BIS Department for Business Innovation & Skills

POWER ELECTRONICS: A STRATEGY FOR SUCCESS

Keeping the UK competitive

OCTOBER 2011

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Foreword by the Minister of State for Business and Enterprise

The underpinning and pervasive nature of their technologies means that the Power Electronics community in the UK covers a breadth of application areas and markets that few other industries can match. It is essential for the efficient conversion and conditioning of energy in a wide range of applications, from smart grids through to electric and hybrid cars, from industrial process control to consumer electronics and lighting. The nature of this sector means that it also has a strong role to play in helping the move to a low-carbon economy as we rethink the way we power our factories, light our homes and fuel our cars. There is a huge commercial opportunity for Power Electronics firms to exploit. While recognising the sector's diversity, individual Power Electronics systems tend to be highly specialised with high added-value, so there are real chances to grow the UK manufacturing base in this field.

The UK is considered to be internationally competitive in many parts of the supply chain - from components through to system-level engineering and the supply of turn-key solutions - with some prominent global players and innovative SMEs. This all brings with it not just the opportunities presented by such a diverse customer base but also the challenges of how to achieve the necessary focus amongst companies when considering strategic issues. As we rebalance and renew our economy, it is essential that industry, in partnership with Government, considers how the sector approaches issues such as innovation and R&D, or increasing the supply of specialist skills in order to tackle barriers to growth and create the right conditions for expansion. I was therefore pleased that - under the leadership of my department and the NMI - the sector has come together to consider how it can best meet the challenges to its future growth. I congratulate all concerned in producing this important piece of work.

By creating the right conditions for economic success, we will free British businesses to seize the new opportunities opening up in global economies. We firmly believe that enterprise, innovation and investment are this nation's route to lasting prosperity. The Power Electronics industry in this country is leading the way in developing technologies that will help provide the answers to some of the biggest challenges we face. By working together, we can reach new heights as we establish private-sector-led, investment-driven growth as the bedrock of our economy in the years ahead.

Mark Prisk MP
Minister of State for Business and Enterprise

Introduction by the Chairman of the Power Electronics Strategy Group

Power Electronics plays to the strengths and aspirations of the UK. It is a high-growth, high-added-value and high-value per employee technology. It demands cross-functional, multi-disciplinary teams of engineers capable of meeting the demands of the complex integration challenges this presents - a capability in which, it could be argued, the UK leads the world. However, what makes Power Electronics so attractive to UK industry also attracts others and so it is, inevitably, highly competitive.

The UK Power Electronics community faces three particular issues:

- The emergence of disruptive technologies which can rapidly transform sectors of the market in which the UK has existing strengths
- A deep-rooted skills shortage affecting UK industry's ability to keep pace with even incremental innovation
- A lack of strategic funding inhibiting the implementation of highly innovative, relatively high-risk projects and stifling the aspirations of Small and Medium-sized Enterprises (SMEs) and start-up companies.

To address these threats, the UK needs a clear and co-ordinated Power Electronics strategy to allow industry, academia and Government to act cohesively to support one another. Recognising this a broad-based Strategy Group was formed, the Department for Business, Innovation and Skills gave its support, and we held formal meetings and consulted extensively with the broader Power Electronics community at workshops in Farnham, Bristol, Newcastle and Nottingham.

The result of our consultations is this strategy document. It articulates a vision for a strong, healthy, globally-competitive UK Power Electronics industry capable of providing large numbers of high-quality jobs and making a substantial contribution to the nation's GDP. The document is not an end point in the process entered into so enthusiastically by the industrial and academic participants, rather it is an initial focus. The Strategy Group is committed to an ongoing annual review of progress against the strategy action plan – to a practical and pragmatic approach that will refresh and re-invigorate the whole Power Electronics community.

I hope that you will join us in recognising the potential and significance of this sector of industry, and that you will find this document reflects your experiences and matches your aspirations. The credit goes to the Strategy Group members and all who contributed: they are listed overleaf.

Bill Drury
Chairman, Power Electronics Strategy Group

Strategy Group Membership

Bill Drury, Emerson-Control Techniques, University of Bristol, Newcastle University

Ian Barton, Siemens

Derek Boyd, NMI

Trevor Cross, e2v technologies

Ashley Evans, Electronics Technology Network

Graham Ferry, ALSTOM Grid

Rob Haase, International Rectifier

David Hinchley, Converteam UK Ltd

Paul Holland, Swansea University

Julian Humphreys, NXP Semiconductors

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Mark Johnson, University of Nottingham

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Phil Mawby, University of Warwick

Phil McGoldrick, Goodrich Power Systems

Adam McLoughlin, Rolls-Royce plc

Volker Pickert, Newcastle University

Gareth Taylor, Evince Technology

Paul Taylor, Dynex Semiconductor Ltd

Matthew Ball, EPSRC

Mark Begbie, Department for Business, Innovation & Skills

Clare Hanmer, Carbon Trust

Greg May, Technology Strategy Board

Stewart Gorman, UK Trade & Investment

Steve Brambley, GAMBICA

Thomas Harder, European Centre for Power Electronics (ECPE)

During the compilation of this report we have received input from the following companies and universities:

ABB, ALSTOM Grid, Anvil Semiconductors Ltd, ARM, Augusta Westland, CamSemi, Chipstart LLC, Converteam UK Ltd, Dayford Designs, Dialog Semiconductor, Diodes Zetex, DMS Technologies, Dynex Semiconductors Ltd, Dyson, Emerson-Control Techniques, EADS Innovation Works, Eco Semiconductors Ltd, Eltek Semiconductors Ltd, EST Drives Technology Ltd, Evince Technology, Furse T&B, GAMBICA, GaN Systems Ltd, GenDrive Ltd, Goodrich Power Systems, Inex, Infineon, Intellect, International Rectifier, Invro, IST Power Products Ltd, Kyocera, Loughborough Surface Analysis Ltd, Mercedes Benz High Performance Engines Ltd, MHI Power, MIRA Ltd, Murata Power Solutions, Narec, Navevo, Norfolk Capacitors Ltd, NXP Semiconductors, P and A Europe, PPA Energy, Ricardo UK Ltd, Rolls-Royce plc, Sevcon, SI Consulting, Siemens, Stadium Power Limited, ST Microelectronics Ltd, TMD Technologies Ltd, TRW Conekt, Turbo Power Systems, Waferdata Ltd

Universities of Bristol, Cambridge, Durham, Edinburgh, Leicester, Loughborough, Manchester, Newcastle, Nottingham, Sheffield, Strathclyde, Swansea, Warwick, Imperial College London, Technical University München.

The Vision of the Power Electronics Strategy Group

This Strategy outlines the main actions required to support the growth of this internationally-competitive sector of UK industry and academia. Our belief is that we can collectively achieve improvements in the operating conditions for these businesses and institutions in the UK and, in the process, provide significant increases in employment, economic contribution and global technology leadership in strategically-important areas and in particular, the need to reduce man-made CO_2 emissions.

The Strategy Group has a vision of a better-connected innovation community with stakeholders from industry, academia and Government working together to tackle the key challenges and achieve the common objectives stated here. We want to achieve a situation where the UK is recognised globally as a leader in innovation. We want a reputation that will continue to attract the high levels of inward investment we've achieved over the last 20 years. We want to see vibrant start-up support and a community where fledgling companies have access to investment and can have the best chance of success with innovative businesses. We want to see a highly-networked community where businesses can explore opportunities to work together to develop world-leading solutions. We want a supply of high-quality engineering talent that is un-rivalled elsewhere on the planet. There is a global shortage of engineers and - if we can lead on skills development - then we put ourselves in a great position to achieve everything else.

We recognise the support that's already been provided by Government, in particular through the Department for Business, Innovation and Skills, the Technology Strategy Board and the Research Councils – notably EPSRC who are currently supporting over £17milion in research grants across the UK. We realise the current financial constraints on the public sector but we must also highlight that there are areas here that require public sector support. Industry cannot acquire a supply of high-quality engineers without the alignment of academia and the public sector. In fact, we need to start pre-university to influence the brightest and best school-children into careers in engineering. There are several other areas where public sector support, and in some cases, investment will be a key factor in the delivery of this vision.

We believe this Strategy provides this industry in the UK with a unique and possibly once-only opportunity. Fundamental to our success is the response from industry and we call on the Power Electronics community, including our own organisations, to respond to this strategy, align efforts, and get everyone working together cohesively and synergistically to tackle the key challenges. We call on the users of Power Electronics in the UK to engage with the technology providers. We believe Power Electronics is driving significant change in almost all sectors of industry, but have identified particularly exciting opportunities in aerospace, automotive, renewable energy generation, energy networks and industrial processes. We call on them to work with the universities and technology providers in the UK to build a stronger research and development community. We also call on the Government and its key agencies to respond positively to this strategy and help create the most innovative, collaborative and successful Power Electronics eco-system to be found anywhere. We believe this is possible and, with the right reaction, we are sure this strategy can be the springboard towards this future.

