Prioritisation of Enabling Technologies for Power Electronics to Enable UK Industry to Capitalise on Market Opportunities

Consultation Green Paper

Issued to the Power Electronics Community

Key Dates

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Responses required by: 09th January 2015
Green Paper on Technology Prioritisation for UK Power Electronics
Released 17th November 2014 – Responses Required By Friday 09th January 2015

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Introduction

Over the past 5 years, thanks to the strategy initiative supported by BIS that led to the publication of “Power Electronics: A Strategy For Success” 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) and, more recently, the establishment of the EPSRC Centre for Power Electronics. The overall aim of both organisations is to ensure that the UK continues to be a major player in the £135bn power electronics market with recognised global excellence in specific areas.

For all the people who have been involved in PowerElectronicsUK in any way, one of the major learning experiences has been to realise just how diverse the industry is – stretching from intelligent chip-based devices that manage battery life on mobile devices, to major feats of large scale engineering to transmit power from mW to GW between separated electricity grids over long distances. Another learning experience has been that the supply chain is both complex and diverse, especially across different industries. Yet despite obvious differences in technology, a large number of common threads have been identified in areas such as skills, investment and technology to name but three.

Over the past 18 months the Technology Working Group (TWG) of PowerElectronicsUK have been undertaking an industry-led effort to identify and prioritise key areas of technology that will have the greatest impact on future power electronics. It must be emphasised that the purpose of the work was not to identify specific technologies such as a preferred wide bandgap semiconductor or converter topology, but instead to identify functional areas where advances in technology would have the greatest overall impact across the industry and for specific industrial sectors. This underpins a belief that rather than try to prescribe specific roadmaps that constrain efforts to specific technologies (which other national strategies such as that in the United States have sought to do), it is more important to define functional market driven goals against areas of greatest impact and let competing technologies vie to deliver the best solution.

This green paper sets out the methodology undertaken and the fledgling proposals for moving forward. The industry input was through consultation with over 60 industrial and academic participants in the UK power electronics community. The result is 12 key findings that address a wide range of issues and opportunities facing the UK power electronics community.

As a green paper, recipients from all walks of the supply chain are invited to respond to the information presented here through written responses to the questions posed. This information will be used to solidify the report for publication as a white paper before the end of 2014. It is hoped that this white paper will help to create common goals and foci that will enable all stakeholders in the UK power electronics community to work more closely together to develop world-class areas of excellence.
Submitting a Response to This Green Paper

Closing date for submission of responses is Friday 09th January 2015

Please structure your responses against the questions raised in this paper. You can submit a response to this paper in the following ways:

Submission of your responses via the questionnaire on the PowerelectronicsUK website, please follow the link on the home page:

http://www.power-electronics.org.uk

Or, email a completed response form that can be downloaded from the website to: info@power-electronics.org.uk

Or, formal letter addressed to:

Power Electronics UK Green Paper
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Suite 47, Geddes House
Kirkton North
Livingston
West Lothian
EH54 6GU
United Kingdom

Please structure your responses against the questions posed within this document to enable us to properly collate information. In all cases please state your name and your affiliation – anonymous responses will not be considered.

The impact and quality of the white paper that will emerge from this consultation process early the first half of 2015 will be magnified significantly if all tiers of the power electronics community respond to this paper. So please participate – all responses are valuable, no matter whether they are comprehensive or just focussed on the questions arising from one or two of the findings. If you have any data, or examples of successes, that reinforce or contradict these findings these would also be very welcome.
Methodology

Rather than try to pursue consensus through workshops, which can only sample a small number of the Power Electronics community, to get a wider cross section a Quality Function Deployment (QFD) methodology was adopted as a basis for collecting and collating data. This is a well established matrix based technique for prioritising functional requirements against market needs – which can be at first daunting, but does quickly lead to priorities being established.

To facilitate the analysis power electronics was broken down into 42 functional attributes (later reduced to 37, see Appendix 1 for complete breakdown) that could be broadly categorised as follows:

![Hierarchical way in which power electronics were defined as functional technological areas](image)

These attributes were then 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. Hence the projects, or variants of them, could be used as the basis of pre-competitive research that could unite the industrial and academic communities.

The analysis covers 4 broad industry areas:

- Energy
- Automotive and Transport
- Aerospace
- Consumer (including lighting and light industrial)

The specific projects identified are defined in the industry sections that follow. For each project correspondents from the TWG were asked to rank the impact of a technological step-change in
each of the functional categories to deliver goals of the project. From this initial 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.

![Diagram showing QFD matrix for technology prioritisation](image)

**Figure 2:** Basic layout of the QFD matrix used as the basis of gathering and collating information

Once the prioritisation of technologies was complete, attention was focused on the identification of areas where the UK may be best placed to deliver technology advance, and what value these industry sectors may bring to the UK. Both of these were undertaken using a benchmarking method. In the case of the functional benchmarking, this was undertaken using an online survey that was completed by 33 invited industrial and 24 academic respondents (see demographic breakdown by sector expertise in figure 3 on next page). This has yielded a pragmatic assessment of the UK’s competitive position that will hopefully stimulate debate regarding collective ability to deliver world-beating technology and where emphasis might be placed to the benefit of a number of industrial sectors.

The results of the exercise were reviewed and discussed at a workshop held on 19th June 2014. Together the results and discussion outputs form the basis of this paper.
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Figure 3: Breakdown of respondents to the benchmarking survey by sector representation

It is anticipated that this exercise will be repeated on a bi-annual or tri-annual basis to assess where the UK is and to ensure that priorities are maintained. The results of this work will be used to inform the whole power electronics community and our stakeholders such as EPSRC, Innovate UK, UKTI, BIS, industry and academia.

Question I: Does the methodology used sufficiently capture technology needs, or is there further information capture that should be considered to ensure the published papers address the needs of the UK Power Electronics community.

