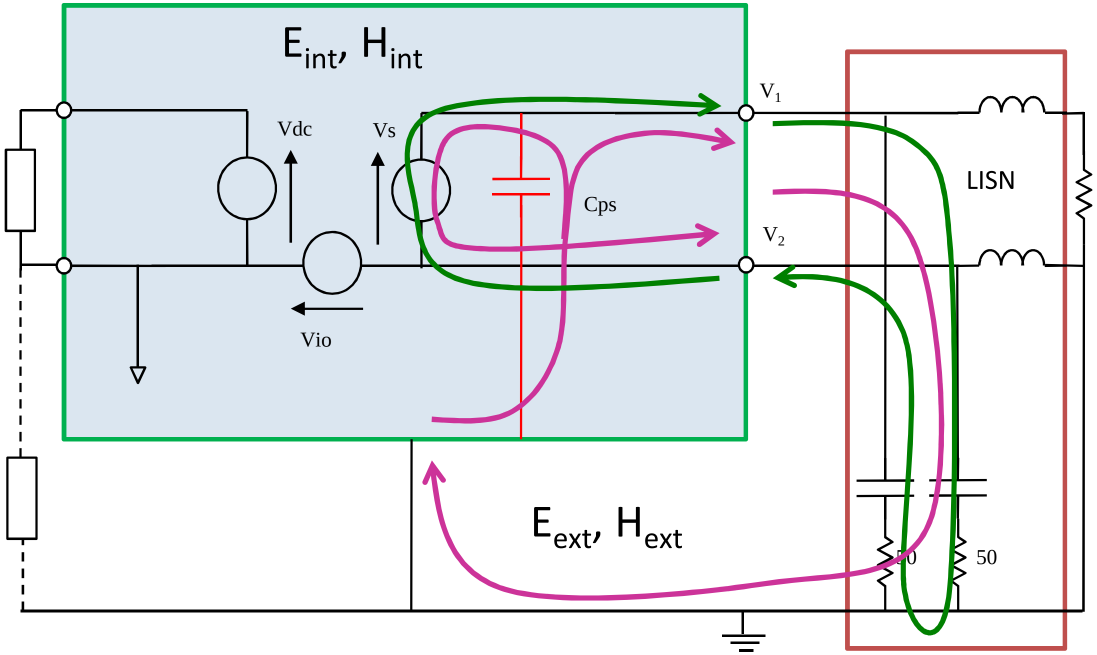
Electromagnetic Interference



- Sources of differential and common mode interference:
  - Switching action of converter
    - Rapid voltage and current transitions
  - Unintentional electromagnetic interactions
    - Coupling of stray fields inside and outside of enclosure

> *Once EMI has "escaped" it is unpredictable and extremely difficult to "recapture"*
> *Better to keep it in its cage!*

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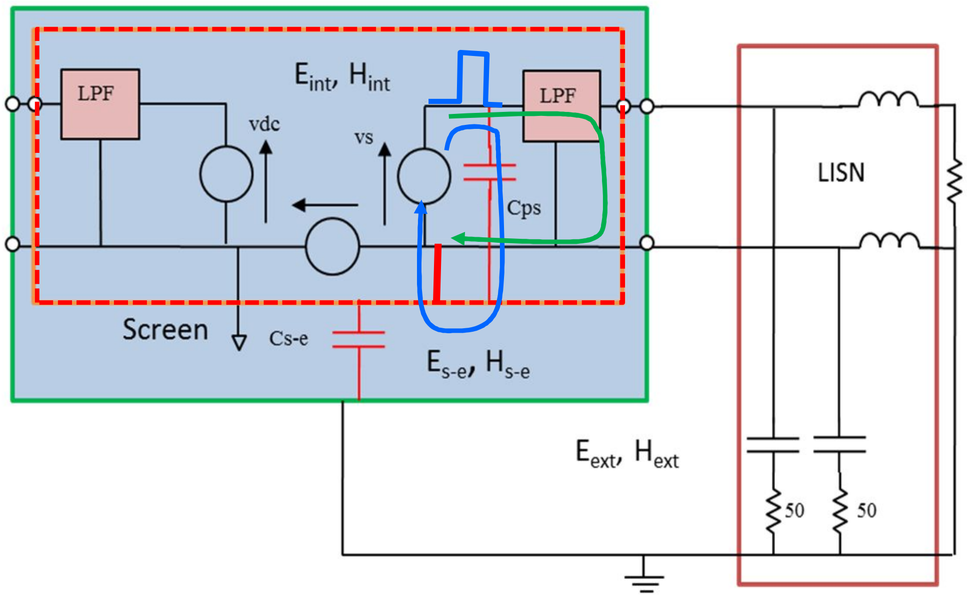
Integration Simplifies EMI Confinement