Please note that a large number of senior people from electronics and engineering companies, Government departments, Trade Associations, universities and research bodies have been involved in producing the UK Power Electronics Strategy. This report reflects the broad consensus of their views, though not necessarily those of the Government, nor of individuals, companies or organisations.

Executive Summary

Power Electronics is the extension of solid-state electronics away from handling communications and data and into the business of efficiently handling power, from milliwatts to gigawatts. It makes the mobile phone battery last longer, it makes hybrid cars practicable, and it helps make electrical generation and distribution possible from sources ranging from a solar cell on your roof to a nuclear reactor in mainland Europe. It has the potential to make a huge contribution to the low-carbon economy – power savings on conventional electrical devices of 30 to 40% are here now, and there is more to come.

It is a technology where the UK – our universities and industry – has extensive expertise and experience. It is high growth and high value, making a significant contribution to exports and the wealth of the nation, as well as providing high-quality employment. The UK's strength and future opportunity is seen clearly in four sectors where Power Electronics is enabling rapid growth and innovation:

- Transport
- Energy generation, transmission and distribution
- Consumer electronics and lighting
- Industrial drives.

We are not alone in recognising the huge potential of Power Electronics, and international competition is fierce. We are strong in terms of our reputation for design and innovation, our supply chain from SMEs to multi-national companies, and our university research and teaching. But there are weaknesses too. Power Electronics is often embedded within larger systems and, as a result, there is a lack of appreciation generally of the enabling contribution that it makes to achieving many critical national objectives, in particular those relating to carbon reduction and renewable energy generation. The global nature of so many Power Electronics-based markets requires that the UK remains a competitive location for design and manufacture. Creativity, often present in SMEs, needs to be nurtured through the often-difficult gestation period. Access to new technology is also an issue for some sectors of the market. There is also a present and growing shortage of suitably-skilled engineers – graduates and technicians – perhaps because the technology is not sufficiently highly-regarded. To address these issues requires co-ordinated action by industry, universities and Government. It is also evident that there is no single organisation promoting Power Electronics nationally, resulting in fragmented initiatives and strategy. This fragmentation leads to poor communication and consequently poor technology, skills and opportunities.

The Power Electronics Strategy Group, representing industry, universities and support organisations, calls for action to redress the weaknesses identified and to turn them to the advantage of UK employment and revenue. Five key challenges are identified and detailed recommendations are proposed.

Challenge 1: The Power Electronics community lacks cohesion and representation

Approach: The National Forum for Power Electronics will maintain and increase the momentum gained during the preparation of this report, driving through its recommendations and monitoring progress made.

Challenge 2: The UK needs to be an exemplar low-energy/low-carbon economy

Approach: Foster the reputation of the UK as an exemplary producer and user of Power Electronics technologies – a world-leader in low carbon, renewables, manufacturing and sustainability. Critical to this is to develop a clear vision for our electricity infrastructure – to define the 'Smart Grid'. National Grid is in a good position to host such work but would need Government direction and multi-sector support. The National Forum for Power Electronics could identify appropriate expertise in key sectors to support and energise this work.

Challenge 3: To ensure the UK remains at the forefront of innovative Power Electronics design and manufacture

Approach: The key to UK competitiveness in Power Electronics is to drive innovation in both product design and manufacture. We need to foster collaboration across industry sectors and supply chain barriers, promoting best practice and access to international standards. Long-term disruptive technologies need focused support through to pre-production.

Challenge 4: To ensure a good supply of talented Power Electronics engineers

Approach: The National Forum would promote Power Electronics in all areas of education, from primary schools onwards, to maintain a critical mass of competent talent on which the viability and vibrancy of the sector depends. Collaborative industrial involvement is needed. Government has also to play its part, and the strategy proposes a number of zero-cost actions to promote the value of science, technology, engineering and mathematics.

Challenge 5: To improve access and the exchange of leading technology

Approach: It is necessary to bridge the gaps between universities, start-ups and industry, so that innovation is pulled through in a timely manner. The onus is on all parties to recognise the needs and the opportunities, to make the necessary investment and to create the mechanisms for vibrant relationships.

The World of Power Electronics

Power Electronics is the application of solid-state electronics for the efficient control and conversion of electrical power. Whereas more familiar electronics and microelectronics is used to carry communications or data, with Power Electronics it is power that is handled and controlled. It is used from the very low milliwatt levels needed to operate a mobile phone through to multi-gigawatt powers for high-voltage energy transmission lines between countries. Wherever there is a need to modify a form of electrical energy - ie change its voltage, current or frequency – then Power Electronics comes into play.

Power Electronics is a £135 billion direct global market, growing at a rate of 10% per annum [1]. It is an enabling technology that often determines the performance of, and provides the competitive advantage for, much more expensive devices or systems. For example, choosing a mobile phone or lap-top computer for its battery life is actually a Power Electronics decision, with the battery performance itself just one part of that. On a bigger scale, Power Electronics typically represents only 6% of the total cost of passenger elevators, yet it is largely responsible for their performance and efficiency. The importance of Power Electronics to the economy is consequently very much greater than its direct market value.

From the examples above it will be seen that Power Electronics is rarely seen as an end product by the general public, but it does play a critical role in almost all aspects of our daily lives:

- Renewable energy and the low-carbon economy are very dependent on Power Electronics
- It is responsible for ensuring the reliability and stability of the whole power-supply infrastructure, and critical to the 'Smart Grid' linking all generation and end use, making electricity networks easier to connect into
- Our transport system is ever more heavily dependent on Power Electronics, in railways, ships and increasingly cars and aeroplanes
- Our industrial processes rely upon the control and energy efficiency facilitated by Power Electronics

[1] Based on semiconductor device sales in 'The World Market for Power Semiconductor Discretes and Modules', IMS Research, 2011, and the judgement of the strategy group that typically semiconductors account for 10% of a Power Electronics system element

- The environment, access and transportation within our buildings are controlled and managed using Power Electronics
- And our homes are proliferated with Power Electronics - in TVs, washing machines, fridges, freezers, cookers, vacuum cleaners, computers, mobile phones and even energy-efficient lighting.

The Nature of Power Electronics

It is important to recognise the role played by Power Electronics as an enabling technology. Frequently the performance and efficiency of a large and complex system can be critically determined by the Power Electronics within that system. Power Electronics is not therefore simply a component, but can be considered the heart of many systems. It is frequently also the high-technology, high-value element of a system in which considerable intellectual property is vested and which provides the competitive advantage for the system.

Power Electronics systems are the result of hierarchies of research, design and manufacturing activities across many scientific and engineering disciplines. System design and integration skills, a competence for which the UK has world recognition, play a core role. Other important aspects include basic materials technology, component technologies, electrical engineering, analogue and digital electronics, control, sensors, thermal management, mechanical engineering and reliability science.

It should be noted that Power Electronics systems' manufacturers are not, in general, heavily vertically integrated: their core competence is systems design and they buy in components and technologies from a critical group of suppliers. Some of these parts - for example standard power semiconductor devices - tend to be sourced from large multinational companies, whilst many others come from SMEs offering custom solutions, often employing proprietary technology. This supply chain is of critical importance to the industry. Indeed, it is recognised that SMEs, alongside academia, generate a large proportion of novel innovative technologies [2].

The pace of change of Power Electronics technology continues to accelerate. Advances are made through basic research at both component level and through advanced systems research. Much of this research is carried out within universities, frequently with strong industrial support and collaboration. Engagement in this innovation process is critical to all areas of the supply chain if the system integrator is to remain competitive.

A comprehensive review of the technology is beyond the scope of this strategy document, but the following broad conclusions relating to disruptive technologies in power semiconductor devices are indicative of the rapidly-changing technological environment:

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[2] Innovation Nation, Department of Innovation, Universities and Skills (2008)

- It appears that silicon is here to stay as the core substrate material for the majority of power semiconductor devices, particularly in insulated gate bipolar transistor (IGBT), diode and thyristor technologies where cost rather than efficiency remains the primary driver

- Silicon carbide (SiC) devices, now entering the market, will grow in importance to complement silicon. Silicon carbide has struggled to achieve economic parity with silicon but may offer particular advantage at higher voltages and temperatures although, so far, it has not been able to deliver the much needed jump to 10kV+ devices that would drive concepts such as Smart Grids

- Gallium nitride (GaN) technologies look set to significantly impact power devices up to voltages of 1200V, notably for integrated power applications

- Diamond is another material of promise, notably for high-voltage applications. This is a potentially disruptive technology in the medium- to long-term and the UK has some world-leading capabilities this area.