Question II: Do you agree that an exercise such as this should be carried out periodically for UK Power Electronics? If so what frequency do you think is best?
Technology Working Group Contributors

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Input also received from the following organisations (note some of the above organisations also provide more than one set of inputs):

Aero Engine Controls, Aston University, Cranfield University, Davtrend, Dynex Semiconductor, ESP KTN, GaN Systems, GE Aviation Systems, IXYS, Liverpool John Moores University, Manchester Metropolitan University, Raytheon, Sheffield University, Staffordshire University, Supply Design, Swansea University, TMD Technologies, University of Birmingham, University of Cambridge, University of Glasgow, University of Warwick
Preliminary Findings

Finding 1: While the UK Power Electronics Industry has a Robust Supply Chain There is a Perception That it Has More Strength in Depth at the Systems Integration Level Rather than at Component Level.

The results of the benchmarking analysis suggest that UK industry is stronger at the systems integration than at the fundamental component technologies level. It is possible that this outcome is again due to the cross-section of the people involved tending to represent the systems end of the Power Electronics sector and serves to highlight the need for the community to engage at all levels of the supply chain.

At the systems level, the UK is effectively an intelligent customer of emerging technologies. Given that component suppliers need to address global markets there is therefore an argument that could be the most cost effective way forward.

However the workshops also recognised that while this approach may work in theory, there are cultural and geographic constraints that can make this difficult (unless you are a truly multinational organisation) to implement in a way that ensures that UK companies are tapping into best leading technologies and getting inside tracks to their deployment. Hence while there is argument for greater emphasis on developing a stronger power electronic systems capability, this has to be balanced with a robust and vibrant UK based upstream supply chain.

Question 1A: Do you agree with this finding? Is having a UK supply chain that is robust at all levels important?

Question 1B: Should the UK focus further developing systems integration capability only, or should more emphasis be placed on levelling a potential imbalance across the supply chain with component-level support and intervention to ensure a stronger UK capability across the board?

Finding 2: Passive Components are a Component Technology that Urgently Need Innovation

Perhaps a surprising result of the QFD process was the identification of passive components as a significant weak link in Power Electronics technology capability. All sectors identified a need for capacitors and inductors that have a smaller physical footprint, and are better able to cope with the higher frequencies and voltages enabled by emerging power semiconductor devices. Further, there was a general requirement to push the current operational envelope well beyond what is commercially available today as the use of Power Electronics increases. Such advances would permit more radical converter topologies to be considered and deliver far greater power
densities (i.e. kilowatts per kilogram and/or kilowatts per litre depending on sector) than is achieved today.

Much of the analysis has highlighted capacitor technology as the area needing significant advances in energy density (at a range of voltages – not just supercapacitors), and the ability to cope with higher frequencies and operating temperatures. However magnetic components were also cited as needing improvements – especially considering the significant cost of current materials such as magnetic steel and copper. In the case of magnetic components it was noted that the industry is highly dispersed with very few (if any) large players, although the workshops felt that the UK does have some strong capabilities at the SME level. The perception however is that while there is considerable know-how there is a very low science base through a combination of low levels of investment and little prior incentive to innovate in this area.

The benchmarking analysis indicated that the UK is not perceived as strong in passive components (both academically and industrially), however the workshop could not identify anywhere else that had a significant lead. This suggests that passive components may be ripe for focused R&D investment possibly through the creation of a hub that builds and expands on the work being undertaken within the EPRSC Centre for PE.

**Finding 3:** For Other Low Level But Key Components and Technologies in PE Systems – Collaboration with Other Supply Chains (both Upstream and Downstream) is Required Rather than Unilateral Focused Effort

Sensors were highlighted as one of the major areas of technology impact to the industry. At the level of the survey method used it was not possible to identify whether there is a particular area of sensing where a step-change would have a major impact, but there was a perception that the major thrust comes down to lower cost and greater accuracy.
With the exception of adaptive gate controls (which are specific to the industry), the workshop consensus was that low level components with wider application than power electronics such as sensors, electronic components, communication busses and low level control software were something that the PE supply chain would be better off finding ways of tapping into or collaborating with developments in other industry sectors rather than simply working within the Power Electronics community.

Question 3A: How can the UK Power Electronics Community better link with other supply chains to help integrate enabling low-level technologies into new Power Electronics Systems? Should this be left to individual company initiatives and collaborations, or is there a wider approach that the Industry itself can take?

Question 3B: Are there particular areas of sensing were major improvements are required?

Finding 4: Advances in Semiconductors are Essential, But the UK Needs to Focus on High Value Cutting Edge Technologies Where It Can Make a Bigger Impact In The Area

As might be expected the analysis work highlighted the fundamental enabling role that advances in power semiconductors play in driving advances in Power Electronics systems. Given that the operational voltages for many applications are not expected to increase, generally emphasis was given to advances that would lead to a reduction in on-state voltages and higher switching frequencies. Further, while improvements in power semiconductors are perceived as the enabling building block of Power Electronic systems it is widely recognized that there is a dynamic at component level – whereby better active devices require better passive devices and vice versa.

For the aerospace and automotive sectors, advances are needed in higher temperature control electronics (200°C sink temp, >300°C junction) especially in the 800V-1kV range. For the energy sector it was also noted that advances in higher voltage electronics (particularly >15kV) could have a major impact on the enablement of many smart grid concepts – potentially opening up applications that to date have been too expensive to implement with existing technology such as intelligent transformers.

The workshops and the benchmarking analysis have identified that UK lags behind other countries such as the USA, Japan and Germany in investment in many of the emerging wide bandgap technologies. Given the significant £100m's that other countries have invested in R&D for many high volume applications, heavy investment in catch-up activities is unlikely to yield
significant results. However it was felt that there are notable strong industrial and academic capabilities in the UK in many high value technology areas that are capable of making an impact on a global basis and therefore are candidates for significant focused investment. These capabilities could be broadly summarised as falling into in three categories:

- Established semiconductor manufacturing infrastructure backed by R&D capability
- Fabless design capabilities (academic and industrial)
- Emerging players with strong sector specific power semiconductor technologies (academic spin-outs and industrial start-ups)

For all the above, support for collaborative efforts to tackle selective focused opportunity areas such as those discussed already in this finding could yield businesses able to occupy a top 10 position in power semiconductors within their fields. It is worth noting that unlike a lot of mainstream semiconductor investments in the UK, Power Electronics fabrication investments have tended to have greater “stickability” due to a number of factors including:

- The greater know-how required to manufacture power semiconductor devices
- The creation of accompanying R&D capabilities around PE manufacturing facilities
- The importance of reputation and traceable components to a conservative industry

Question 4A: Where are the technology (or system) areas in semiconductor power electronics where significant (10s of £m+) focused public-private support in the UK would enhance UK strength?