SCREENING

- Effective CM screening achievable with a conducting layer
- Screen is connected to converter "0V" or similar

SHIELDING

- For AC electromagnetic fields, conducting shields can reflect and absorb incident fields

FILTERS

- Low-pass filters return h.f. noise to source for external connections

> - *Combination of screening, shielding and filtering embedded within the converter switching cell can confine all EM fields*
> - *No more EMI!*

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Challenges for High Frequency Integration

- Need radically new approaches to packaging and converters to realise the full potential
- Circuit parasitic components and associated electromagnetic interference must be reduced to unprecedentedly low levels
- Compact physical layout
- Enhanced switching strategies and topologies
- Optimised electromagnetic (EMI) & thermal management

➢ *Many end-users are unwilling or unable to enter into major re-design for their systems*

➢ *Preference for "like-for-like" substitution*

➢ *May lead to stagnation*

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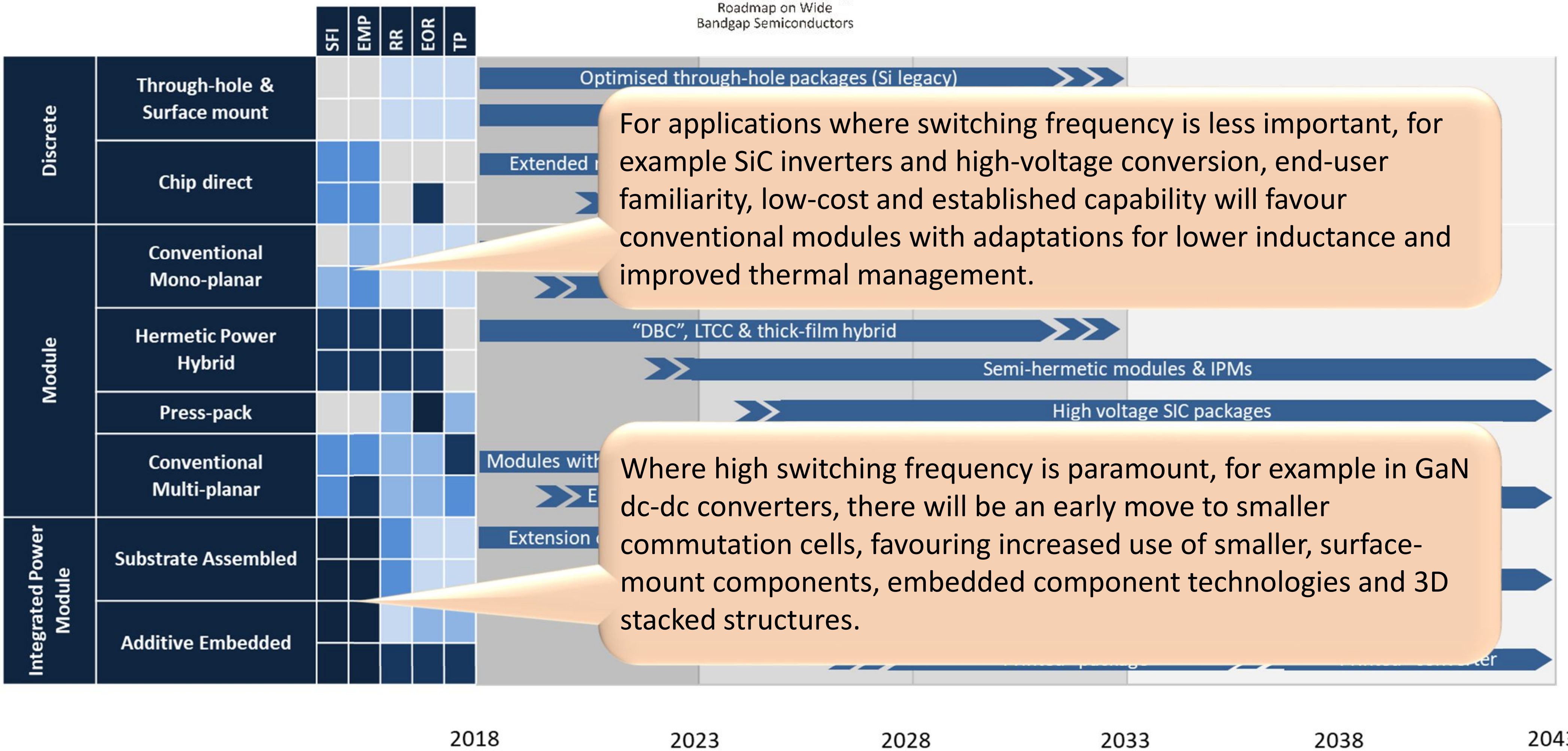
Wide Band-Gap Semiconductors

