DRIVING INNOVATION IN POWER ELECTRONICS ACROSS THE UK COMMUNITY

A Route Map to Success

WHITE PAPER

28th March 2017

POWER ELECTRONICS UK

Executive Summary

PowerelectronicsUK was established in 2012 to address the challenges identified by the Department of Business, Innovation and Skills (now BEIS) from their industry consultation which informed "Power Electronics: A Strategy For Success"[1] published in November 2011. Initially run as an industry-led voluntary group it is now entering a new phase as a community within the recently announced TechWorks Connected Communities.

From the start, PowerelectronicsUK has embraced a wide cross-section of the UK power electronics industry straddling multiple sectors, supply chains and academia. By providing a consolidated voice across a diverse, high value industry it has been able to provide valuable input into sector roadmaps such as the Aerospace Technology Institute and the Advanced Propulsion Centre and other governmental organisations including EPSRC and Innovate UK.

Over the past 5 years PowerelectronicsUK has worked with over 100 senior engineers from diverse UK organisations to undertake a comprehensive technology mapping activity to guide future investment in R&D. This was undertaken through workshops, structured analysis, industry questionnaires and capability benchmarking. A green paper was published in 2015 leading to a period of reflection and further workshops to verify the outcomes. This process not only focused on technology but also the underpinning challenges of ensuring that the UK power electronics community makes best use of that investment.

Further consultation stimulated by the green paper has led to this white paper, a Joint Industry Action Plan that aims to strengthen the UK's position as a global leader in power electronics across many sectors. The plan entirely arises from the work that has been undertaken over the past four years with stakeholders in the sector. The plan can be summarised as:

- Establish PowerelectronicsUK as a trade body to facilitate and disseminate best practice and shared knowledge across the whole UK power electronics community;
- PowerelectronicsUK to occupy a coordinating role to ensure better linkages with, and cohesion between Catapult Centres, innovation funding bodies and government to eliminate unnecessary duplication and maintain a coherent focus for technologies using power electronics;
- Support power electronics as a major pillar of the newly created Compound Semiconductor Applications Catapult;
- Instigate and deliver three major grand challenge programmes that exercise the whole UK supply/value chain and unite academia, industry and innovation support organisations to accelerate the development of key technologies; and,
- Develop and grow the UK skills base through recognition that power electronics is a unique discipline in its own right and a core competence for UK competitiveness.

Power electronics is too often a hidden industry that contributes nearly £50bn annually to the UK economy, with over 400 identifiable companies and organisations operating in the space. Importantly, the nature of the technology means that the large majority of companies are research-performing. We believe that industry leadership and focussed activity, in partnership with the public sector support, can help drive continued high growth, directly and as an enabler of other key UK sectors including automotive, energy and aerospace.

We believe that the grand challenge research programmes, coupled with expanded skills training, could unlock industry investment of over £40m over the next 5 to 7 years with the help of targeted public sector support of similar magnitude and duration. The resultant economic impact is likely to be more than £1bn per annum, given the scale and growth prospects of the current supply chain.

1. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/31795/11-1073-power-electronics-strategy-for-success.pdf*

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Contents

Introduction

Power electronics is the muscle that makes possible electric and hybrid vehicles, smart appliances, smart buildings, the smart grid, all renewable energy sources and the efficient use of electrical energy. Its applications range from mobile phones to multi-megawatt industrial motors to multi-gigawatt long distance power grid interconnections. It is a critical enabling technology to reduce energy demand across all energy vectors and is at the heart of radical innovation in aerospace, automotive, factory automation, robotics, medical engineering and communications.

Power electronics is a success story in the UK. The supply chain supports 82,000 high value jobs in design and manufacture, of which 50,000 are at graduate level, and underpins a £49bn contribution to GDP[2]. The R&D know-how in the UK encourages international companies to foster high value-add activities in the UK. Crucially, a major portion (approx. 95%) of the power electronics designed and made in the UK goes to export.

Since BIS published "Power Electronics: A Strategy For Success"[3] in November 2011, the UK power electronics community has come together through the creation of the industry led PowerelectronicsUK (a key recommendation of the strategy). Initially run as an industry led voluntary group it is now entering into a new phase as a community within TechWorks connected communities. To date it has been supported and run by the efforts of its members with no direct government intervention. In part due to the efforts and support of PowerelectronicsUK the industry has been reinforced by the creation of a dedicated EPSRC Centre for Power Electronics bringing together the UK's leading universities in the field.

For everyone who has become involved in PowerelectronicsUK, in any way, an increasing appreciation of the diversity of the industry has developed. Power electronics is a largely hidden technology that is all about the real-time control of electrical energy – stretching from milliwatt rated intelligent chip-based devices that manage battery life on mobile devices, to major feats of large scale engineering to transmit power in the gigawatt range between electricity grids. Yet despite differences, there are many common threads in the areas of skills, investment and technology that PowerelectronicsUK, building on the BIS strategy, has sought to define and articulate on behalf of the industry.

In 2013 the Technology Working Group of PowerelectronicsUK started a consultation exercise to identify the key technologies where advances could have major impact on the industry. This was undertaken through workshops, structured analysis, industry questionnaires and capability benchmarking. This was published in a green paper at the end of 2015, followed by a period of reflection and further workshops to verify the outcomes during 2016. The process involved over 65 companies and universities and input from over 100 senior engineers heavily involved in the industry.

The key issues identified did not simply focus on technologies, but on the business drivers and needs of high value-add technology development. These are aspects that can make the UK power electronics supply chain even stronger and more competitive around the world. This can be summed up in five strategic focus areas:

1. Maintaining a Robust Power Electronics Supply Chain to keep the UK in a Leadership Position
2. Maintaining UK leadership in Power Electronics through a coherent infrastructure
3. Improving Manufacturing and Design Capability and Effectiveness in Power Electronics – A Skills Issue
4. Tackling the Technology Challenges in Power Electronics
5. Developing an Industry-owned Framework to Pull Power Electronics Technology Through to Market

2. *PowerelectronicsUK Impact Review 2014*
3. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/31795/11-1073-power-electronics-strategy-for-success.pdf*

The Five Key Stategic Areas

FOCUS AREA 1 Maintaining a Robust Power Electronics Supply Chain to Keep the UK in a Leadership Position