Question 4B: What would be the best mechanisms to focus investment – through Innovation centres such as Catapults, demonstrator projects or pilot lines based in existing manufacturing and design facilities, though targeted support for pockets of excellence or some other approach?

Finding 5: Systems and Enabling Low Level Technologies to Improve Reliability and Availability are Key

The workshop activity identified that, with increasing pressure on companies throughout the supply chain to take on a greater share of the risk over the life of products supplied, reliability and availability (and, to a significant though lesser extent, fault tolerance) are increasingly important. With this matter extending from components through to systems this area is hence subject to a wide range of issues and solutions.
Within this, functional lower level technologies such as adaptive gate controls were cited as a major area for development and exploitation. Likewise condition-monitoring techniques to facilitate system health management should also be considered to part of the solution. In the case of the latter, the workshops highlighted that many approaches have already been developed and explored but that implementation in commercial systems has so far been limited (with the general exception of very high end systems where these factors can command significant penalties in the event of failure).

The perceived challenge for this finding, is that while systems can be designed to have very high reliability and availability through use of over-specification, redundancy and complex monitoring, in most cases this is not a cost effective option. Further, it does not address the observation that this is a supply chain issue not just a matter for the systems integrators. Hence component/knowledge based approaches are important, so too is the need for integration (and, by implication, finding ways to cost effectively improve availability and reliability). Overall this area is seen as an area ripe for active research and collaboration.

**Question 5A:** At what levels in the supply chain would collaborative activities be meaningful in this area? Are there any specific areas not mentioned that are ripe for exploration?

**Question 5B:** What should be the focus of any supported activity in the area – developing partnerships with EPSRC and the Universities to look at the longer term picture, or looking at closer to market developments?

**Finding 6:** While There May Be Specific Needs for Advanced Manufacturing, It is Not Seen as a Transformative Issue for the Power Electronics Industry, However Greater Proliferation of Advanced Skills May Be More the Issue

For all sectors other than consumer, advanced manufacturing was not perceived as being a priority to power electronics. A possible explanation for this is that the analysis did not seek to clarify where in the technology supply chain advanced manufacturing is required and/or that the sample of people who participated in the process were not sufficiently involved in this aspect of power electronics. Alternatively this may be symptomatic of the other sectors being characterised by varying degrees of generally lower volume, batch manufacture and bespoke elements with no two sector supply chains being identical.

There was a small but significant consensus that manufacturing remains extremely important to the UK and that a better expression for the manufacturing challenge of the power electronics industry is flexibility, particularly at component and sub-systems level. In particular this must translate into greater and more widespread skills able to better respond to end customer project demands.
One area relating to manufacture is the matter of international standards and their use in biasing the international playing field in favour of the countries who are able to more strongly influence their preparation through greater representation in the relevant standards making bodies. In this respect the workshops felt that the UK continues to be under-represented on the relevant standards committees and, as such, were not in a position prevent or react to standards being drafted that would necessitate changes in practice or design to remain competitive.

**Question 6A:** Is there a role for greater adoption of advanced manufacturing in the power electronics supply chain? If so, does this lie at component and sub-component level or should systems integrators be taking the lead here?

**Question 6B:** Are skills a greater issue? How can we better develop skills and who should be taking the lead on this matter?

**Question 6C:** Is the UK power electronics community weak on standards participation? What can be done to improve our level of representation?

**Finding 7: Accelerated Testing is Essential To Ensuring Early Technology Adoption, But Cross Sector Validation Is Perceived to Have Limited Value**

This finding has areas in common with Finding 5, but it is considered that accelerated testing is a major functional area in its own right, where advances could have significant impact on Power Electronics across all sectors. This area would include development of methods that the industry could subscribe to. It should also include modelling methods and standardised approaches which where not specifically stated in the QFD analysis, but were captured during the workshop events.

The challenge for accelerated testing is not seen as being at the laboratory validation level but at the pilot demonstration level where a far larger range of factors associated with operating in a working environment come into play. Hence, with the exception of aerospace, end-market sectors see little synergy whereby cross-platform validation systems would be a practical viable proposition. For aerospace, because of the longer gestation periods in product development and very high safety criteria, cross platform validation is seen as necessary to deliver the reliability and performance data necessary for adoption.
Nevertheless, the question remains how much faster can the testing and adoption cycle be accelerated? One suggestion at the final workshop was that the development of shared open databases (or partially open) for lifetime data would be highly beneficial. However it is recognised that this could prove problematic with respect to warranties and a desire to keep certain information confidential.

A possibly valuable halfway house may be to find common ways of determining, specifying and qualifying compliance/reliability that industry sectors would recognise and accept.

**Question 7A: Do you agree with this finding? Is there really little scope for cross sector validation?**

**Question 7B: Is there a viable “big data” approach by which databases could be created (for example, on a ‘show and tell’ basis though a signed-up consortium), to the extent that common failure modes could be made visible? Could such an effort be initiated within the UK alone or it would require cross-country co-operation at even the earliest stages?**

**Question 7C: Is modelling a compliment or viable alternative to “big data”?**

**Finding 8: There is a Conflict of Goals Between Systems Integrators and Component Technology Providers That Slows the Development and Adoption of Technology**

During the workshops it became clear that there is an inherent conflict of goals between systems integrators and component technology providers, which significantly slows the pull-through of technology. Systems are reliant on advances in component technologies where innovation can yield significant downstream impact. However, systems integrators can be reluctant to invest in meaningful programmes that pull through component technologies.