- Much recent interest in use of Wide Band-Gap semiconductors for power electronics
- ITRW identifies high frequency/speed switching as a major differentiator but…
- Much of this is shared with existing Silicon MOSFET power electronics
- WBG and Silicon can take advantage of enhanced integration techniques

ITRW
International Technology Roadmap on Wide Bandgap Semiconductors

pels IEEE POWER ELECTRONICS SOCIETY Powering a Sustainable Future

IEEE Advancing Technology for Humanity



Power Electronic Building Blocks

Historical Perspective

- Typical kW-level power converter includes
  - semiconductor power modules
  - a physically separate DC-link
  - a separate input and/or output filter
  - EMI filters
  - gate drivers
  - controllers and sensors
  - embedded software
- Demarcation of technological disciplines
  - Electrical, mechanical and thermal aspects are treated separately by separate teams
  - Each element is designed separately, manufactured separately then assembled – often by hand

Integrated Power Modules (IPMs)

- Desire for higher switching speeds will drive a move to physically-small (10-100mm), highly-integrated commutation cells to limit impact of parasitic L & C
- Drive towards surface-mount components, embedded component technologies and 3D stacked structures
- Integrated features for control, thermal management and EMI suppression
- Simplified end-user design and application

> - *Low-power (< few 100s W), dc-dc converters are already fabricated as single-package, integrated assemblies*
> - *Can we establish a flexible, cost-effective manufacturing route to power conversion at kW-MW level that can meet customer needs?*

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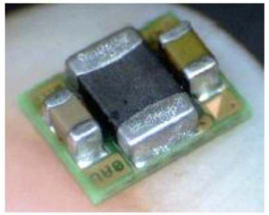
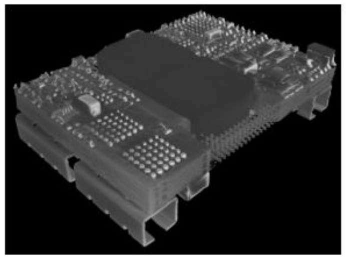
Evolution from Towards Integrated Power Modules

Low Power (W-100sW)