Power Electronics and the Environment

Power Electronics is critical to achieving the UK's ambitions for a low-carbon economy. Government targets are for a 34% cut in 1990 CO_2 emission levels by 2020, and a greater than 80% cut by 2050 [3]. To achieve these levels will require action on many fronts, but consider the potential of Power Electronics in just one area – motor drives.

Industrial electric motors account for more than 60% of all electrical energy consumption. The application of Power Electronics in their control results in typically a 30-40% reduction in energy used, and could be applied in about 50% of applications [4]. In consequence, applying current Power Electronics technology in just this area would directly result in a 9% reduction in all electrical energy consumption – a significant contribution achieved at modest cost as payback on applications tends to be within months rather than several years.

In addition to its targets for the low-carbon economy, the UK Government has also set the target of 15% of all energy generation to come from renewable sources by 2020. This will actually require a more than five-fold increase in renewable electricity generation from 2009, to more than 30% of the total [5]. We will need to drastically restructure our national energy portfolio to achieve this transition.

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[3] Engineering UK 2011, Exec Summary
www.engineeringuk.com/_db/_documents/6152_EngUK11_ES&C.pdf

[4] Electronics enabling efficient energy usage, e4u, 2009

[5] The UK Renewable Energy Strategy, 2009

"There are tremendous potential opportunities for the UK in the new low-carbon economy. It's about newer, greener businesses and projects, those that should be in the vanguard of meeting the low-carbon challenge, and that should be working with traditional industries to deliver effective solutions." John Cridland, CBI Director-General, June 2011

Generating electricity in a variety of ways from ever more sites, each contributing a wide variety of power levels, is inevitable. So too is the changing customer demand for more flexibility and economy in their electricity provision. To bring this about will require electrical generation, distribution and the load to be controlled interactively. The electricity grids at all levels, in particular at the distribution level, will need to become 'Smart Grids' – and that requires the widespread use of Power Electronics.

One vision for the Smart Grid is shown in Figure 1. Communication between key parts of the system is essential to provide the data with which control decisions can be made. Power Electronics provides the 'muscle' to effect the control on all areas of the system in order to realise the required benefits. The Smart Grid cannot be built by any single organisation - a collaborative, systems approach is key. Leadership is critical in setting the long-term direction, but it will also require a new way of working for many organisations. Customers will have to work towards longer-term frameworks, and alliance-based agreements. SMEs will need to be more closely integrated in the technology and business plans of the larger companies. Standards will be critical to allow the inter-operability which

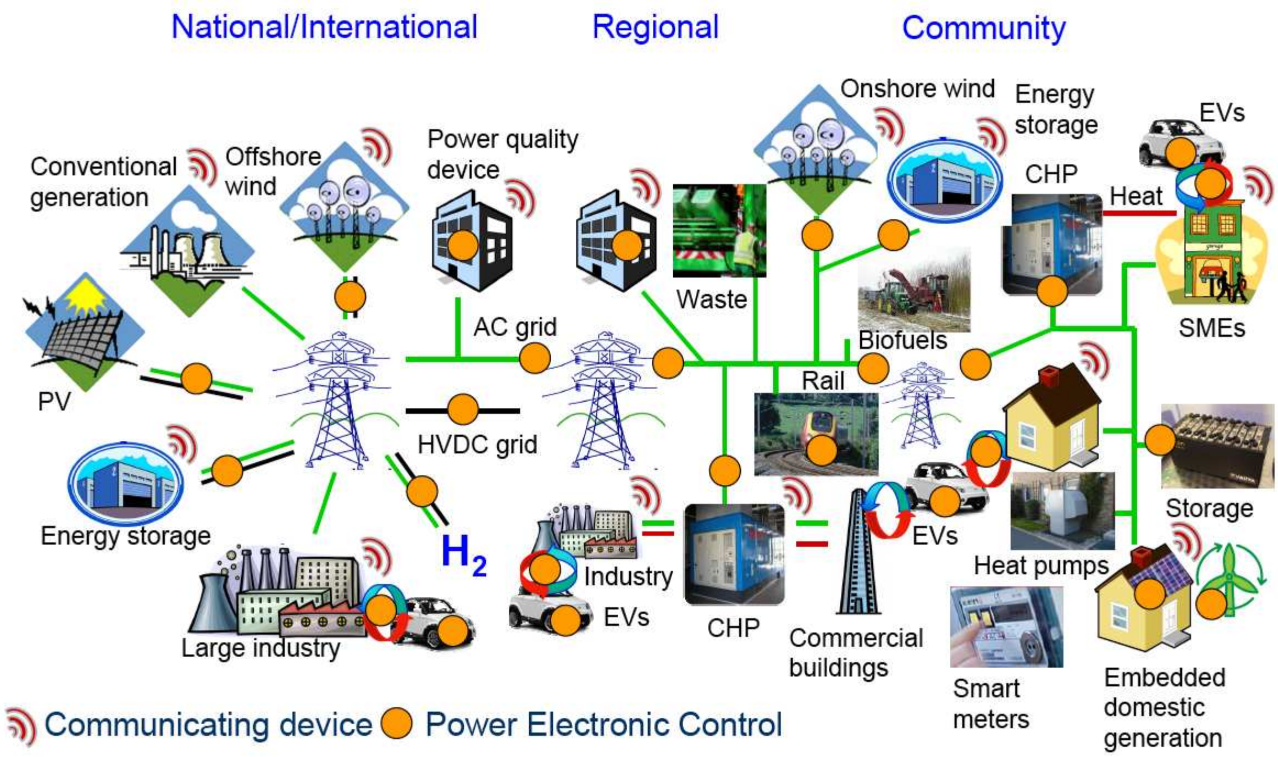

Figure 1: Smart Grid, courtesy of the University of Nottingham

is at the core of the concept. The Power Electronics community is in a unique position to contribute to both the concept and the implementation plan, not only because its scope embraces the entire system, but also because of its knowledge and experience in energy management systems engineering.

Case study	
Tidal Generation Ltd	 Working through its subsidiary, Tidal Generation Ltd, Rolls-Royce is currently testing a prototype 500kW tidal power generation system in Orkney. The turbine has generated 53MWh of electrical power and achieved Renewable Obligation Accreditation from Ofgem – the first tidal stream device to do so. The next step is the development and deployment of the next generation of demonstrator, a 1MW system, via the Energy Technologies Institute's ReDAPT project. By the middle of the decade the company plans to provide a 10MW array of these machines. Whilst much of the intellectual property for this application is based in mechanical and marine engineering disciplines, Power Electronics is a key enabling technology for realising a viable product. Within the body of the tidal turbine, which is deployed undersea at depths of up to 80m, is an array of electronic units that provide control, conditioning and monitoring functions for the turbine. They range from low-power data communications through to blade pitch actuation and finally up to 500kW of power converters that condition the electrical power from the induction generator so that it can be grid-connected. www.tidalgeneration.co.uk

The Market for Power Electronics

In the low-carbon and renewable areas considered above, the impact of Power Electronics is striking. The global market for low-carbon goods and services was worth £3 trillion in 2008 and is projected to grow by 50% to just under £4.5 trillion by 2015 [6], the majority enabled by Power Electronics. The Department for Energy and Climate Change estimates that the renewable energy sector could create 500,000 new jobs in the UK by 2020. The UK wind industry alone has the potential to create 60,000 new jobs over the course of the next ten years. This would effectively expand the workforce to well over ten times its current size.

In 2005 the US Department of Energy stated [7], "Approximately 30% of all electric power generated utilises Power Electronics somewhere between the point of generation and its end use. Most Power Electronics uses today are for improved control of loads such as variable-speed drives for motors that drive fans, pumps, and compressors or in switching power supplies found throughout most consumer products. By 2030, it is expected that perhaps as much as 80% of all electric power will use Power Electronics somewhere between generation and consumption."

For Power Electronics itself, the direct global market is estimated at £135 billion, growing at a rate of 10% per annum [8].

The shape of the market – see Figure 2 [9] - continues to evolve, with the growth of electric propulsion in the automotive sector and of renewable energy in the industry and energy sector particularly strong currently.

Many sectors within Power Electronics could be considered as established - industrial electric motor drives, for example - though very few could be considered mature as technology continues to significantly and dynamically change the market.

The size and growth of this market makes it highly competitive. Many markets are highly fragmented, with SMEs competing successfully in low-volume or highly-specialised system sectors. In the established and many emerging applications, Power Electronics is a global market, with major multi-national companies competing for high-volume business, with global design and manufacturing locations.