The fundamental reason is that for component providers to succeed, they need to be able to supply to a global market. However, for the generally larger system integrators to gain advantage from investment in the upstream supply chain, they often require exclusivity for some period. These two polar opposite objectives can make meaningful early stage collaboration difficult to effect, leading to a considerable slowdown in the technology adoption cycle.

A collective recognition from a number of PowerelectronicsUK discussions is that for UK companies, and in particular SMEs, to become more competitive, they must find ways of working with the upstream supply chain (i.e. generally smaller companies and development groups) with greater agility than they manage today. Despite this, the sector has not been good at taking up large-scale support funding calls such as the Advanced Manufacturing Supply Chain Initiative. However targeted collaborative R&D programmes, such as those supported...
and run by Innovate UK (formerly Technology Strategy Board) do go some way to encouraging the generally larger system integrators to work with smaller supply chain companies at a smaller level.

Nevertheless, while grant-funding schemes do successfully stimulate a degree of collaboration, they are not a universal solution. Further incentive mechanisms are required to encourage and enable companies to collaborate within a commercially competitive framework where there can be a significant element of risk in getting technology to market. Such mechanisms may also look to shift the break point in the supply chain where collaboration normally stops to encourage greater upstream and/or downstream participation.

**Question 8A:** Does this conflict truly exist and is it a barrier to accelerating the adoption of new technologies? Are SME’s more susceptible to this issue?

**Question 8B:** What incentives or interventions could be introduced (either by the public sector or by the industry itself) to encourage the supply chain to collaborate more effectively – in particular for systems integrators to be more supportive upstream?

**Finding 9:** Energy and Aerospace Appear to be the Sectors in which the UK Power Electronics Community Can Make Its Biggest Global Technological Impact (but New Innovations May Change This)

The QFD matrix analysis included a benchmark section to look at the competitive potential of the UK to deliver breakthrough technology against the “Go to the Moon” projects. This was determined by consensus at the final workshop. The benchmark question asked was: what is competitive potential to deliver breakthrough technology in terms of UK vs. world? With the score criteria ranging from the potential to create world leadership with multiple global players down to extremely weak and unlikely to create any strong UK players able to compete on a global basis.

From the representation in attendance, there was a distinct perception that the UK is better placed to competitively deliver breakthrough technologies through companies in energy and aerospace. Clearly this finding is subjective due to the cross-section and sample size represented by the attendees who attended the final workshop (although all sectors were represented) rather the collective opinion of the Power Electronics industry in the UK.

The consensus of the final workshop was that while the UK has notable strengths in Power Electronics for the consumer and automotive sectors, other countries have greater depth and the ability to exploit. This does not mean to say that the ability to make a technological benchmark should be the only final deciding factor in any potential conclusion that may be
drawn from this process with factors such as market size, high value jobs created and export potential all being of equal importance.

Question 9A: Do you agree with this assertion, or does it simply highlight the need for more accurate sectorial breakdown of the contribution Power Electronics makes to the UK economy through jobs created and revenues generated?

Question 9B: Are there any specific market sector areas (either in the 4 considered or outside) where the UK is well positioned to deliver innovation and global leadership?

Finding 10: Industry’s Perception of Academia is Good, while Academia Has a Less Rosy View of Industry

One interesting outcome of the benchmarking survey is the indication that there is a reverse perception whereby industry ranks academia as more capable than academia does itself. Meanwhile academia ranks the abilities of industry lower than industry does itself.

One possible reason for this may be the failure of industry to pull through academic stemming technology to market, while industry perceives greater value on the stimulation to business thinking provided by academia rather than the tangible outcomes of industry.

Another possible reason is that academic work can be often be focused on a specific technology area that requires the participation of aspects of the supply chain to deliver who would not normally be invited to collaborate.

It is clear that academic / industry links need to be strengthened. The working group and workshops feel that the issue here is one of finding more effective ways for the industry, the supply chain itself and academia to collaborate, particularly at ‘root’ level using mechanisms such KTP’s to help develop industry-academia relationships and long-term partnerships.

Question 10: What are the underlying causes of the perceptions gaps between Industry and Academia and what can be done to align them? Are there some strong exemplar case studies and mechanisms that show how academia and the industry supply chain have collaborated effectively?
Finding 11: Overall the UK perceives itself as a Middle Ranking Global Competitor With Pockets of World Leadership in Some Technologies

The result of the functional capability benchmarking exercise suggests that the UK is a better than average middle ranking player in the world with a greater competitive standing at the systems level. However, without undertaking a similar exercise in other territories that are perceived to be stronger competitively such as Germany, Japan and the USA, the results should not be taken as an absolute measure.

What is clear is that the UK’s strength as a system integrator creates opportunities for lead industries to drive to strengthen and ensure a more robust UK supply chain.

Question 11A Do you agree with this assertion? If not, why?

Question 11B: What three (3) things would you do you make the UK more competitive in Power Electronics?

Finding 12: The 13 “Go to the Moon” Projects while a Useful Focus Tool Have Limited Crossover Across Sectors (and don’t address all the issues).

An original hypothesis of the approach taken to collect and prioritise data was the challenge projects identified for each sector would yield a degree of overlap that could lead to potential cross-platform projects. By and large, this has not been the case, although there are some potential synergies between Power Electronics for the automotive and aerospace sectors due to the more extreme environments and the need for high energy density designs.

However, as the technology priorities presented later in this section show, there are issues that cut across sectors that could be addressed. For example, through common threads within multiple collaborative R&D calls. To make this effective would require some form of oversight to ensure that duplication is minimised and results are disseminated properly to the entire community. Another possibility is that these matters are best addressed at a manufacturing level rather than fundamental R&D.