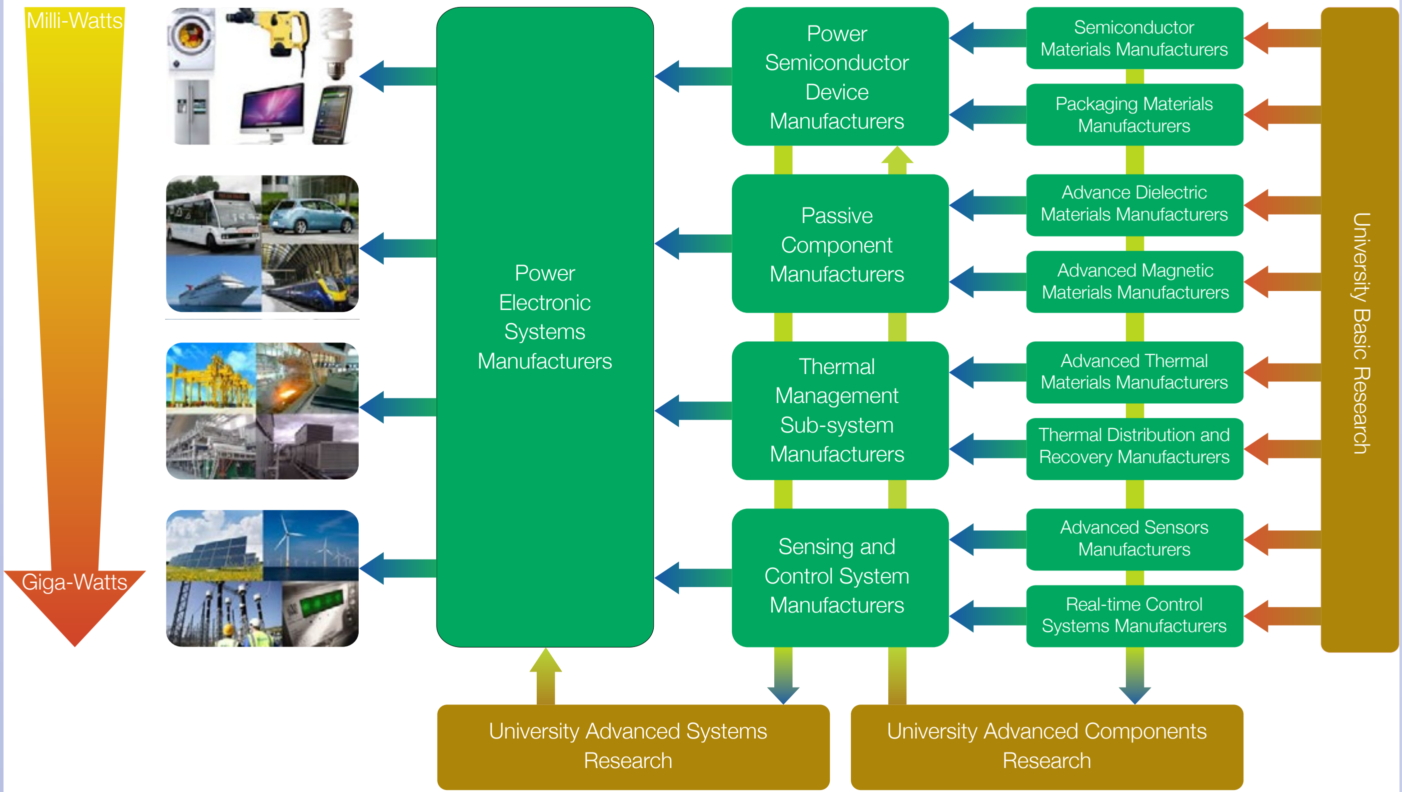
A Power Electronic System can consist of several thousand hardware and software components – especially in complex products such as hybrid cars and aircraft. The UK is a very strong player in the power electronics systems market, integrating components into functional power controllers.

Advances in component technologies, such as compound semiconductor devices or new ways of managing heat, can have a game changing impact on the way these systems are designed and manufactured.

Crucially, getting access to new component technologies early on in their development to assess how they can be adopted for commercial exploitation is a vital activity for systems companies in order to maintain market leadership.

To be competitive, systems companies source components on a global basis. However, in the highly technology-intensive power electronics space, there is a strong case for a strong local upstream supply chain where intensive supplier-customer interaction breeds innovation and optimised solutions. The joint industry work undertaken by PowerelectronicsUK showed consensus that those countries that may be considered to be strong in power electronics - notably China, Germany, Japan, USA and the UK (to a lesser, but still notable extent) – all benefit from strong local supply chains.

Proximity to technology providers in the supply chain offers cultural and geographic advantages. It eases communication of challenges, needs and opportunities and, allows parties to participate in proactive developments



The power electronics industry covers a wide spectrum of energy control spanning 12 orders of magnitude and embracing a highly technology orientated supply chain.

AESIN - providing collaborative leadership of power electronics for automotive powertrain applications

CASE STUDY

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The Automotive Electronic Systems Innovation Network (AESIN) is an industry body focused on accelerating the delivery of electronic systems in both vehicles and infrastructure. Launched in 2012, AESIN is now one of the TechWorks Connected Communities and its activities complement those of the SMMT and the UK Automotive Council.

Through work in AESIN's More Electric Powertrain (MEP) workstream, chaired by Ricardo's Global Technical Expert Dr Will Drury, the power electronic and automotive worlds unite to provide thought leadership. Members consist of representatives of vehicle manufacturers, tier one suppliers, SMEs and UK universities working together in a symbiotic relationship to facilitate the growth of power electronics and associated supply chain in the UK. The biggest electrification driver is cost and only through increased volume can the cost targets be met. Furthermore, without general consensus this will never achieved because everyone is otherwise going to pursue their own variants.

The overall goal is to ensure that the UK is best-placed to be at the forefront on technology developments within this sector. Through collaboration across the industry and, through the relaunch of PowerelectronicsUK, cross sector interactions, members are looking to collaborate to do the right thing for UK industry in growing the capability we have.

that jointly benefit from national programmes designed to promote collaboration. This ensures system integrators have easier and better informed access to emerging technologies to create disruptive, world leading products, whilst upstream component suppliers gain strong early adopters to pull through new technology.

A strong UK upstream supply chain does not necessarily mean extensive UK component manufacturing capability. It does mean having a critical mass of UK based players with global standing in the know-how and expertise relating to design and manufacture of components and sub-systems.

Despite the need for a robust supply chain there is a conflict of goals. The major underlying causes are: a combination of the different dynamics of the industries at systems and component levels, notably end user risk averseness that ripples down the supply chain. This often manifests itself as systems integrators being reluctant to reach down into the supply chain to support component development, because they don't always see the benefit of first mover advantage in the conservative markets in which many operate. Simply put, component developers need to sell to all systems integrators and no single system integrator can provide sufficient pull through to justify an exclusive arrangement, which may be counterproductive.

This market failure in supply chain engagement leads to long adoption times and barriers to entry that make it difficult for new players in the component technology area to enter the market. For SMEs this equates to a valley of death that very few successfully cross.

There is therefore a need to find frameworks and mechanisms within the UK that allow systems and component suppliers to work together to anticipate, manage and mitigate the risks that are inherent in the adoption of new technology. This lies not necessarily in addressing the technology per se, but addressing the manufacturability and ways to build confidence relating to the technology.

Importantly, this challenge is not about working in isolation, but reinforcing the UK's position as a leader in the field.

Focus Area 1 Conclusion

The UK Power electronics Industry needs to be able to better de-risk the pull through of technologies within the supply chain, focussing on key areas where we can make a difference.

FOCUS AREA 2 Maintaining UK Leadership Through a Coherent Infrastructure

Since the publication of 'Power Electronics: A Strategy for Success' in 2011, there has been considerable and very welcome public sector support for Power Electronics, notably through the creation of the EPSRC Centre for Power Electronics, and the naming of Power Electronics as a key enabling technology by Innovate UK.