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[6] Engineering UK 2011, Exec Summary
www.engineeringuk.com/_db/_documents/6152_EngUK11_ES&C.pdf

[7] www.ece.utk.edu/~tolbert/publications/ornl_tm_2005_230.pdf

[8] Based on semiconductor device sales in 'The World Market for Power Semiconductor Discretes and Modules, IMS Research, 2011, and the judgement of the strategy group that typically semiconductors account for 10% of a Power Electronics system element

[9] Electronics enabling efficient energy usage, e4u, 2009

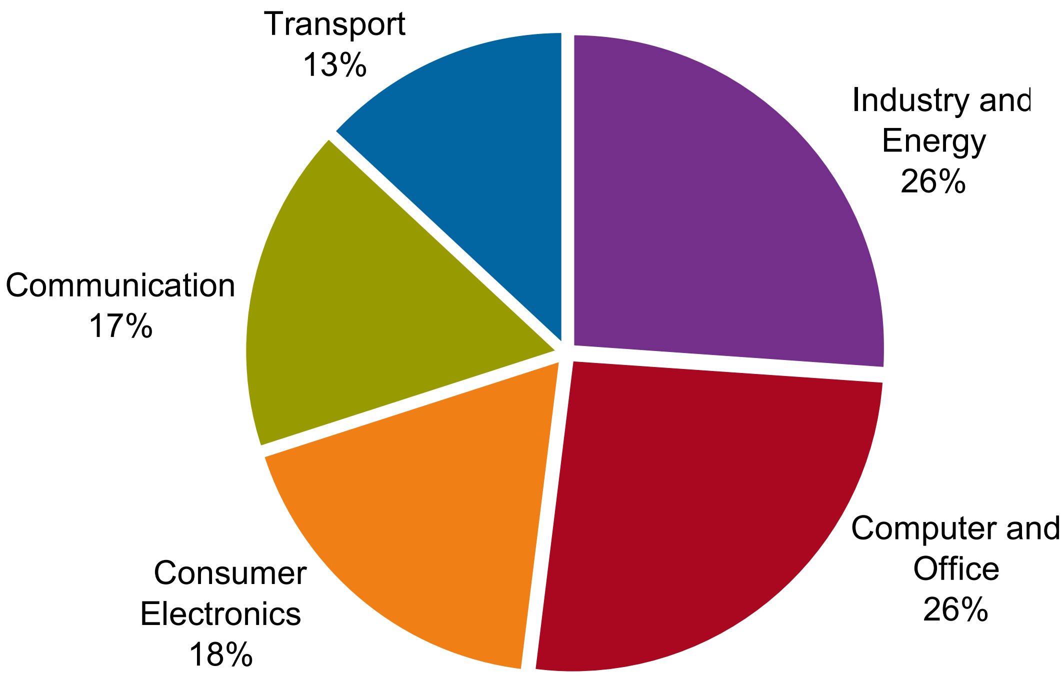

Figure 2: The Power Electronics Market

The decision of where a company designs a product is governed by a number of considerations. Cost has a significant impact, but Power Electronics design depends upon creative and innovative individuals working within well-organised and managed teams. Further, systems integration design demands both highly-skilled and experienced engineering talent, often including application-specific design knowledge. Many large global companies have set up distributed design teams, linked through dynamic computer-based systems for sharing design information, and so the communications infrastructure is critical. The UK is well-positioned to participate in and drive such global design teams, having historically well-educated and innovative engineers and a good communications infrastructure.

The decision of where a company manufactures a product is governed by another set of considerations. Here overall cost is, in general, a predominant concern, but the customer location and its supply chain, coupled with security considerations, result in some companies having dual or even multiple manufacturing locations. Power Electronics systems, other than high-volume commodity items, are - in general - high value, with relatively low labour content and where there are tangible benefits of manufacture being located close to design.

The Power Electronics market is vibrant, with a lot of innovation - often in disruptive technologies - driven by the need to provide solutions for both new markets and expanding scope within existing markets. As an enabling technology, it is critical to almost all aspects of our lives and it plays a key role in helping sustain our world.

Power Electronics in the UK

The UK has a rich history in Power Electronics, with a number of world-class companies involved in design, manufacture and global marketing in many market sectors.

It is recognised that SMEs are important drivers of innovation, and play a significant role in supporting larger companies with technology and/or as part of the critical supply chain. The UK has a broad network of SMEs working in Power Electronics areas including innovative power semiconductor devices, device substrates, passive components, renewable energy converters, battery management, energy storage and novel control techniques.

Further, UK universities play a critical role in educating the future generations of Power Electronic engineers and developing the knowledge base through leading internationally-recognised research.

Industrial companies

The engineering sector makes up nearly a fifth of the UK economy (19.6% of GDP) and employs over 4.5 million people [10]. Within this, the electronics industry directly contributes in excess of £16 billion to the UK GDP and provides direct employment for over 300,000 people in 12,000 companies [11]. Power Electronics contributes significantly to this, and has an indirect economic impact many times this size through an infrastructure of suppliers and dependent trades. It is, then, a significant part of the electronics portfolio, built on more than 50 years experience in the field and with many internationally-recognised players and technology and with market leadership in certain sectors.

As well as having a strong international reputation for design, the UK is the manufacturing base for not only local but also many global companies. The UK also has a strong SME base. Overall it contributes about 3.1% of the global Power Electronics product (as opposed to component) manufacturing (based on power semiconductor module sales), with a very high percentage of that production being exported [12]. The influence of the UK Power Electronics industry on the global market is even more significant, however, as UK-based design groups contribute strongly to equipment that is manufactured in part or in whole overseas.

Power semiconductor devices and smart-control integrated circuits have been key technology drivers for the last two decades. In the next two decades, packaging and

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[10] Engineering UK 2011

[11] ONS Annual Business Survey 2009

[12] Based on semiconductor device sales in 'The World Market for Power Semiconductor Discretes and Modules', IMS Research, 2011, and the judgement of the strategy group that typically semiconductors account for 10% of a Power Electronics system element

interconnection technologies, high-power density system integration together with advances in silicon devices and system reliability will drive the technical development of Power Electronics. The UK has made very significant contributions to research, based on the number of papers published in international journals and conferences. It is also interesting to note that the UK hosts world-leading power semiconductor substrate development. With expertise in both industry and universities, and with excellent educational facilities and an outstanding research infrastructure, the UK has an excellent base from which to compete and grow in the world market.

Further, with Power Electronics systems tending to be application-specific, highly-customised and having a relatively high added-value, their manufacture is suited to a technologically-advanced manufacturing base and can absorb the relatively high UK labour costs.

The system design and manufacturing industry in the UK covers many industrial sectors, with ‘global top 10 companies’ including:

- ALSTOM Grid (high voltage direct current)
- Converteam (industrial and marine drives, renewable energy converters)
- Emerson-Control Techniques (industrial drives and renewable energy converters)
- Goodrich Power Systems (aerospace control and actuation systems)
- Rolls-Royce (aerospace, marine, energy)
- Siemens (industrial drives, generation/transmission/distribution, lighting)
- TRW Conekt (automotive).

On the component level, semiconductor fabrication is an often-hidden UK strength, with a notable presence in some specific areas of power semiconductor fabrication, notably:

- IQE Group (power semiconductor device substrates)
- International Rectifier (power semiconductor devices)
- Dynex Semiconductor (power semiconductor devices)
- NXP Semiconductors (power management)
- Zetex (diodes)
- National Semiconductor (power management)
- Semifab (MEMs and power semiconductor foundry).

The SME base, critical to the Power Electronics systems companies, includes:

- International Transformers (power transformers and high frequency inductors)
- Norfolk Capacitors (energy storage capacitors for traction, industrial drives, power conditioning and avionics)
- Industrial Capacitors Wrexham (energy storage capacitors for industrial and military applications)
- Telcon (current sensors)
- Cambridge Semiconductor (design of integrated power control chips).

While such SME companies are well-established, their characteristics should be recognised and addressed. They have particular research and development needs; they operate with much shorter development cycles than established industries; they are very much ‘problem-driven’; and they do not necessarily have in-house expertise, computational tools or test facilities to fully analyse problems. These characteristics can present problems to both larger companies and universities when trying to build relationships with SMEs. But such relationships can be mutually invaluable, and can be helped through existing Government-funded/driven initiatives.

There are also some exciting start-ups in the Power Electronics field such as:

- Amantys (novel device control systems)
- Anvil Semiconductors (silicon carbide power devices)
- Enecsys (embeddable PV converters)
- Evince Technology (diamond power semiconductors)
- GenDrive (optimised wind and PV converters)
- Juice (novel solid state lighting control).

These companies have similar issues to SMEs, with one important addition - that the time it can take industry to accept new ideas and technologies is longer than that over which investment capital is traditionally comfortable. Finding ways to bridge this void should also be a consideration for Government-funded/driven initiatives.

Academic profile

The UK has a significant number of world-class universities in the field of electrical energy conversion, including Power Electronics. This capability is built on the UK’s historical involvement in energy conversion.