The study, to date, has focused on 4 areas, leaving notable gaps in other significant applications. In particular, the needs of rail/marine traction at the 10MW level, low/mid-range industrial drives, and defence are not adequately represented at this stage of publication. Representatives of these sectors are therefore invited to participate in addressing this gap ahead of the white paper that will emerge from this consultation.
<table>
<thead>
<tr>
<th>Question 12A: Do you agree with the areas identified in the analysis, or are there significant gaps or “Go to the Moon” project that you propose?</th>
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<tr>
<td>Question 12B: Could a structured family of 5-10 year horizon projects with “Go to the Moon” stretch goals be part of a “Big Ask” for government leveraged support that could ensure that available funds are coordinated and channelled towards achieving these projects? Is there a specific project you could propose that could be part of this?</td>
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<tr>
<td>Question 12C: Within the “Go to the Moon” projects are there collaboration opportunities across elements of the supply chain to address more specific issues that would have multiple cross-sector impacts and significance?</td>
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Top 10 Functional Technology Areas (aggregated across industry)

1. Fault tolerance and system reliability
   *This includes technologies for fault mitigation response, system health management and adaptive gate controls*

2. Lower loss power semiconductor devices

3. Reliability of semiconductor devices and other electrical components

4. Higher performance passive components
   *In particular this relates to higher frequency (or dV/dt or dI/dt) and higher energy density capacitors and inductors, and higher voltage capacitors*

5. Thermal management
   *Particularly with respect to better thermal management within semiconductor components and heat conductors for power systems*

6. Sensors

7. Accelerated testing

8. Advanced converter topologies

9. Electrical insulation coordination and isolation technologies (component and systems)

10. Control software design toolboxes and standards
Perceived UK position in Top Functional Technology Areas

Key to benchmark scores:

5  UK world leader - multiple (>3) players,
4  top 5 position multiple players or leadership with 1 or 2 players)
3  top 10 position and multiple (>3) players in top 20
2  outside top 10 but multiple (>3) players in top 30
1  extremely weak, few credible UK players

Question 13: Does the ranking of the top 10 functional technology areas tally with your perception of needs? If not, what key functional attributes are missing (please also refer to Appendices 1 & 2)? Is the perceived competitive position a fair representation of UK capability?
Energy

Overview

The energy sector covers a multiple range of applications, with the common thread that they are about the control and conditioning of electrical energy from the point of generation, through the transmission and distribution of that energy and selective end uses of grid energy at the larger end of utilisation. Within that thread lie multiple standards and practices that reflect the fact that in small or large ways the power electronics used has to contribute to ensuring the integrity of the grid is maintained.

Power electronics has a major role to play as energy systems evolve from today’s largely electro-mechanical systems. While Smart Grid concepts have so far tended to focus on the informational side of things, without power electronics as the actual muscle to implement control decisions, many of these concepts will remain just that. The major challenges for power electronics in energy are therefore centred around reliability, fault tolerance, greater efficiency and management of the large amounts that can be generated – especially when controlling 1MW and above, recognising that thermal management continues to be a weak link in terms of system availability and maintenance burden.

Perhaps one of the biggest challenges for power electronics is to be able to directly connect into the grid without the need for interface transformers. While there is undoubted benefit from this – primarily avoiding a large cost item and source of losses – it would also require a number of technological advances in passive and active components to offer greater robustness and most likely much higher operating voltages. This latter would have big implications to systems integrators requiring new disciplines to design and build equipment capable of operating much higher voltages, which only a handful of organisations have today.

Go to the Moon Projects

The energy sector covers possibly largest range of power levels of all the sectors considered in the data-gathering phase. As a consequence, 4 “go the moon” projects where defined to form the basis of the QFD analysis. They were chosen to reflect perceived challenge areas ranging from around 1kW up to 1GW.

- **HVDC** – this programme would look at the next generation of high voltage DC systems > 100MW with targets of using higher voltage devices, reducing converter losses and improving fault tolerance and reliability.

- **11kV Intelligent Transformer (1 – 6 MW)** - this programme would look at the development of an 11kV:400V intelligent power electronic "transformer" able to generate multiple end use voltages and improve energy efficiency. Most significant challenge area would be the 11kV+ electronics suitable for direct connection into distribution systems and passive cooling arrangements to ensure low maintenance burden.
• 1MW Industrial/Renewables/Traction Drive – this programme would look at improvements to industrial drive systems. The project would also look at ways to increase efficiency and make improvements to reliability and fault tolerance.

• 0.5-2.0kW micro grid converter – this project addresses the development of a fully integrated converter/energy storage management interface for use with domestic microgen systems. The converter would be capable of load following up to rated capacity using information from a smart meter. The major technological thrust of the project would be component integration into a single discrete packaged device requiring few external components.

Key Functional Technology Impact Areas

Technology areas overlapping with the overall top 10 are shown in bold.

1  **Fault tolerance and system reliability**
   *This includes technologies for fault mitigation and improved component and system reliability (including system health management – although this is seen as a lower priority than the other two)*

2  Automated manufacture

3  **Higher performance passive components**
   *In particular this relates to higher energy densities, higher frequency (or dV/dt or dI/dt) and higher voltage capacitors and inductors*

4  **More advanced semiconductors**
   *More specifically lower loss and higher switching frequency power semiconductor devices*

5  **Thermal management**
   *Particularly with respect to better thermal management within semiconductor components and heat conductor and heat exchangers for power systems*

6  Modularisation – in particular at the sub-systems level

7  **Control software design toolboxes and standards**

8  Sensors
Perceived UK position in Top Functional Technology Areas for Energy Sector

Key to benchmark scores:
5  UK world leader - multiple (>3) players,
4  top 5 position multiple players or leadership with 1 or 2 players)
3  top 10 position and multiple (>3) players in top 20
2  outside top 10 but multiple (>3) players in top 30
1  extremely weak, few credible UK players

Question 14A: Do the “Go to the Moon” projects provide a sufficiently representative cross-section of technology challenges facing the energy sector? Are the stretch goals sufficiently challenging over the next 10 years to drive innovation programmes?

Question 14B: Do you agree that the key functional technology impact areas are correct? Are there any specific attributes of power electronics that are missing that will have a major impact on the energy sector?
Automotive and Transport

Overview

The automotive sector is currently going through one of the largest shifts in technology since the development and productionisation of the diesel engine. The technology is called electrification. Through this electrification power electronics is one of the major underpinning technologies that will enable future vehicles to be greener and more efficient, reducing CO$_2$ and correspondingly global warming.