In parallel, this report is the outcome of a technology road-mapping activity led by the Industry Leadership Group of PowerelectronicsUK which in itself is an outcome of the 2011 report.

There is now a strong landscape of organisations, activities and mechanisms through which power electronics in the UK can be supported including:

- PowerelectronicsUK, the UK Power Electronics Connected Community, under the TechWorks umbrella
- The EPSRC Centre for Power Electronics
- Innovate UK collaborative Funding and support
- End market-focussed innovation activities such as the Aerospace Technology Institute and the Advanced Propulsion Centre
- The Compound Semiconductor Applications Catapult
- Linked activities within other catapults such as High Value Manufacturing, Energy Systems and Transport Systems
- Internationalisation and inward investment support through UKTI and the devolved administrations
- The IET Power Electronics, Machines and Drives Network

With these elements and mechanisms in place, there is now an opportunity for greater cohesion across the power electronics landscape that will help pull-through new technologies into commercial reality.

Ways in which that can be done include:

- Better Alignment of R&D funding by Innovate UK and EPSRC within Power Electronics' Key Technology Areas will underpin those technologies and achieve maximum impact across the major application sectors
- Sustaining the EPSRC Centre for Power Electronics Research to focus on the key technology areas and act as a central point to bring together the best of the best academic research groups, support the training of graduate and postgraduate students focused on UK employability, foster industry-academia links and disseminate research outcomes.
- Make more effective use of the existing UK Catapult Centres; or, if appropriate, create a dedicated new centre; or, following the EPSRC Centre model, create a Virtual Centre focussed on power electronics design, power semiconductor device and system development.
- Through existing Department for International Trade channels, stimulate further overseas inward investment and export opportunities for the UK power electronics industry by overseas promotion and awareness of the UK strengths across the power electronics supply chain to highlight trade and investment opportunities throughout the sector.
- Establish industry-led grand challenge programmes that encapsulate the future much-in-common technology demands of the key application sectors of aerospace, automotive (& other transport), and energy, in a framework that encourages sectors to connect, share and stretch development to deliver world leadership positions.

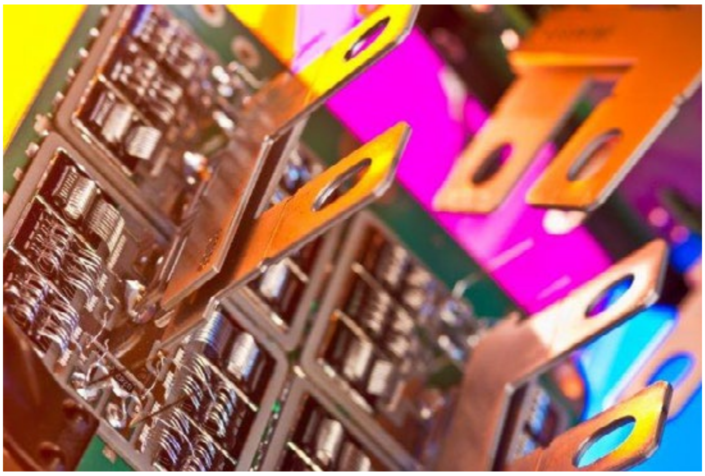
The ambition is to facilitate a UK power electronics community that delivers world-leading technology focused on the top ten technology areas that deliver maximum functional impact (see focus area 4 for the list). That impact should have strong technology connection up and down the supply chain from materials to systems. It should be funded by a strong UK power electronics and application systems industry, by inward investment and by focussed, coherent funding from UK bodies such as Innovate UK and EPSRC.

If the above ambition is realised it will sustain UK leadership in key technology areas. The impact will be to increase UK competitiveness in power electronics systems and components, and thereby increase the UK global market share in the main, high growth, power electronic applications sectors including aerospace, automotive, energy and consumer; creating jobs, attracting investment and increasing GDP.

Dynex Semiconductor: Investing in the UK's Expertise in Power Semiconductors

CASE STUDY

In 2010 one of the world's largest railway rolling stock corporations, CRRC China, took the decision to locate their Global Power Semiconductor R&D Technology Centre in the UK, based at Dynex in Lincoln. Its success after the first three years led to further investment in 2013 and the decision to expand the R&D team to embrace automotive power electronic sub-systems. These business decisions have already added more than 50 highly skill jobs in this semiconductor division, have acted as a magnet to attract inward investment in power electronics R&D research, and have enabled Dynex to continue to expand and invest in its manufacturing facility alongside the R&D centre. It was access to highly skilled power electronics talent in the UK, the strength of the UK academic research and education capability and the power electronics market opportunities in Europe that were the deciding factors in bringing this investment for the UK.



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Focus Area 2 Conclusion

The work undertaken to date by PowerelectronicsUK as a volunteer organisation has done a lot to focus industry needs. However for the initiatives that have been identified to succeed, PowerelectronicsUK needs to become a fully resourced industry association, funded by industry and working for industry, to drive supply chain cohesion and growth.

FOCUS AREA 3

Maintaining UK Leadership Through a Coherent Infrastructure

The diversity of the power electronics industry globally, and in the UK, would on the face of it make the definition of precise manufacturing needs challenging. The reality, however, is that the needs of power electronics manufacturing are not unique or indeed specific.

Power electronics manufacturing is highly competitive, and demands exceptional levels of reliability, consistency and precision. Volumes of manufacture can vary from ones to tens of thousands a day at component and standard product level through to unique systems, which may take many months to manufacture. Notable challenges faced in many power electronics products are to deliver highly robust and reliable energy management while simultaneously operating in often hostile environments (e.g. high vibration/shock, high temperature, high altitude, high humidity). This in turn must be delivered against a backdrop of ever more compact designs, improved packaging and interconnection, cheaper and more efficient thermal management and above all maintaining electrical safety. To remain competitive it is essential that the power electronics industry embraces Industry 4.0[4] with particular reference to connectivity and control of power electronic systems enabling high value, high density, automated and flexible manufacturing.

Many of the specific and/or challenging processes, techniques and skills required for power electronics manufacture mirror those of electronic systems and accordingly PowerelectronicsUK has worked alongside

Electronic Systems Challenges and Opportunities (ESCO) in this area.

Recognising the need for, and investing in, new approaches to competitive manufacturing is essential to the power electronics sector. Effective implementation however is dependent on the availability of well-trained staff. The skills shortage in power electronics impacts both design and manufacture.

Power electronics is a multi-disciplined subject embracing electrical, mechanical and structural engineers, computer scientists, physicists, mathematicians and others. At the design and senior manufacturing level, most roles are fulfilled by graduates. There is a critical shortage of available people in this area, which we (and others) have previously estimated to require a three-fold increase in the number of engineering graduates to address[5].

A fully recognised approved apprenticeship scheme would be highly beneficial to the power electronics industry. This apprenticeship need mirrors, but remains seperate to, the broader electronics systems industry apprenticeship scheme called for by ESCO.

Focus Area 3 Conclusion

To meet increasing performance demands the supply chain needs to look at the manufacture of power electronics systems as a whole rather than a collective of discrete components. The ability and bandwidth to deliver this is going to need more skilled people than are currently in the sector.