The quality of teaching at these universities is excellent, demonstrated in part by the number of overseas students studying undergraduate courses in electrical and electronics engineering and MSc programmes relating to Power Electronics. However, the number of UK students on these courses is cumulatively too low to meet industrial demand, as discussed later (see page 46). There are also concerns about the maintenance of standards, as universities look to increase or even maintain intake at historic levels, particularly when there are difficulties in filling lectureships with competent staff.

The quality of Power Electronics research in UK universities also remains very high. There is concern in the community, however, that the national research budgets are spread too thinly in this subject area, with funding being given to too many institutions and researchers with little prospect of 'making a difference'.

Notable UK universities in the field of Power Electronics include:

- Cambridge University (power semiconductor devices, drivers and simulation models, wind and solar systems, propulsion systems)
- Imperial College London (high voltage direct current, flexible AC transmission systems, generation interfaces, distribution network Power Electronics, energy harvesting)
- Newcastle University (drives and machines, energy management, thermal management, power converters and energy storage; automotive, aerospace, industry)
- University of Bristol (energy management, electrical machines and power conversion for transport, industrial applications and renewable generation, energy harvesting)
- University of Edinburgh (drives and machines for renewables, energy management, network integration, demand side management)
- University of Manchester (energy conversion systems, industrial drive systems and machine control, energy storage and management, aerospace, marine, automotive)
- University of Nottingham (high voltage direct current, power conversion, control, integration, reliability, thermal management, drives and machines, aerospace, energy networks and energy management, surface transport, pulsed power)
- University of Sheffield (power semiconductors, machines and drives, actuators, renewables, energy management, battery management, aerospace, automotive, marine)
- University of Strathclyde (grid interface for renewable energy sources, high voltage direct current and flexible AC transmission systems, high-power converters, power semiconductors, pulsed power)
- University of Warwick (power semiconductors for automotive, renewable energy and aerospace applications, advanced electrothermal modelling, silicon carbide).

The UK Power Electronics Community

The enabling role of Power Electronics across a broad range of application areas leads to a naturally-distributed and fragmented community. Industry-specific communities exist in the UK, notably through numerous trade associations. At the European level, technology-centric organisations are seen, notably the European Centre for Power Electronics (ECPE) which provides a focus and network for technology roadmapping, and the European Power Electronics Association (EPE) which organises major international conferences, seminars and publications.

The Institution of Engineering and Technology (IET) has historically provided a UK hub for the electrical and electronics engineering community. Whilst the IET hosts a number of international conferences and seminars and publishes technical journals relating to Power Electronics, it does not currently provide a good forum for the Power Electronics community to meet, discuss common problems and plan a unified course of action. The IET is currently undertaking a review of its communities, and the Power Electronics Strategy Group is engaged with this review process.

NMI has recently facilitated reviews of Power Electronics with The Carbon Trust [13] and the present strategy review. The development of this strategy document has shown clearly the benefit of such forums, and the Group is committed to continue with the process.

[13] 'The potential contribution of power electronics to carbon reduction', The Carbon Trust, 2010

Focusing on Market Sectors

The Strategy Group focused on four sectors of UK strength to illustrate the opportunities and risks faced by the Power Electronics industry as a whole. In selecting them it was recognised that, in order to succeed in the competitive global markets that characterise Power Electronics, it is necessary to have good technology, good material and component availability, good manufacturing and – very importantly – good market access.

The four areas considered are:

- Transport
- Energy generation, transmission and distribution
- Consumer electronics and lighting
- Industrial drives.

Before assessing the characteristics of each, however, it is important to consider some common issues that were identified in all four.

Common issues

In analyses of strengths, opportunities, weaknesses and threats undertaken separately in all four focus sectors, some issues were found to be common to all. Rather than repeat them in each sector focus, they are listed here. They form a large part of the rationale for the 'Skills in Power Electronics' section following, and the 'Challenges, opportunities and actions' section that follows that.

UK strengths

- A high international reputation for design and a good record of innovation
- A good supply chain including specialist and innovative SMEs
- World-class university research and undergraduate teaching.

UK weaknesses

- A shortage of suitably-skilled engineers - graduates and technicians
- Power Electronics is not recognised by Government or society generally, particularly in terms of its value as a key enabler for a low-carbon economy

- The activities of industry, universities and Government are not co-ordinated
- There is no single organisation promoting the Power Electronics community.

UK opportunities

- The UK's infrastructure, economy and natural resources make it an ideal 'showroom' to display UK-based industry as an exemplary producer and user of Power Electronics products, and a world-leader on low-carbon, renewables, manufacturing and sustainability
- There is a movement to re-balance the economy by increasing 'high-value' manufacturing: this could provide the momentum to strengthen, extend and exploit UK strengths in Power Electronics
- There is a growing interest in power and energy disciplines from electrical and electronics engineering students
- Schemes for sponsoring students have great potential to aid recruitment.

UK threats

- An inability to recruit high-quality engineers could make global companies move their design and manufacturing out of the UK
- Regulatory barriers (eg not approving work visas from experienced engineers) could make the UK an unattractive place to undertake design and/or manufacture
- Changes to the taxation regime could make global companies move their design and manufacturing out of the UK
- Restrictions on intellectual property rights
- Competition from low-cost countries (China, India, Brazil)
- The impact of tuition fees on potential engineering undergraduates.

The area of most concern to all sectors - and embracing academia as well as industry - is the shortage of high-quality Power Electronics engineers. This issue is outlined on page 46.

Transport

Transport is the fastest growing sector in the European economy. It consumes over 30% of total primary energy [14].

The electrification of transport is not new - the earliest motorised vehicles were propelled by electric motors, including most early buses and trams. The subsequent ascendancy of the internal combustion engine was simply a result of the low cost of hydrocarbons.

Currently, however, there is a desire to move from a dependency on burning fossil fuels. There is increasing support for many future transport systems to rely on electrical propulsion based on low-carbon electricity. The most significant demand will be in surface transportation – automotive and rail – with both being huge sectors in terms of the potential use of electrical energy and the diversity of issues faced by the different areas of application. For the marine and aerospace sectors, problems surrounding the storage of electrical energy will limit applications for propulsion. But in replacing conventional electrical, pneumatic and hydraulic systems on aircraft and marine vessels, Power Electronics is seen as having enormous potential as a disruptive technology driving radical change.

The UK has been a global leader in all aspects of transport, and retains expertise both at research and manufacturing level. There is a desire to safeguard and grow the manufacturing base in the historical heartlands of these industries, and this high-value-added market offers a key opportunity to do this.

The market

Automotive

The growth and development of the electric hybrid and all-electric vehicles has received considerable publicity in recent years. Power Electronics is a core technology that controls the energy flow from the battery to the motor and vice versa, and enables this flow to be accomplished as efficiently as possible. In addition to the main traction function, there are also numerous other areas where Power Electronics is key - for example the battery charger and the provision of a 12V supply for legacy loads. All of these are based around the same core - Power Electronics.

It is very easy to assemble parts from a number of suppliers to make an electric vehicle (EV) that can act as a demonstrator: indeed there are many of these vehicles around. The real issue is engineering a vehicle that is reliable, cost effective and desirable enough to persuade people to buy it without having to make an ‘environmental’ decision. This is where both the challenge and the opportunity lie in this sector.

Based simply on the number of vehicles produced each year, the automotive market is the one where Power Electronics will probably have its biggest impact. As an example, an

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[14] Eurostat, epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/main_tables

average electric engine requires a peak output power of 75kW and, with approximately 1.7 million vehicles sold in the UK every year, this gives a potential of 130GW of newly-installed Power Electronics per year. Even at only 20% penetration, this is still equivalent to the total installed capacity of the wind generation sector. On a global basis the figure is close to 5,000GW, a truly massive potential market. Such a market demand significantly impacts the scale of the entire Power Electronics supply chain. Based on today's material costs, this would very conservatively translate into a UK market of £1 billion and a global market of £40 billion.

In addition to the above, all-electric solutions are dependent on a battery-charging system - needed both at home and as part of a broader public infrastructure - which is again Power Electronics-dependent.

Rail

The electrification of rail transport has been underway for the last 30 years. The benefits are there for all to see, and high-speed rail is exclusively based on this approach. The power levels are in the multi-MW range, and the fixed infrastructure of rail means that the power is not stored on the vehicle. However, the underpinning technology is very similar to that of the automotive sector.

In considering the marketplace for rail, consider that in 2003 there was a total of 3,588 vehicles in the UK. China is planning to employ more than 7,000 new 3MW vehicles per annum, giving an installed Power Electronics capacity of over 20GW. The market is clearly global, but it is one in which the UK has the potential for success.

Around the world, Power Electronics is playing an ever more important role in the development of the rail industry, driven largely by energy efficiency considerations. The use of AC traction motors and converter equipment is now becoming standard for most new equipment, with considerable mechatronic integration (combining mechanical, electronic, computer, software and control engineering), some involving direct (gearless) drives. All electric solutions including 'energy backfeeding' (feeding energy back into the supply during braking and downhill operation) provide significant savings.