Power electronics does not stop there, it also used in all manner of other aspects that are taken for granted such as power steering, ABS, injection systems, infotainment, through to each little electronic control module that is on every vehicle. Correspondingly the market opportunity is vast.

However, by value, the electrification market is set to become the most significant. Due to the stringent emissions targets placed on vehicle manufacturers new technologies have to be deployed to reduce emissions. As the battery is the most expensive item of the electric powertrain, anything that can be done to maximise performance of this is utilised. In particular weight needs to be reduced and efficiency needs to be increased.

Go to the Moon Projects

Some of general overriding issues that present themselves to the automotive sector are:

- Cost
- Reliability/robustness
- Power density

The projects chosen below aim to address some of these concerns. An inverter which is integrated with the E-machine would increase the power density of the drive system. Reduction in cabling would improve this further, as well as address issues such as EMI. Vehicles are expected to have a long lifetime in that they must last at least 10 years endure many hours of service.

- Integrated Traction Inverter (>20kW/kg, >20kW/l, 150°C, >97% efficiency, 10K hour life) An inverter that is integrated with the E-machine would increase the power density of the drive system. Reduction in cabling would improve this further and also address EMI. Power electronics is also expected to be robust to the harsh environments associated with automotive applications whilst still achieving the lifetimes expected from modern vehicles.

- On board wireless battery charger (>20kW/kg, >20kW/l, 75°C, >95% efficiency, 20K hour life). Wireless battery charging is being investigated by many OEMs and is likely to deployed on future vehicles. Volume is key such that the charging system does not
encroach on the passenger space in the vehicle. Weight is also key as during driving the charging system will not be providing any extra effort to the wheels.

- **FC/Supercap Bi-directional Power Converter (>20kW/kg, >20kW/l, 75ºC, > 98% efficiency, 10K hour life).** The current market trend is for the use of larger lithium-ion battery packs as part of EVs. In the future this focus may change to hydrogen fuel cells coupled with super capacitors. These systems are currently too expensive, but if the cost of the power electronics were to reduce then it could become a viable option.

### Key Functional Technology Impact Areas for Automotive and Transport Sector

Technology areas overlapping with the overall top 10 are shown in bold.

1. **Higher reliability semiconductor devices and other low level electrical components**
   - In particular reliability and robustness in view of the fact that power converters in vehicle are non-servicable items and, as such, are expected to last the lifetime of the vehicle. The more robust the power devices, the lower the cost to the OEM in not requiring large engineering margins to failure.

2. **Fault tolerance and system reliability**
   - Power converter is part of the primary drive mechanism for an EV. If this fails the vehicle stops. Fault tolerance will reduce these events.

3. **Sensors**

4. **Integrated adaptive gate and control functionality within power semiconductor devices**

5. **Advanced converter topologies**

6. **More advanced semiconductors**
   - Specifically lower loss and higher voltage power semiconductor devices. Efficiency is key due to the large cost of batteries.

7. **Thermal management**
   - Specifically thermal distribution, heat conductor and active cooling technologies. Currently power converters have their own dedicated coolant circuit. If this could be removed and a single engine coolant loop used it would reduce system cost, weight and volume.

8. **Higher performance passive components**
   - In particular this relates to higher voltage capacitors and magnetics. For example DC link capacitors can often be the weak point in the power converter due to the limited temperature capability. Higher temperature operation would allow for smaller converters to be built, reducing volume and weight.
9 Advanced control software

In particular this relates to control software design toolboxes and standards and embeddable software

10 Accelerated testing

Perceived UK position in Top Functional Technology Areas for Automotive and Transport Sector

![Graph showing perceived UK position in Top Functional Technology Areas for Automotive and Transport Sector]

Key to benchmark scores:

5 UK world leader - multiple (>3) players,
4 top 5 position multiple players or leadership with 1 or 2 players)
3 top 10 position and multiple (>3) players in top 20
2 outside top 10 but multiple (>3) players in top 30
1 extremely weak, few credible UK players

Detailed Data

See accompanying industry sector QFD matrices

Question 15A: Do the “Go to the Moon” projects provide a sufficiently representative cross-section of technology challenges facing the automotive and transport sector? Are
the stretch goals sufficiently challenging over the next 10 years to drive innovation programmes?

Question 15B: Do you agree that the key functional technology impact areas are correct? Are there any specific attributes of power electronics that are missing that will have a major impact on the automotive and transport sector?
Aerospace

Overview

The Aerospace industry seeks the benefits of electrification to improve the safety, performance, and cost of aircraft and other such assets upon which operators and their customers depend upon. The civil aerospace industry has set challenging environmental performance targets such as those of the Advisory Council for Aeronautics Research in Europe (ACARE). For example, ACARE have agreed a target of reducing perceived noise to one half of current average levels, and a 50% cut in CO2 emissions per passenger kilometre by 2020. Electrical technology is seen as providing an evolutionary improvement in aircraft and gas turbine performance, and power electronics systems are inherently at the heart of this endeavour.

The evolution is two-fold: the proliferation of electrical systems as an alternative to traditionally pneumatic and hydraulic systems, and the enabling ability of power electronics to increase aircraft functionality, load control and the overall performance of the electrical generation and distribution system. In the longer-term, power electronics is also seen as an enabler for disruptive propulsive technology concepts such as distributed propulsion, where power electronics may control a sizable proportion of the aircraft’s thrust.

The nature of the industry is such that power electronics needs to be high-integrity yet reflective of today’s fiscal reality. The challenge is both on-airframe and on-engine. For the latter, power electronics can be likened to the electrical equivalent of a solid-state gearbox. Both on-engine and on-airframe applications necessitate particularly stringent electrical conformance requirements as compared to many terrestrial systems, and most applications will also dictate particularly challenging constraints in terms of volume, mass, efficiency, and environment.