SIEMENS – Supporting the UK as a global development centre for new generation power electronics

CASE STUDY

Siemens plc is heavily involved in helping to define the UKs digitisation strategy and this includes Industry 4.0. Whilst intelligent control provides the brains, it requires power electronics to deliver the muscle to move things in many applications right through the supply chain. This extends from designing power electronics for use in motor control and wind power converter products to the implementation of smart energy systems including smart grid and smart load to designing end user solutions for conveyors, lifting, machining, pumping, cooling, energy storage and robotics to name but a few.

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Siemens Congleton design and manufacture over over 1.2 million power electronic products providing up to 18.5kW of control. There is a passion to drive innovation and productivity in order to achieve a successful sustainable future here in the UK. This needs a forward thinking UK power electronic strategy and delivery, both in terms of an innovative and supported supply chain and also access to Power Electronics research and skills. The challenges around power electronics are greater than ever, bringing with them the expectation of smaller more efficient, robust, intelligent, lower cost power electronic solutions for which the UK needs to be at the forefront in providing novel creative solutions. There also needs to be a good supply of engineers that understand Power Electronics and this requires the right strategy and investment

4. https://en.wikipedia.org/wiki/Industry_4.0
5. PowerelectronicsUK Impact Review 2014

FOCUS AREA 4

Tackling the Technology Challenges in Power Electronics

The top ten technology priority areas in power electronics that will have the greatest functional impact across the UK power electronics industry were identified and prioritized in the Green Paper, and subsequent consultation across the Power Electronics Community has refined and endorsed these findings. In ranking order of impact, they can be summarised as follows:

1. Higher reliability and more robust semiconductor devices (and substrates) together with other low level electrical components
2. More advanced semiconductors that yield better voltage and current ratings, faster switching speed, greater efficiency (lower losses), higher operating temperature and, (at high power) higher switching voltage
3. Higher performance passive components (transformers, inductors and capacitors) to better match capabilities of semiconductors
4. Integrated adaptive gate and control functionality within power semiconductor devices
5. Sensors (lower cost current and voltage measurement plus integrated functionality)
6. Advanced control software
7. Advanced converter topologies
8. Thermal management
9. Fault tolerance and system reliability
10. Accelerated testing

Encapsulating all of the above is the need to embrace more advanced manufacturing strategies and techniques. A review of these top ten technology priority areas by applications sector identified a surprising amount of coherence, verifying their collective impact across aerospace, automotive and transportation, energy and consumer sectors.

Overall, the benchmarking element of the consultation exercise identified the UK as a mid-ranking global competitor with pockets of world leadership in certain key technology areas. The lower ranking areas were passive components such as capacitors; in the mid to upper range were semiconductor devices, thermal management, control, and insulation; the highest-ranking areas were advanced converter technologies, systems reliability, sensors, and thermal management. Modelling and simulation also have a key role to play and this plays well to the UK's strength as a knowledge provider.

Critically, our consultation highlighted that the integration of new power electronic components and architectures into systems is by no means straightforward. Key issues associated with the 10 technology issues above include:

- New components create design and integration challenges and opportunities for the systems they underpin. For example, smaller and lighter power modules that can operate at higher temperatures can enable new power management architectures (very significant in marine and aerospace applications).
- Systems in safety-critical applications such as automotive powertrain management require quality and reliability data that is challenging to prove for relatively new technologies.

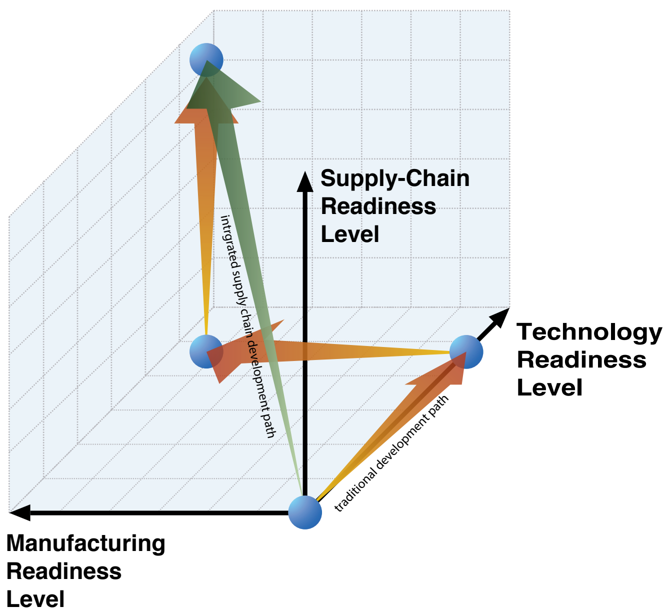
Despite the energy savings potential of power electronics it is still perceived as expensive to implement in many applications. Part of the problem is that the manipulation of electrical power places a lot of stress on the components in a power electronic system. For designers there is a constant balancing act to deliver performance and efficiency against costly over-engineering to accommodate the most onerous operational situations, which are usually only transient. However this does lead to compromises on the reliability and robustness of the power electronics. For example the lifetime of low energy lighting is more frequently dictated by the longevity of the power electronic converters in the base rather than the light source.

The challenges within this theme are twofold:

- Finding ways to design components with greater reliability and robustness without adding significant cost
- Finding ways to use and integrate components into systems that are robust and reliable without over-engineering that adds unnecessary cost

For systems manufacturers a standard approach is to try and pass risk down to the component supply level, however this oversimplifies the interaction of components and systems. This makes it very difficult for emerging technology providers to gain entry into the supply chain. To overcome this the supply chain needs to better understand each contribution to reliability and ways in which combined, joined up thinking may lead to improvement as systems complexity increases at architecture level without this.

With many component technology supply chains well established the focus needs to be on reliability of technologies in the TRL 5-7 range, i.e. closer to market, and find ways to take a more balanced, proactive approach to risk sharing. For this to happen, Supply Readiness Level (SRL), Manufacturing Readiness Level (MRL) and Technology Readiness Level (TRL) must be treated as a whole, with all three taken along their respective axis to achieve success (see figure below).



Too often new technology follows a convoluted path that shows its viability, but then requires additional funding and time to get to market often involving reinventive steps. Involving the whole supply chain from the start of the technology process can avoid step-wise funding and accelerate time to market.

By way of example in 2014 Google initiated the $1m prize "little box challenge"[6] competition to create an inverter with a power density of greater than 25 watts per cubic inch. The Belgian based winner achieved an impressive 153 watts per cubic inch. However while such competitions demonstrate what is possible with state-of-the-art technology they do not address how supply-chains work together to pull these developments into the real world.

Robust supply chains require collaborative development to manage and accelerate the speed of adoption of new technology. While different sectors have different specific needs, the technology challenges identified can be addressed through a small number of grand challenge projects that seek to address common roots and provide the basis by which diverse sectors can more readily adopt new technologies.

By defining grand challenges, potentially competing developments can be undertaken as separate but collaborative projects that involve multiple elements of the supply chain that work towards a common goal, thus providing impetus. Clear on-going coordination by an oversight body can ensure that projects continue to focus on the grand challenge and that dissemination is in place so that collaborations may evolve as progress gets closer to real end-use applications.