Power Electronics is also critical to the auxiliary supplies in rail traction equipment. Such loads are important as - in new tram cars, for example - the energy consumption for air-conditioning/heating, doors, lighting and information screens is in the same range as that used for propulsion.

Marine

Power Electronics is having a substantial impact in the marine sector, driven by energy efficiency, volume and weight considerations, and the flexibility electric propulsion offers such as rotating pods which allow dramatically-improved manoeuvrability for large ships.

In 2010 the world merchant fleet comprised some 77,768 vessels [15]. This is a large market, where the UK has a strong record of achievement, most notably with Rolls-Royce and Converteam. Both companies service the merchant fleet and the extensive military market, where leading-edge technology is so often developed and applied.

The global electrical marine propulsion market is predicted to grow from about 2% (£500m) in 2003 to a projected 10% (£2.8bn) in 2013 of the total global marine propulsion market. Like the automotive sector, this has been in part enabled by developments in Power Electronics. The use of electric propulsion equipment in marine offers a number of advantages - such as better vessel manoeuvrability, increased system redundancy and more efficient vessel operation at part powers. The use of Power Electronics provides the necessary control to realise these benefits. With further improvements in the technology, and especially when synergies with the predicted growth in the marine energy field (tidal and wave) are exploited, the global marine electrical propulsion market should grow further.

Aerospace

The majority of large aircraft being built today use the same power source and equipment controls' technologies as were used in the 1950s – electrical, hydraulic and pneumatic (compressed air). This gives aircraft that are both safe and whose construction is familiar to the mass aviation market – but it comes at a cost in efficiency when compared to what would be possible by employing Power Electronics technologies. With fuel costs escalating, manufacturers are increasingly looking to enhance efficiency. The Airbus A380 first introduced electrical control actuators in civil service to back up the primary hydraulic systems, and the Boeing 787 has replaced all hydraulic and pneumatic power and controls with electrical alternatives enabled by Power Electronics. Future aircraft are likely to follow this example and within 10-15 years all new airliners are expected to have done so.

The global market value of the Power Electronics components of civil airliners will grow on current estimates to £1.225 billion per year [16].

Based on the aerospace industry average of a high-productivity turnover per employee of £213,000 per year, and a 20% share of this global market, 1,150 jobs would be retained or created in the UK. (The current UK market share for conventional technology equipment and systems is 15% to 18%). Aerospace industry economic research [17] also indicates that, for each direct high skills/productivity job, an additional 3.1 jobs are created

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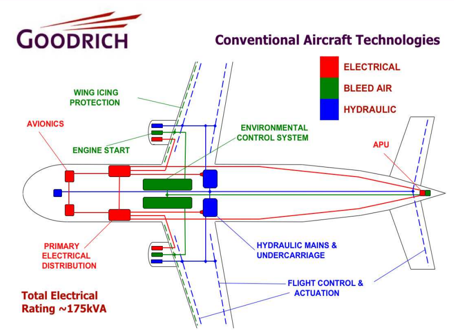
[15] www.emsa.europa.eu/documents/item/472-annual-statistical-report-on-the-world-merchant-statistics-from-equasisics-from-equasis.html

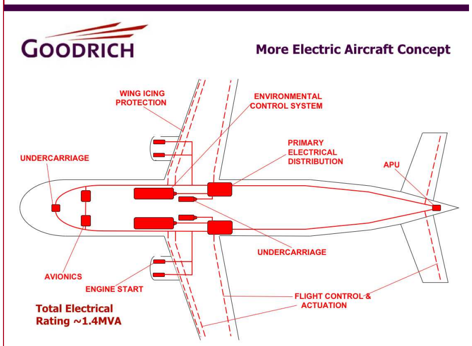
[16] Electrical Power Systems National Technical Committee (advisory panel for the National Aerospace Technology Strategy, sponsored by the Aerospace, Aviation & Defence Knowledge Transfer Network)

[17] UK Aerospace Industry Survey 2009, published by trade association Society of British Aerospace Companies (now ADS)

elsewhere in UK manufacturing. However, there is considerable scope for a national strategy to develop the vertical integration of the supply chain within the UK – increasing and extending this 3.1 times factor for jobs.

<table>
<tr><th>Case study</th><th></th></tr>
<tr><td>Goodrich Power Systems</td><td>
Goodrich Power Systems is a UK-based aerospace company at the forefront of ‘More Electric Aircraft’ technologies – whereby the equipment ‘under the skin’ of civil airliners uses electrical power instead of hydraulics and pneumatics. The integration of multiple electronic technologies at systems’ level enables significant improvements in the functionality and efficiency of the whole aircraft.





Goodrich already supplies airborne electrical power systems for use on rotorcraft, business jets and military aircraft, as well as on large airliners. Recent projects have demonstrated how aircraft generators can be electrically-driven as motors to start the engines, and that the Power Electronics controllers can be used to drive multiple motoring and pumping applications whilst in flight.

The global market for the type of products Goodrich designs and manufactures will migrate over to power electronic variants in the medium term. Raymond Collins, the Goodrich R&D Team Manager says, ‘investment in electronics and systems integration is the key for us to realise the Goodrich strategy of positioning ourselves for new platforms through technology and cost leadership.’

www.goodrich.com/Goodrich/Businesses/Electrical-Power-Systems
</td></tr>
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Our main competitor in this sector is the USA, which could target 60% or more of the market. Significant competition can also be expected from France and Germany, whose combined market share is similar to the UK's. Apart from the USA, the UK is the only country that could develop and manufacture a complete set of new technology Power Electronics equipment and controls for a large civil airliner.

The UK Supply Chain

The UK has a long history of innovation in the automotive sector, which carries on to this day. There are 380,000 people employed in the sector at the present time. These are core strengths that we can build on. However, a shift change is needed, both in terms of capacity and the required skills in order to embrace the move to electric vehicles. This is not an industry that requires low labour costs, it is a high-added-value industry.

The UK retains a significant strength in both complete train-building itself but also the manufacture of components such as auxiliary power supplies and signalling

The main players in the UK marine sector, Rolls-Royce and Converteam, are both supported by the experience and expertise of a significant supply chain, and by a long tradition of collaboration with universities. Rolls-Royce has been most widely known for the supply of gas turbines to the marine industry, but its scope of supply has grown considerably to take in complete ship design as well as onboard equipment and systems solutions. Converteam supplies some of the most advanced technologies in power generation and distribution, electric propulsion, vessel automation, dynamic positioning, power management and control systems to merchant marine vessels (including cruise-liners) and to coastguard and naval vessels around the world.

In aerospace, the UK boasts a significant number of companies with world-leading technology and strong market penetration in equipment incorporating Power Electronics and controls. These include GE Aviation, BAE Systems, Goodrich, ULTRA, GKN, Eaton, Honeywell and Rolls-Royce. They are served in turn by a significant cohort of supply chain specialists: Raytheon, Dynex Semiconductor, TT Electronics, NCL, ICW, Ferranti, Aero Stanrew, Magnetic Precision etc. All these companies have UK-based engineering and development teams.

The UK strength in systems integration is complemented by an extensive UK industrial base providing products and services bespoke to the requirements of technology and product development, including the rigorous safety requirements in aerospace.

The Technology Base

It is clear that the new Power Electronics demand and power-handling capability in the automotive sector is massive. From a UK perspective, we presently have a significant number of small companies who are leading the world in the area of automotive Power Electronics design. The main risk in establishing this new technology is the severe shortage of appropriately-skilled people, highlighted elsewhere in this document. If we do not raise this as a strategic priority, this technology will be developed in Germany or the Far East.

This is a real opportunity for the UK, but there must be Government support in order to de-risk the massive investments needed to enter the market in readiness for large-scale demand. There will undoubtedly be EVs built in the UK by the large multinationals but, with the present business model, the high-end, value-added technology will be bought in from overseas, thus relinquishing a significant opportunity for long-term UK wealth creation in a newly-developing and long-lasting high technology arena.

Technology is advancing apace in both rail and marine. The greatest risk to the UK's specific strengths in both these markets is the availability of skilled people to embrace the changing technologies.

A number of universities have specialised in electrical engineering for aerospace and the pipeline feeding the technological capability in aerospace is extensive.. A wide scope of technical areas is addressed, from die packaging through to full platform/vehicle integration, including end-to-end simulation.

Common to all transport applications utilising Power Electronics technologies, there is a significant research and development task ahead that must address four perennial areas:

- Power density, ie kW/kg
- Robustness in a harsh environment
- Reliability
- Industrialisation, ie 'design to cost'.