Go to the Moon Projects

The Aerospace sector covers perhaps the most diverse range of unit level constraints, and in the immediate future is likely to consider power levels from kilowatts to single megawatts, with operational voltages generally below 1kV. The three ‘go to the moon’ projects considered are:

- Primary Power Distribution - Development of units that can operate at 270V DC and >100A to replace electro-mechanical contactors.
- High Temperature Capable Integrated Power and Control - Distributed high temperature electronics for power and control in secondary power systems (reduced need for cooling and cable weight).
- Power generation - energy optimisation - Energy optimisation in aerospace system power generation - optimisation of energy usage and reduce generator weight - >100kW
Key Functional Technology Impact Areas for Aerospace Sector

Technology areas overlapping with the overall top 10 are shown in bold.

1. **Electro-magnetic compatibility of systems and components**

2. **System reliability and health management**
   
   This includes technologies for fault tolerance/ fault mitigation response and adaptive gate controls

3. **Lower loss power semiconductor devices**

4. **Thermal management**
   
   Particularly with respect to better thermal distribution/ management, heat exchangers and thermo-electric recovery technologies

5. **Advanced converter topologies**
   
   This also includes approaches to modularise power electronic systems and subsystems

6. **Accelerated testing**
   
   This also includes establishment of cross-platform benchmarks and validation techniques

7. Integrated adaptive gate and control functionality within power semiconductor devices

8. **Higher performance passive components**
   
   In particular this relates to higher frequency (or dV/dt or dI/dt) and higher energy density capacitors

9. **Electrical insulation coordination and isolation technologies (materials)**
Perceived UK position in Top Functional Technology Areas for Aerospace Sector

Key to benchmark scores:
5  UK world leader - multiple (>3) players,
4  top 5 position multiple players or leadership with 1 or 2 players)
3  top 10 position and multiple (>3) players in top 20
2  outside top 10 but multiple (>3) players in top 30
1  extremely weak, few credible UK players

Detailed Data

See accompanying industry sector QFD matrices

Question 16A: Do the “Go to the Moon” projects provide a sufficiently representative cross-section of technology challenges facing the aerospace sector? Are the stretch goals sufficiently challenging over the next 10 years to drive innovation programmes?

Question 16B: Do you agree that the key functional technology impact areas are correct? Are there any specific attributes of power electronics that are missing that will have a major impact on the aerospace sector?
Consumer

Overview

The consumer sector encompasses a broad range of electronic products and devices generally manufactured in high volume. Mobile phones, PC’s, laptops, tablets, TV’s, white goods and, LED lighting are all examples of high volume consumer products. While the product category is diverse, all the products are similarly challenged by the efficiency with which the power they need can be taken from the mains supply and delivered to the equipment in the form it requires. Mains electricity is generally supplied at either 220/240 or 110/120V AC. Today’s consumer devices require very stable and highly regulated voltages and currents at very different levels to those supplied by the mains. All products therefore require sophisticated power regulation electronics that can convert the mains electricity to something that can be used by the equipment. As an example the microprocessor in a modern computer will require a stable 1V supply where the power demands can vary from almost zero to a hundred Watts and back to zero almost instantaneously. The power supplies inside the computer must meet this demand, providing exactly the power when needed but also ensuring power is not wasted when it is not needed.

Many consumer devices are additionally challenged by the need to be small and light weight and with an increasing number running from batteries. The space constraints, coupled with highest efficiency demand, push power supply design to the limits of what can be achieved with the technology available. The power semiconductors, magnetics and capacitors are all critical in achieving high power densities at high efficiencies.

The growth in portable equipment also demands high efficiency battery charging, where consumers require the charging to be as fast as possible and the charging unit to be compact and light-weight. These all represent challenges for the power electronics systems.

Many consumer goods depend on electric motors for their functionality, washing machines, dishwashers and, vacuum cleaners as examples. Energy efficiency is a critical issue with regulatory requirements to be met and energy star ratings published as part of the product specification. The power electronics must convert the mains electricity to the drive power for the motors, controlling the rotation speed and performance of the motor while maximising the power efficiency,

Go to the Moon Projects

The key challenges for power electronics in consumer products are compact design, highest possible efficiency and low cost. The projects below are chosen to cover the underlying functionalities of consumer equipment, driving high efficiency lighting, controlling motors and charging batteries. Each of these projects would stretch the boundaries of form factor and power density requiring new developments in semiconductor and passive components and approaches to thermal management:
• Compact Integrated Intelligent Lighting Driver (could be LED or CFL but < 20W, input voltage may be 24VDC or 220V AC) – that can be embedded in light assemblies.

• Embeddable Domestic (or Light Industrial) Machine Drive (<2kW but mains voltage) with simplified plug-in functionality and reduced footprint suitable for mechatronic integration.

• Integrated Battery Energy Management (up to 48V DC) – system that can be integrated into domestic energy storage systems and is able to manage charge/discharge and cell balancing for optimal usage.

Key Functional Technology Impact Areas for Consumer Sector

1 More advanced semiconductors
   *Specifically higher operating temperature and lower loss power semiconductor devices*

2 Higher performance passive components
   *In particular this relates to higher energy densities, higher frequency (or dV/dt or dI/dt) capacitors and inductors*

3 Integrated adaptive gate and control functionality within power semiconductor devices (potentially all on single chip with suitable isolation techniques)
   *This also includes adaptive gate controls*

4 Thermal management
   *Particularly with respect to better thermal distribution management within semiconductor components and systems*

5 Electro-magnetic compatibility of systems and components

6 Advanced automation
   *Specifically automation of manufacturing processes and production testing*

7 Accelerated testing
Perceived UK position in Top Functional Technology Areas for Consumer Sector

Key to benchmark scores:
5  UK world leader - multiple (>3) players,
4  top 5 position multiple players or leadership with 1 or 2 players)
3  top 10 position and multiple (>3) players in top 20
2  outside top 10 but multiple (>3) players in top 30
1  extremely weak, few credible UK players

Detailed Data

See accompanying industry sector QFD matrices

Question 17A: Do the “Go to the Moon” projects provide a sufficiently representative cross-section of technology challenges facing the consumer sector? Are the stretch goals sufficiently challenging over the next 10 years to drive innovation programmes?