It is proposed that three grand challenge programmes that should run over a 5-7 year time period be instigated and themed as follows:

- "**The Watts Challenge**": Compact integrated package converter module (up to 1,000W)

  Converter building blocks that replace bulky systems used today with simple building blocks that eliminate redundant packaging and make power electronics simple to deploy – potentially including flexibility to perform a variety of tasks through simple reprogramming via a simple USB (or wireless) interface.

- "**The Kilo-Watts Challenge**": The high robustness, harsh environment converter (up to 50kW)

  Converter system designed to operate without the need for complex cooling systems able to operate in the conditions encountered in aerospace, automotive and some energy applications that can support drive-train and electrically challenging loads.

- "**The Mega-Watts Challenge**": The 11kV transformerless grid power converter (up to 5MW)

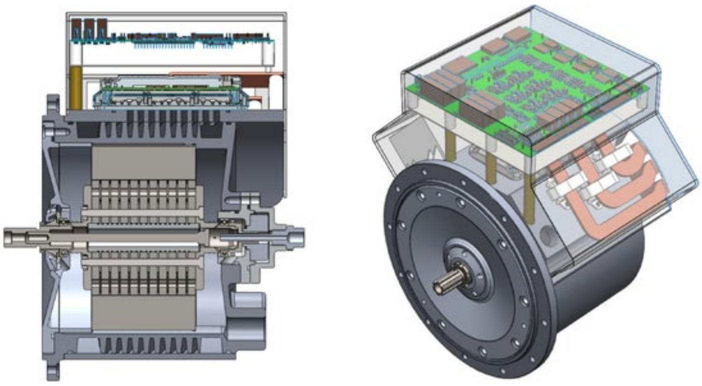
  Power electronics that can be directly connected to the electricity grid to facilitate the development of a truly smart grid. Specifically this would address the high voltage design of electronics to interface directly with utility 15kV (11kV in the UK) class distribution network in conditions that rarely optimal for power electronics.

6. https://www.littleboxchallenge.com

EPSRC National Centre for Power Electronics – Consolidating Academic Leadership and Skills

CASE STUDY

Founded in 2013 as part of a direct response to the BIS Strategy for Power Electronics, the EPSRC Centre for Power Electronics brings together the very best research groups in a UK-wide, world-leading, multi-disciplinary, virtual centre. Deep involvement of users and Government provides the industry and policy context for directing generic research into new technologies which can subsequently be translated into an applications context.



Integrated Non-Rare-Earth High Performance Drive reproduced with permission of EPSRC funded Vehicle Electrical Systems Integration (VESI) Project

During the recent mid-term EPSRC review the panel commended the Centre for bringing together leading power electronics research capability and developing an extensive and challenging research portfolio in an area that previously did not have an appropriate UK focus point. The Centre through its community-building activities, new collaborations and ventures, including those with researchers outside the more traditional power electronics community, has resulted in a clear identity for power electronics in the UK.

More detail on these challenges and how they align to the technology priorities can be found in Annex 1, which provides a more detailed outline of the sort of objectives and goals they should follow. Should these challenges be implemented further industry and stakeholder consultation would be needed.

Focus Area 4 Conclusions

1. The top 10 technology priority areas of focus for B2B, A2B and funded activity have been identified through a process of industry consensus.
2. Coalescing technology priorities around grand challenge themes so that innovation funding such as the Industrial Strategy Challenge Fund and industry roadmaps can better align to deliver against common needs along with a dissemination mechanism to ensure that best practice is shared and grand challenges are met would greatly benefit the whole UK community.

FOCUS AREA 5

Developing an Industry-owned Framework to Pull Power Electronics Technology Through to Market

Technology pull-through of disruptive power technologies is an innovation value-chain problem

Most innovation-focussed companies in the Power Electronics community believe that the supporting innovation infrastructure in the UK is good, with Power electronics a recognised key technology, albeit often embedded within wider thematic programmes. We believe that relatively small changes in emphasis, led by strong industry participation, are needed to assist technology pull-through.

The current UK innovation support landscape includes:

- Collaborative support mechanisms from funding bodies such as Innovate UK and BEIS;
- EPSRC focus, both in terms of the Power Electronics Centre, and focussed platform grants such as "Silicon Compatible GaN Power Electronics";
- A strong and growing Catapult Centre infrastructure along with other technology innovation centres that support elements of power electronics development as part of their remit;
- Well developed roadmaps in certain sectors such as automotive and aerospace that are often implicit in the role and goals for power electronics but not explicit in the detail of what power electronics needs to do to achieve those goals. An example of this is the recent announcement that Electrical Motors and Drives (where power electronics is core) is one of only 12 headline areas for increased support by EPSRC .

The UK has strength in wide band-gap (including compound semiconductor) electronic materials and devices at one end of the power electronics supply chain and automotive, energy, industrial and aerospace systems integration at the other. There are also strong pockets of world leading excellence in many of the other component and sub-system technologies that go into a power electronics system, as well as expertise into the integration of power electronics into end use applications such as cars, planes, trains and industrial plant. The consultation exercise found that, while end applications may be very different, there are many commonalities in the implementation strategies for power electronics.

Given that R&D resources are finite, sharing best practice and avoiding unnecessary duplication of effort is therefore a requisite. This applies to facilities as well as knowledge. An example of this is access to independent testing and validation facilities. Given the breadth of the sector, there is unlikely to be a one size fits all solution, but establishment of a distributed capability that builds on existing pockets of capability could provide independent and, equally importantly, cross-sector validation of new technologies.

An on-going challenge is the highly conservative nature of many industries, driven by concerns of reliability, safety and operational security. As the discussion in focus area 1 has highlighted, the business imperatives of component and systems manufacturers can make meaningful collaboration challenging. Innovation support funding mechanisms with longer-term support horizons would help the bridge the "valley of death" that is a major problem for SME technology developers in power electronics. Correctly structured goal-driven projects that involve clear supply chain involvement would ensure continuity for successful programmes. By providing greater security of support, organisations would be able to focus on delivering disruptive world-leading technology rather than being distracted by the need to maintain the finance runway to get there.

The intention of the grand challenge programmes, outlined in the previous focus area discussion, is therefore to provide a series of umbrella themes that enable industry, government and academia to structure multiple projects that collectively work towards delivering a common vision.

For the grand challenges to be successful they have to:

- Have simple headline goals that can be communicated outside the community and be supported by detailed roadmaps that ensure that the correct technologies are delivered;
- Operate over a 5 to 7 year horizon with goals that deliver world leadership but at the same time be realistically achievable by the end of the cycle;
- Evolve over time so that greater (but not exclusive) emphasis on fundamental enabling component technologies at the start translates into greater emphasis on systems integration towards the end of the programme to ensure that one or more advanced proof of concept demonstrators that are relevant to key adoption sectors are delivered;

ATI – Defining the Goals and Strategy to Deliver the More Electric Aircraft by 2035

CASE STUDY

In 2016, the Aerospace Technology Institute (ATI) published an updated technology strategy and portfolio update, Raising Ambition. This document identified four strategic themes: Aircraft of the Future; Aerostructures of the Future; Propulsion of the Future; and Smart, Connected and More Electric Aircraft. In this fourth theme, there is a key element around 'enabling introduction of more electric systems'. These more electric systems drive the need to develop more electric architectures, electrical machines, and power electronics. Aerospace needs power-dense power electronics as an enabler for new aircraft and propulsion architectures – supporting the continued development of more electric aircraft and the introduction of hybrid or all electric propulsion.