Analysis

In addition to the common issues identified on page 22, the workshops found that UK strengths in the various aspects of this sector were: systems integration; access to global markets; and the technical capability to conduct high-integrity simulation of new technology equipment, controls and complete systems.

The systems integration and simulation capabilities are the UK's key differentiator. The extensive access to the global market and the current industrial critical mass is a position worth investing in.

High skills and high-productivity operations based on product design or manufacturing are difficult to displace in this high science content industry. Indeed, as top-level systems integration becomes a bigger fraction of the overall activity, this may form a 'critical mass' that attracts more opportunities to UK plc [18].

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[18] UK Civil Aerospace Strategy Report June 2009, published by trade association Society of British Aerospace Companies (now ADS)

Weaknesses particular to the aerospace industry were identified: technology exploitation along the full Technology Readiness Level (TRL) pipeline; the key supply chain issue of ‘commodity vs customisation’; and engagement with new international technical standards.

An improved engagement on standards can be addressed by support for commercial companies and research organisations at national level, but the supply chain and technology base weaknesses cannot be alleviated by relying on the UK’s critical mass and other strengths – they need to be mitigated by a national strategy.

Overall, transport is an attractive global market which UK plc is well-placed to exploit – with significant opportunities for high added-value products and services (almost exclusively for export). Current high-value products based on hydraulics and pneumatics will become technologically obsolete. That value needs to be replaced.

However, there is still competition from other countries with a high-skills, high-productivity industrial capability in this area. Most if not all are undertaking extensive, ambitious and publicly-funded research and development strategies to further strengthen their positions for the global market [19] [20]. By investing in R&D, these countries are building up their overall technology, research and industrial capability in a progressive and structured manner. The risk to UK plc is that - without an equally ambitious and effective national strategy - we shall lose access to these prime opportunities.

Strengths

- Significant critical mass compared with our competitors, access to global markets
- Systems engineering/integration, including manufacturing quality
- End-to-end simulation, complete systems/platforms.

Weaknesses

- Technology exploitation - poor critical mass for new products feeding into trials
- Standards – gaps in knowledge and engagement
- Commodities vs customisation.

Opportunities

- Power Electronics is ‘disruptive’, replacing conventional technology
- Significant exports for high value-added products and services

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[19] European Commission public domain communication 21st March 2007

[20] www.ohiothirdfrontier.com/ mfrtech.com/articles/3267.html

- The global market is growing
- Vertical integration of supply chain within UK.

Threats

- Regulations covering the export of defence equipment
- Competitor national strategies are very active – particularly USA, France, Germany
- The UK industrial base on hydraulic and pneumatic equipment and controls will become progressively obsolete.

Case study	
Rolls Royce plc	Unmanned Aerial Vehicles (UAVs) are becoming increasingly diverse in terms of their design, scope and performance. More electric UAVs are placing greater demands on the control and Power Electronics requirements in order to meet higher power, longer component lifetime and lower weight requirements. The Electrical Power and Control Systems Group (EPACS) at Rolls-Royce in Derby, Bristol and Indianapolis has been conducting applied research and development of new products in the areas of Power Electronics and electrical machine design for application on a wide range of military and civilian aircraft. EPACS has also been working closely with the Sheffield University Technology Centre (UTC) in advanced electrical machines and drives and its own defence aerospace engineers to produce products for use on UAV engines, with a recent application being the Small Engine Electrical Demonstrator (SEED) programme. One particular product is a bi-directional converter for gas turbine high pressure spool starting and generating, which is based on novel silicon carbide Power Electronics devices. This converter will be demonstrated as part of the three-year collaborative industry research programme ASTRAEA2 (Autonomous Systems Technology Related Airborne Evaluation & Assessment) in 2012, which is being supported with around £14m public funding through the Technology Strategy Board. www.rolls-royce.com

Electricity generation, transmission and distribution

The electrical energy supply chain is conventionally divided into three sectors: generation, transmission and distribution. Generation is the production of electricity, from fossil-fuels, nuclear or renewable energy sources. Transmission is the 'transport' of electricity from generation to the points of bulk distribution, usually at very high voltages. Distribution is the local area supply of electricity to end-users. The UK electricity grid is a single giant system and Power Electronics plays a key role in ensuring that the network remains stable and secure.

Power Electronics is now cited as the critical enabling technology for Smart Grids, with a vital role to play throughout the energy supply chain. MW-scale Power Electronics converters are essential components in new generation plant such as wind turbines, photovoltaic systems and tidal generators, where they convert variable voltage inputs into fixed voltage outputs for connection to the grid.

At transmission level, MW-scale converters are also used in Flexible AC Transmission Systems (FACTS) to support the existing AC grid. High-Voltage DC (HVDC) systems using GW-scale Power Electronics converters to boost voltages up to 800kV for transmission over long distances are now being seen as the key enabling technology for offshore wind and the European Supergrid.

At distribution level, Power Electronics is an integral part of ensuring that our distribution networks are able to accommodate ever-increasing levels of embedded generation and emerging technologies such as energy storage and electric vehicle charging networks.

The market

By GW of power controlled, energy is the largest sector for Power Electronics. Key global markets include:

- Wind converters: 36GW pa
- PV converters: 17GW pa
- HVDC systems: 24GW pa
- FACTS systems: 3.5GW pa.

The total value of these markets is greater than £7 billion for the Power Electronics content alone, with most of these systems being a key component within far bigger infrastructure projects worth as much as 10 times this value. In all cases the growth forecasts for the next 5-10 years are more than 10% per annum.

The UK electricity industry is set to undergo the most significant change in its structure since the 1930s. With over 50% of energy to come from renewable sources, this will present unprecedented challenges to the continued security, stability and quality of supply of electricity. In all energy scenarios, Power Electronics systems will play a pivotal role.

Case study	
ALSTOM Grid	 High-Voltage Direct Current (HVDC) is a Power Electronics technology that is ideal for moving very large amounts of power over very long distances within or between countries. It is of growing interest in large developing countries such as China, India and Brazil. In China, for example, there is rapid economic development in the major cities in the east of the country, but the main sources of primary energy (hydroelectric dams and coal) are in the west. Addressing this is the Ningdong-Shandong project - the first ±660kV HVDC transmission project in the world. It has a transmission capacity of 4,000MW over a distance of 1,300km, and the thyristor valves that are a crucially important component have been supplied entirely by ALSTOM Grid based in Stafford, working with its partner in China, the China Electric Power Research Institute (CEPRI). Each of the two converter stations contains two 2,000MW HVDC converters, each in turn comprising six suspended double-valve structures using ALSTOM's H400 HVDC valve technology and 7.2kV electrically-triggered thyristors. The rated power of 2,000MW per converter is the highest of any single power electronic converter for any type of application. The thyristor valve has successfully passed all operational and dielectric type tests and the project is now in commercial operation. www.alstom.com/grid/

Hence, over the next 25 years, the UK spend on Power Electronics to enable the implementation of 'smarter' electricity grids (see page 13) is expected to be in excess of £60 billion.

The UK supply chain

There is significant expertise and know-how in the UK for the design of Power Electronics systems able to meet the standards required by the electricity grid. They are complex systems, requiring a diverse mix of electrical and mechanical engineering and scientific skills. Such skills are hard to acquire and companies operating in this field still mainly operate from the developed countries.

The UK has some major players in generation, transmission and distribution. Converteam UK, based in Rugby, delivered 3.5GW of wind turbine converters in 2010 [21], representing 10% of the global market. Emerson - Control Techniques is enjoying similar success in photovoltaic converters. ALSTOM Grid in Stafford has established itself as a world leader in HVDC and FACTS technology.

The technology base

System cost and reliability/availability are the key drivers for Power Electronics in generation, transmission and distribution. Reducing costs and improving reliability/availability are dependent on the emergence of new technology in the fields of power semiconductor devices, passive components (inductors, capacitors and resistors), thermal management, transformers, control, insulation, converter topologies and modelling/design tools.

It is widely recognised that a new generation of semiconductor devices able to operate at greater than 10kV will be critical to driving down the cost of transmission and distribution Power Electronics systems in the future. Whilst silicon designs at these voltage and power levels are practicable, silicon carbide, gallium nitride and diamond are possible alternatives, each having advantages. To extract the maximum benefit that this new generation of devices can offer will require extensive upstream development to properly integrate them. Strong collaboration frameworks that co-ordinate the supply chain through to demonstration are vital in ensuring that the UK remains strongly competitive in this field.

Diamond is the least mature of these emerging technologies, but it is widely seen as the ultimate for very-high-power applications. The UK is home to a thriving community including the world-leader in synthetic diamond materials - Element 6 - and a strong start-up base with companies such as Evince Technology. These companies are demonstrating highly novel high-voltage/high-power devices that fully exploit diamond's potential.