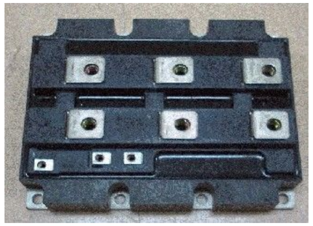
Texas Instruments

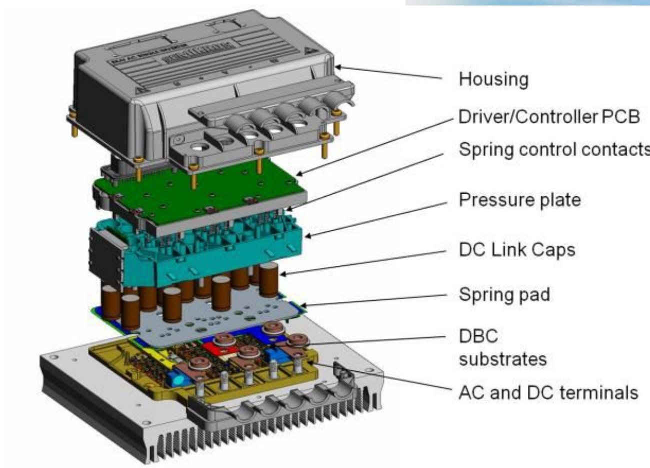


Additive Embedded CiP

?

High Power (kW-MW)





Substrate Assembled CiP

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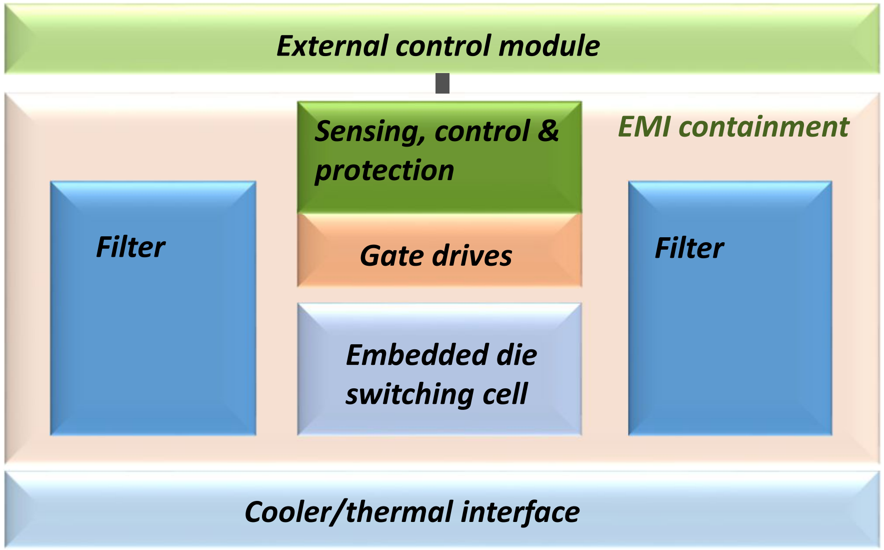
Flexible Power Electronic Building Blocks (PEBBs)



- Scalable technology: smaller, low current modules connected in parallel/series to create high power & multi-phase converters
- Optimised commutation paths – reduced parasitics
- Inbuilt passive components, sensors & filtering
- Optimised embedded control – ability to interleave gate signals & alter configuration e.g. inverter dc-dc converter

➢ *Advantages:*
  - Building block approach to high power converters
  - Contain EMI at source
  - Low weight solution
  - Certification/qualification of different converters simplified

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Summary

- Power Electronics is a key enabler for the Electric Revolution
- UK has a strong heritage and capability but must consolidate and grow the supply chain AND skills base to maximise benefits
- Government support is being delivered through ISCF Driving The Electric Revolution, Innovate, APC, ATI
- Opportunities across all sectors and across the supply chain
- Technology challenges for power electronics demand new approaches for manufacturing to deliver easy-to-use, low-cost, power-dense systems at all power levels

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