More Electric Engine concept reproduced with permission of Rolls-Royce plc

Power converter technologies will be key to high power (Megawatt) electrical systems for propulsion and a power density target of 50kW/litre compared to conventional air cooled converters (currently limited to 20kW/litre) is envisaged. Continued research and development is necessary for a range of technologies and in the application of new materials, innovative designs, power converter topologies, manufacturing techniques and semiconductor devices/packaging. The combined impact of these underpinning technologies on the design and construction of electrical machines and power converters will be significant. Technology development to deliver these capabilities needs to achieve market readiness within a horizon of the next ten years.

- Embrace competing clusters that allow different technologies to compete to deliver the goals;
- Involve the whole or significant portions of the supply chain and operate on a collaborative basis so that they advance manufacturing, supply and technology readiness levels;
- Be managed so that best practice is shared and becomes fed into industry specific roadmaps; and,
- Be constantly reviewed to ensure that the vision is sustained and successfully delivered.

Notwithstanding the role of industry and academia in the above, to deliver against the grand challenges will also require the support of EPSRC, Innovate UK, BEIS and the expected Industrial Strategy Challenge Fund due to launch later in 2017. Working together all parties will need to coordinate and collaborate to ensure UK organisations to work together towards these goals. Here, PowerelectronicsUK could play a major role in facilitation of this process, ensuring that the community reviews shared goals and objectives and that as many stakeholders as possible are given a chance to provide and input into this process.

Focus Area 5 Conclusions

There is an acute need for a point of focus to drive innovation in the 10 key technology priority areas. Rather than create a single physical hub there needs to be better coordination of the development path that:

1. Brings both ends of the innovation value chain together: the materials and device innovators and the systems integrators;
2. Provides a platform that also addresses intermediate technologies such as packaging, reliability, performance validation and component integration;
3. Avoids unnecessary duplication while embracing and sustaining competition between alternative technologies directed towards common goals.

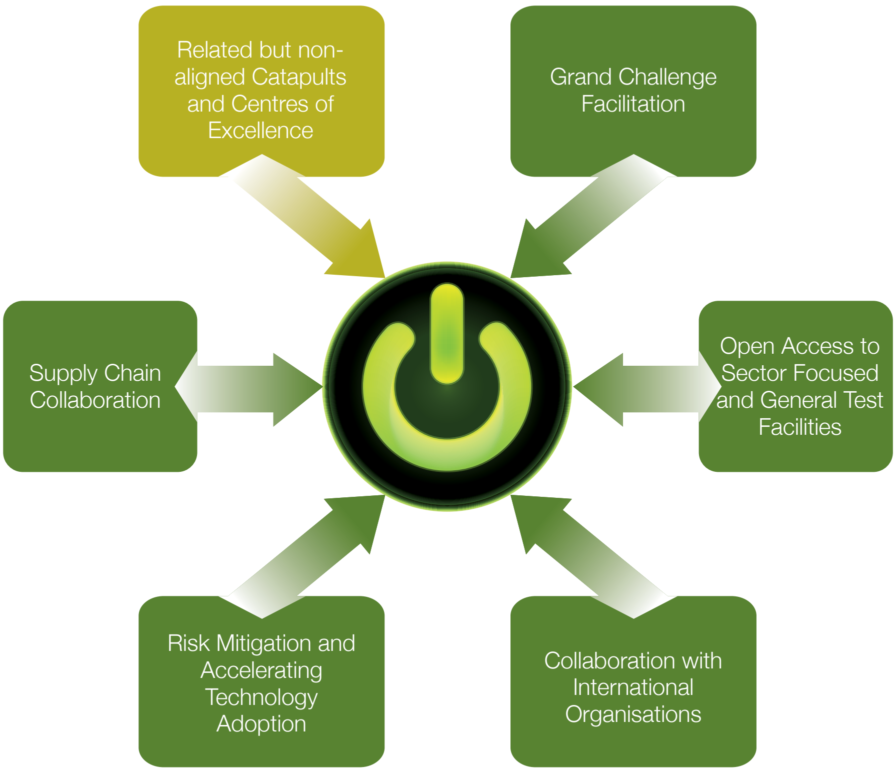
Recommendations

Recomendation 1

Escalation of the role of PowerelectronicsUK as an industry-led focal point for power electronics activities in the UK. This will require PowerelectronicsUK be a member supported body with a small, but full-time, coordination team that will work with the membership and wider afield to promote and facilitate the growth of the UK power electronics sector.

The proposed foci of PowerelectronicsUK would be:

- To work with the UK innovation support system (BEIS, Catapults, Innovate UK, EPSRC etc.) to help facilitate development and innovation in the key technology areas identified; and, to periodically review technology needs to ensure that priorities are addressed.
- Maintain oversight of the grand challenge programmes, consulting with members and stakeholders to ensure that programmes remain relevant and institute mechanisms to ensure transfer of best practices between the programmes.
- Work with UK industry, academia, research organisations and government to ensure that the industry has access to suitable test beds and facilities, and support developing cross-sector test benchmarks.
- Building, facilitating and maintaining collaborations between UK component suppliers and systems integrators
- Supporting supply chain projects to develop balanced and mitigated risk plans that accelerate the introduction of new technologies and practices
- Liaison with existing catapults and related, but non-PE specific, technology centres of excellence to minimise duplication and to ensure that the power electronics community has access to arising innovation and best practice
- Develop and maintain relationships and collaborations with similar international organisations



As an industry led body, PowerelectronicsUK has a central role to play in ensuring that the whole supply chain works together to improve UK global competitiveness in power electronics

Recomendation 2

The implementation of three major grand challenge programmes that exercise the whole supply/ value chain and unite academia and industry to accelerate the development of key technologies.

These projects will seek to drive parallel technology developments that can run as separate projects but work towards common goals. It is proposed that the projects should be themed as set out in more detail in focus area 4 and Annex 1 under the umbrella themes of:

- "**The Watts Challenge**": The compact single integrated package converter (up to 1,000W)
- "**The Kilo-Watts Challenge**": The high robustness, harsh environment converter (up to 50kW)
- "**The Mega-Watts Challenge**": The 11kV transformerless grid power converter (up to 5MW)

Making these programmes will require not only further work to ratify and agree goals, but also the support of government in the form of its funding agencies to match the investment that the industry itself will be prepared to put into these programmes.

Recomendation 3

Develop and grow the skills base through recognition that power electronics is a unique discipline that integrates electrical, electronic, mechanical, materials and software skills – often operating at the limit of what technologies can deliver. As an underpinning and often hidden technology it is not an obvious first choice of career for STEM minded students at all levels.