Question 17B: Do you agree that the key functional technology impact areas are correct? Are there any specific attributes of power electronics that are missing that will have a major impact on the consumer sector?
## Appendix 1 – The 37 Functional Attributes Used to Define Power Electronics

<table>
<thead>
<tr>
<th>Category</th>
<th>Functional Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Semiconductors</strong></td>
<td><strong>Fundamental Semiconductor Attributes</strong></td>
</tr>
<tr>
<td></td>
<td>Higher voltage</td>
</tr>
<tr>
<td></td>
<td>Lower on-state loss</td>
</tr>
<tr>
<td></td>
<td>Higher switching frequency</td>
</tr>
<tr>
<td></td>
<td>Higher operating temperature</td>
</tr>
<tr>
<td></td>
<td>Functional integration/isolation</td>
</tr>
<tr>
<td></td>
<td>Reliability</td>
</tr>
<tr>
<td></td>
<td><strong>Semiconductor Packaging Attributes</strong></td>
</tr>
<tr>
<td></td>
<td>Thermal distribution management</td>
</tr>
<tr>
<td></td>
<td>Isolation/Insulation and Insulation coordination</td>
</tr>
<tr>
<td></td>
<td>Integrate gate/control functionality</td>
</tr>
<tr>
<td></td>
<td>Electro-Magnetic Compatibility</td>
</tr>
<tr>
<td><strong>Passive components</strong></td>
<td><strong>Capacitors</strong></td>
</tr>
<tr>
<td></td>
<td>Higher voltage</td>
</tr>
<tr>
<td></td>
<td>Higher energy density (or k)</td>
</tr>
<tr>
<td></td>
<td>Higher frequency (or dV/dt or dI/dt)</td>
</tr>
<tr>
<td><strong>Wound components</strong></td>
<td><strong>Higher voltage</strong></td>
</tr>
<tr>
<td></td>
<td>Higher energy density (ferrite µ)</td>
</tr>
<tr>
<td></td>
<td>Higher frequency (or dV/dt or dI/dt)</td>
</tr>
<tr>
<td><strong>Other low level components</strong></td>
<td><strong>Low Level control</strong></td>
</tr>
<tr>
<td></td>
<td>Embeddable control software</td>
</tr>
<tr>
<td></td>
<td>Adaptive gate controls</td>
</tr>
<tr>
<td></td>
<td>Communications busses</td>
</tr>
<tr>
<td></td>
<td><strong>Other Low Level control</strong></td>
</tr>
<tr>
<td></td>
<td>Sensors (voltage, current, temperature etc.)</td>
</tr>
<tr>
<td></td>
<td>PCB design</td>
</tr>
<tr>
<td><strong>Thermal Management</strong></td>
<td><strong>Heat conductors (inc. insulating cooling fluids)</strong></td>
</tr>
<tr>
<td></td>
<td>Heat Exchangers</td>
</tr>
<tr>
<td></td>
<td>Active cooling</td>
</tr>
<tr>
<td></td>
<td>Thermo-electric recovery</td>
</tr>
<tr>
<td><strong>System Architecture</strong></td>
<td><strong>Advanced converter topologies</strong></td>
</tr>
<tr>
<td></td>
<td>Modularisation</td>
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<tr>
<td></td>
<td>Mechatronic/other embeddable Integration</td>
</tr>
<tr>
<td></td>
<td>Electrical Insulation (systems)</td>
</tr>
<tr>
<td></td>
<td>Fault tolerance (fault mitigation response)</td>
</tr>
<tr>
<td><strong>System Control</strong></td>
<td><strong>Reliability/System health Management</strong></td>
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<tr>
<td></td>
<td>Supervisory Communications/busses</td>
</tr>
<tr>
<td></td>
<td>Control software design toolboxes/standards</td>
</tr>
<tr>
<td><strong>Manufacturing</strong></td>
<td><strong>Automated manufacture</strong></td>
</tr>
<tr>
<td></td>
<td>Automated Production Testing</td>
</tr>
<tr>
<td><strong>Acceptance Testing</strong></td>
<td><strong>Accelerated testing</strong></td>
</tr>
<tr>
<td></td>
<td>Cross application validation (test benchmarks)</td>
</tr>
</tbody>
</table>
Appendix 2 – The QFD Matrix Used To Gather and Collate Data For The Power Electronics Green Paper

See attached sheet.
### Power Electronics UK GFD Prioritisation Matrix - As of 09/08/2014

#### Required Functional Attributes

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerospace</td>
<td>Higher Operating Temperature, Lower Weight, High Reliability</td>
</tr>
<tr>
<td>Automotive</td>
<td>Better Efficiency, Reduced Size, Improved Reliability</td>
</tr>
<tr>
<td>Consumer</td>
<td>Better Value, Increased Durability, Improved Safety</td>
</tr>
<tr>
<td>Others</td>
<td>Higher Efficiency, Reduced Size, Improved Reliability</td>
</tr>
</tbody>
</table>

#### Perceived Functional Competitors

<table>
<thead>
<tr>
<th>Competitor</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens</td>
<td>Germany</td>
</tr>
<tr>
<td>Toshiba</td>
<td>Japan</td>
</tr>
</tbody>
</table>

#### Current Functional Rankings

- 1 = Highest Ranking
- 2 = Medium
- 3 = Low

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Rank 1</th>
<th>Rank 2</th>
<th>Rank 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Energy</td>
<td>5</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Aerospace</td>
<td>3</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Automotive</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Consumer</td>
<td>4</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Others</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Key to Symbols Used in Main Correlation Matrix

- Major step change required - major improvement in this parameter would have major implications in project outcome
- Significant improvement required - action on this parameter would yield significant benefits to project outcome
- Improvement to this parameter expected - action on this parameter would yield benefit to other parameter improvements
- Improvements to existing technologies/predictions expected to enhance but not significantly improve project outcome
- Existing technology/technique is satisfactory to meet requirements

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**Green Paper on Technology Prioritisation for UK Power Electronics**

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