To maintain the UK's position in as a leader in power electronics the following actions are recommended that would address skills gaps and further grow and develop the skills base:

- Creation of a Centre for Doctoral Training in power electronics, ideally building on the existing EPSRC Centre of Excellence to ensure that the UK continues to produce top-flight power electronics engineers;
- Creation of a recognised apprenticeship scheme to develop skilled power electronics technicians and engineers – recognising that some of the best engineers often emerge from this vocational route. While larger companies can tailor programmes, there is a broad base of SME's within the supply chain that would benefit from being able to put apprentices through recognised accredited schemes or potentially through collective schemes that an organisation such as PowerelectronicsUK could facilitate. However for such schemes to work, this would require industry and academia to work together to create of a small number of suitably geographically located centres within the existing training infrastructure (possibly in collaboration with the EPRSC hub) and support initiatives to encourage people to enrol on these courses; and,
- In order to overcome nearer term skills shortages the UK power electronics industry would also welcome the discipline of power electronics design and development being included on the UK skills shortage list, and for government to recognise that the ability to attract and recruit good engineers and technicians from a global pool is an imperative for the UK to be competitive in the sector.

Recommendations Summary

The recommendations in this white paper have been arrived at through extensive consultation with the power electronics industry over the past four years. The three actions outlined are first and foremost about the industry and community coordinating and working better together. However there is a clear role for government and its support agencies to look at the support mechanisms necessary to drive growth in this important, high value exporting industry. PowerelectronicsUK can provide a pivotal point of focus to ensuring that all concerned get the best return possible.

Appendices to the White Paper

ANNEX 1 The Grand Challenge Projects

The Watts Challenge

The Watts challenge would focus on the creation of compact integrated packaged converter building blocks that effectively replace bulky systems made up of discrete components used today with building blocks that eliminate redundant packaging and make power electronics simple to deploy – potentially including flexibility to perform a variety of tasks through simple reprogramming via a simple commercial serial (or wireless) interface.

By significantly reducing the cost of deploying electronics at the supply level this would lead to greater energy efficiency of domestic and light industrial equipment and enabling economic implementation of energy management concepts associated with smart homes. In this challenge both a low unit cost for the equipment, and low energy losses to minimise running costs and achieve low carbon are key requirements. The Watts challenge would address the needs of sectors against the top 10 technology prior:

- Domestic motor drives (washing machines, vacuum cleaners, refrigerators etc.)
- Embeddable converter modules for domestic PV and other micro-generation or domestic energy storage systems
- Low power industrial tools

The Watts challenge would address the top 10 technology challenges as show in the table below.

Technology Priority		How the Watts challenge addresses priority
1	Higher reliability semiconductor devices and components	Determination of safe operating area and practices for highly integrated component assemblies
2	More advanced semiconductors	Development of wide bandgap high power speed semiconductors capable of >20MHz switching
3	Higher performance passive components	New materials and elimination/ minimisation of packaging
4	Integrated control functionality within power semiconductors	Single chip or multi-wafer integration of power and logic functions
5	Sensors	Low cost voltage, current and temperature sensors
6	Advanced control software	Advanced control algorithms interlinking with smart meter and start home requirements
7	Advanced converter topologies	High speed converter designs that integrate and optimise AC:DC, DC:DC converter concepts
8	Thermal management	Advanced thermal substrates and heat flow management in dense packages
9	Fault tolerance and system reliability	Safety and fail-safe strategies of highly integrated converters
10	Accelerated testing	Development of test beds and regimes to validate modules

Goals for the Watts Challenge

- Deliver mains level power conversion/control at >10Wcm-3 in converters up to 1,000W
- Single safe encapsulated design with minimal packaging (i.e. avoidance of redundant packaging around components with optimised insulation coordination
- Incorporation of both AC to DC and DC to DC conversion functionality to accommodate integration with energy storage and DC busses
- Programmable from simple serial interface

The Kilo-Watts Challenge

The Kilo-Watts challenge would focus on the development of a compact, light and robust, harsh environment converter (up to 50kW). The goal would be a power electronic system designed to operate without the need for complex cooling systems or else able to operate using the limited thermal management options that may be available in the end use application.

The Kilo-Watts challenge would able to operate in the conditions encountered in aerospace, automotive (including public transport) and some energy applications. The common denominator is that all present electrically challenging loads, which require power electronics that can be integrated into a drive-train of some sort (i.e. taking mechanical energy and converting to electrical energy or vice versa).

The Kilo-Watts challenge would address the top 10 technology challenges as summarised below.

Technology Priority		How the Kilo-Watts challenge addresses priority
1	Higher reliability semiconductor devices and components	Design of components for high mechanical stress and high ambient temperature environments, better component monitoring
2	More advanced semiconductors	Devices able to operate up to 400ºC and lower losses
3	Higher performance passive components	Complimentary components able to operate up to 400ºC, novel packaging/ assembly for better integration into drive train systems
4	Integrated control functionality within power semiconductors	Embeddable (or more easily integrated) gate drive and accompanying monitoring functionality
5	Sensors	High accuracy, low cost DC current DC voltage sensors and temperature measurement up to 400ºC, better component monitoring
6	Advanced control software	Better real-time monitoring and control, adaptive knowledge based load behaviour response, improved inter-systems communications and coordinated response
7	Advanced converter topologies	EMC compatible, high frequency converter design up to 2MHz, design of systems for high mechanical stress environments, adaptive topologies to accommodate component failure
8	Thermal management	Integrated thermal path and heat conduction systems utilising ambient resources
9	Fault tolerance and system reliability	Critical component redundancy optimisation and fail-safe strategies
10	Accelerated testing	Development of test beds and regimes to validate power electronics in drive trains, identification of cross-sector validation techniques

Goals for the Kilo-Watts Challenge

- Deliver power conversion/control at [>5kWkg-1] in converters up to 50kW
- Achieve conversion efficiency of 99.2%
- Ability to operate in ambient conditions of -40ºC and up to +250ºC with no forced cooling
- Minimal packaging (i.e. avoidance of redundant packaging around components with optimised insulation coordination
- Flexible form factor allowing for mechatronic integration

The Mega-Watts Challenge

The main goal of the Mega-Watts Challenge is to realise the high voltage connection of energy efficient power conversion systems to the 15kV (in the UK, 11kV) electricity distribution network without the need for an interface transformer. The availability of power electronics that can be directly connected to the electricity grid are probably the most cited required building block to facilitate the development of a truly smart electricity grid.

The Mega-Watts challenge would address the needs of sectors such as below:

- Smart buildings, in particular the high side stage of the intelligent transformer
- Larger scale energy storage
- Grid connection of larger renewable energy sources
- Reinforcement of the distribution grid through light High Voltage DC schemes
- Industrial and grid compensation systems to balance and regulate power flow on electrical networks (Statcoms, UPFC etc.)

The Mega-Watts challenge would address the top 10 technology challenges as summarised in the table on the next page

Goals for the Mega-Watts Challenge

- Deliver transformerless connection of power electronics at up to 5MW to the 15kV class electricity
- Low running cost
- Compliance with grid codes driving harmonics, DC offset etc.
- Ability to withstand grid faults
- Able to use ambient cooling (i.e. no forced cooling)
- Transformation of electricity from one voltage to another at >99% efficiency

Technology Priority		How the Mega-Watts challenge addresses priority
1	Higher reliability semiconductor devices and components	Design for 25 year life, minimisation of maintenance consumables and strategies, improvement of components to deliver overall reliability of >99.8%
2	More advanced semiconductors	Up to 22kV power switching devices and diodes, able to operate up to 200ºC
3	Higher performance passive components	High frequency power magnetics, high voltage (up to 25kV DC)/ high ripple capacitors
4	Integrated control functionality within power semiconductors	More advanced integrated gate drives to permit series connection of power semiconductors
5	Sensors	Low cost AC voltage and current sensors to 25kV
6	Advanced control software	Better real-time monitoring and control, adaptive knowledge based load behaviour response, improved distributed-systems communications and coordinated response
7	Advanced converter topologies	Adaptive topologies to accommodate component failure, design of high voltage converters to avoid corona and partial discharge failure
8	Thermal management	Minimisation of pumped liquid cooling systems, better heat exchange systems
9	Fault tolerance and system reliability	Grid fault response capable systems (over current ride through, lightning or switching surge response, protective actions), system diagnostics
10	Accelerated testing	Development of actual grid test beds with reduced regulatory burdens, creation of laboratory test beds to pre-validate ahead of field demonstration

ANNEX 2 Contributors to the Green/White Paper Workshops and Feedback Process

The UK supply chain in electronics covers everything from materials supply to systems end users, with well over 400 identifiable companies working in the space. In the course of this exercise, many organisations within the supply chain have been engaged. These include:

Amantys Ltd.
Anvil Semiconductors Ltd
API Capacitors Limited
Aston University
AVID Technology Group
AVL Powertrain UK Ltd
Coilcraft
Converter Technology
Cranfield University
Davtrend
DeMontfort University
Dialog Semiconductor
Dynex Semiconductor
Element 6
Evince Technology Ltd
GaN Systems Inc.
GE Aviation Systems
GE Grid Solutions
GE Power Conversion
UTC Aerospace
Imperial College London
INEX Microtechnology
Inspirit Ventures Limited
IQE
IXYS Westcode
Jaguar Land Rover
Safran
Landis & Gyr
Liverpool John Moores University
Lotus Cars
Manchester Metropolitan University
Manufacturing Technology Centre
Microsemi
Newcastle University
Nidec
API Capacitors
NXP Semiconductors
On-systems ltd
Plessey Semiconductor
PPM Power
RAM Innovations Limited
Raytheon Systems Limited
Renishaw
REO
Ricardo UK
Rolls Royce
Semefab (Scotland) Limited
Staffordshire University,
Supply Design Limited
Swansea University
TDK-Lambda
Turbo Power Systems
University of Sheffield
TMD Technologies Ltd
Tribus-D
Ultra Electronics Limited
University of Bath
University of Birmingham
University of Bristol
University of Cambridge
University of Glasgow
University of Greenwich
University of Manchester
University of Nottingham
University of Warwick
UTC Aerospace Systems

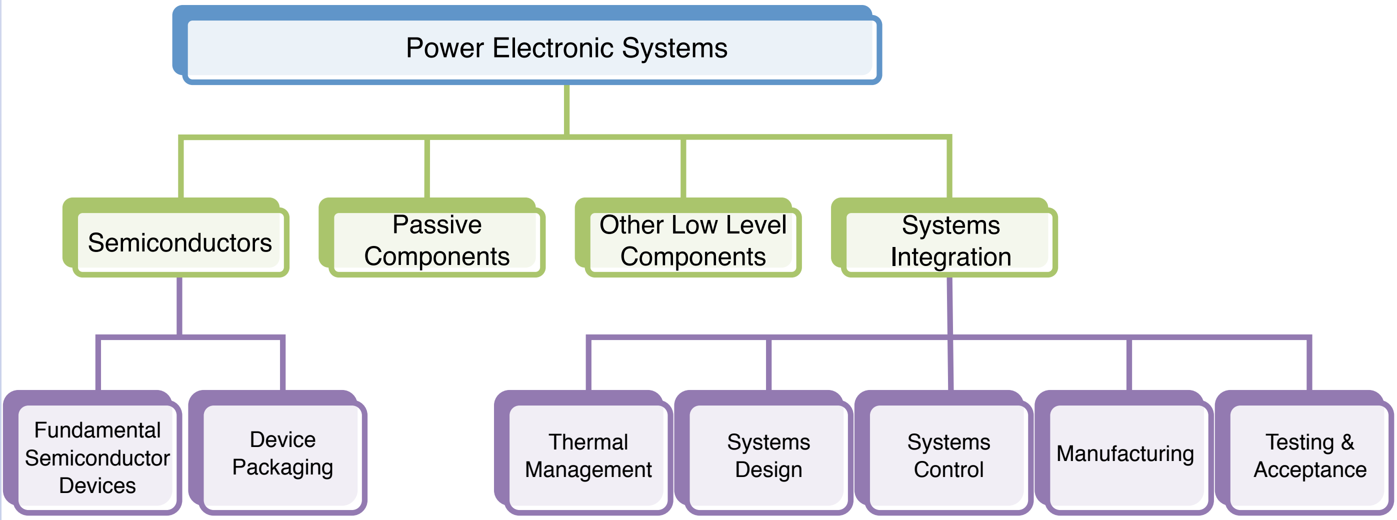
ANNEX 3 White Paper Methodology

In order to get the widest cross-section of opinion across the industry the PowerelectronicsUK technology working group used a structured market prioritisation tool that broke power electronics was broken down into 42 functional technical attributes (these were later reduced to 37 that could be broadly categorised as shown in the figure below. From the start the approach taken was to identify and define those functional needs that would have most impact on the industry without any supposition of any specific technology that might deliver that technology. This approach ensured that partisan bias was kept to a minimum.

Through an online questionnaire sent to a broad range of members of the power electronics community, that yielded 57 responses, these attributes were benchmarked for the impact they would have on delivering a step-change against a number of "go to the moon" projects. These projects were spread across four industry sectors and represented generic challenge themes within the sectors with a 7-10 year horizon to deliver technological impetus.

From this work it was then possible to identify not only those attributes that could lead the greatest impact, but also to identify commonalities and differences between projects and industry sectors. The survey also yielded a pragmatic assessment of the UK's competitive position that was debated and discussed at a workshop held on 19th June 2014. Together the results and discussion outputs formed the basis of a green paper containing 12 findings published in November 2014.

The green paper was downloaded by over 120 organisations and led to 26 formal responses in early 2015 and was further debated at an invited workshop of 20 senior members of the power electronics community held in July 2015. This led to a focussing of the findings and the prepared the basis for the white paper.



Power electronic systems were broken down into a hierarchy in order to identify key underpinning technological components required to manufacture them

Empowering the UK power electronics industry through...

- ☐ Leadership
- ☐ Engaging the community
- ☐ Promoting capability technology
- ☐ Supply chain
- ☐ Skills

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