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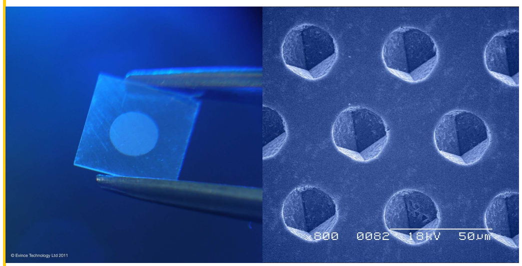
[21] Converteam 2010 Annual Report

Case study	
Evince Technology	 Evince Technology was set up in 2008 to develop a new class of Power Electronic devices that exploit the unique properties of diamond. These devices will be able to directly operate at electricity network voltages of 15,000V and above, which is now a widely-recognised challenge area for Smart Grids. The same basic devices have applications at the heart of renewable and conventional generation systems, electricity grid control, and end-use applications such as rail traction and industrial process drives. The company has already attracted strong international interest from major systems manufacturers and plans to launch its first product, a high voltage diode, in 2012. www.evincetechnology.com

Analysis

An issue for Power Electronics deployment in this sector is that the electricity industry is highly conservative. The need to ensure continuity of electricity supply means that there is no easy route to market for disruptive new technologies – which by their very nature carry risk. Hence adoption times of five to ten years are not uncommon. This makes it very difficult for start-ups and SMEs to enter as a supplier to this sector (even as a 2nd or 3rd tier supplier) and grow to become a major player.

Countering this, pressures on the industry mean that it now needs to embrace new technologies to accommodate the increasing strain placed by non-scheduled generation, new types of load and the increasing risk of instability. There is a critical need for industry-based funding schemes such as the Innovative Finance Initiative [22] and Low Carbon Networks Fund [23] , and the Energy Technologies Institute [24] to place increasing emphasis

[22] www.unepfi.org

[23] www.ofgem.gov.uk/networks/elecdist/lcnf

[24] Energy Technologies Institute strategy summary July 2010: www.energytechnologies.co.uk/Libraries/Related_Documents/Programme_Areas_and_Plans.sflb

on Power Electronic systems as a way of improving the stability and efficiency of the electricity supply system. This needs to be coupled with registered power zones being able to accommodate higher levels of risk.

Case study	
Converteam UK	 Whitelee Windfarm, ten miles from Glasgow on Eaglesham Moor, is Europe's largest wind farm. Its 140 Siemens Wind Power turbines can generate 322 MW of electricity, enough to power 180,000 homes. Each individual turbine includes a 2.3MW, 690V Power Electronics converter, supplied by Converteam UK, to convert the variable frequency and voltage output of the generator into fixed-voltage, fixed-frequency electricity suitable for export to the grid. Converteam UK is a leader in wind power converter technology. At the end of 2010, it had supplied over 10GW (10,000MW) of converters to the wind industry as a whole. www.converteam.com

The UK market and energy infrastructure offers a unique environment to develop solutions to these challenges and a strong opportunity for UK companies to take a global lead in the implementation of Power Electronics for truly smart grids. Achieving this will require Government, industry and academia to co-ordinate and incentivise each other to work towards demonstrators that show the clear benefits that Power Electronics can bring.

Strengths

- An international reputation for systems integration with major players providing a supply chain route to the global market

- Lots of new ideas from academia, industry and SMEs, innovative start-ups

- A large UK market.

Weaknesses

- The industry is conservative - lacking a clear long-term strategy and leaving no easy route to market for new/disruptive technologies

- It is difficult for small companies to enter the market (even as Tier 2 and 3 suppliers)

- There is a gap in implementation (scale-up and proof-of-concept to pilot production) support mechanisms – both financial and the availability of test-beds.

Opportunities

- Smart sustainable energy (eg renewables, Smart Grid and Super Grid (HVDC), and electric vehicle charging) are dependent on Power Electronics

- The UK grid infrastructure is old and offers a unique environment to develop novel solutions that have strong export potential.

Threats

- UK standards are generally more onerous than in other countries, leading to over-design

- Without managing the expectations of the public and Government, major infrastructure projects will inevitably be seen as running over time, over budget and failing to deliver

- There is an ongoing consolidation of the industry with tier 1 manufacturers acquiring innovation through the purchase of funding-starved SMEs.

Consumer electronics and lighting

More than 20% of the electricity consumed worldwide is used to power small low-power products such as consumer electronics, computers, office equipment and lighting. Power Electronics is at the heart of every one of them. Even small gains in efficiency can lead to significant global reductions in energy consumption.

Opportunities offered by Power Electronics depends on the type of product, but typically motor-driven appliances can be made 40% more efficient, lighting up to 75% more efficient and computers up to 30% more efficient.

The market

Consumer

In terms of power semiconductors, the global market for consumer products in 2011 is £2.3 billion with an annual growth of 10.1% [25].

Consumer electronics is a diverse market with varied and challenging demands for Power Electronics. Any consumer product requiring electrical power from a battery or the mains will require some kind of power management for electrical energy conversion. Applications range from motor drive systems with ratings up to a few kW in white goods

[25] 'The World Market for Power Semiconductor Discretes and Modules', IMS Research, 2011

and ventilation fans, through to power supplies of a few watts in a clock. Regulation and legislation have driven efficiency to be a key issue and - as elsewhere - Power Electronics is critical to efficient energy conversion. Consumer designs are also generally very cost-sensitive and often have demanding size requirements, both demanding novel and innovative solutions.

Lighting

In terms of power semiconductors, the global market for lighting in 2011 is £478 million with an annual growth of 10.8% [26]. This projected growth figure excludes the disruptive impact of LED lighting which will dramatically accelerate the growth of Power Electronics in this market.

Over 15% of the world's electricity is used in lighting, much still provided – very inefficiently - by tungsten filament bulbs. Low-energy alternatives include low-voltage halogen, fluorescent, compact fluorescent, HID (high intensity discharge) and LED (light-emitting diodes). All these require Power Electronics. With efficiency improvements of typically 70% over conventional filament bulbs, the potential savings equate to more than 10% of electrical energy consumption.

Computer and office equipment

In terms of power semiconductors, the global market for computing and office equipment in 2011 is £2.1 billion with annual growth of 9.6% [27].

Power management is crucial to the computer and network communications market. Computer server centres are very significant consumers of electricity. Up to a third of the total energy consumed by a typical server is wasted before reaching the computing components. The majority of these losses occur when converting electricity from one form to another, notably in the power supplies, which convert the standard mains AC voltage to a low DC voltage suitable for the computer processors. This power conversion has traditionally been designed with low-cost, low-efficiency power semiconductors. The market is now demanding higher levels of efficiency to reduce energy bills and CO_2 emissions, and to lower the consumption of cooling water.

Potential savings are substantial. Google, for example, has an estimated 1 million servers, each server enjoying annual savings enabled by Power Electronics of 500kWh (direct electrical energy), 300kg of CO_2 and 1,000 gallons of water.

Similar savings for data servers apply to desktop PCs laptops, notebooks, mobile phones and tablet computers. In the case of battery-operated mobile applications, the efficiencies also enhance battery life. In recent years average laptop operating-time under battery

[26] As 25

[27] As 25

power has increased from 1 hour to over 6 hours, much of this driven by advances in power management technology, all enabled by Power Electronics.

The UK supply chain

Most of the end products covered in this section are manufactured outside the UK, in low-cost large-scale assembly sites in Eastern Europe or Asia. In most applications the Power Electronics content is buried deep inside 'black boxes'. But the contribution from UK-based companies is significant, with ARM, CSR, ST Microelectronics, Freescale and Infineon all heavily involved in the design, and with UK-based semiconductor fabrication plants manufacturing millions of high-performance components such as MOSFETs, IGBTs, power ICs and rectifiers. Many of the global top twenty semiconductor manufacturing companies have significant UK facilities including NXP, International Rectifier, Zetex/DIODES and National Semiconductor. These facilities are the legacy of over 25 years of semiconductor manufacturing in the UK. All now have world-class process technologies and export more than 95% of production.

The technology base

A consequence of the long and varied legacy of semiconductor fabrication in the UK is the expertise and experience of UK-based process engineers. This 25-year legacy has meant that facilities such as those at International Rectifier, NXP, National Semiconductor and Zetex/Diodes have been able to maintain world-class technologies in the UK, which continue to attract inward investment for new technologies and expansion.

Analysis

Whilst much of UK manufacturing struggles to compete with low-cost manufacturing locations (notably those in Asia), we are able to compete in this sector by focusing on state-of-the-art components which carry a premium price. This business model requires a constant pipeline of new technology in both components and manufacturing process development, supported by incentives to attract capital investment. Underlying this is the retention and development of world-class engineering talent. A number of UK universities have departments specialising in Power Electronics research and teaching. It is imperative that these departments continue to generate sufficient students and knowledge to support innovation in industry. In recent years, the recruitment of engineering talent has become a major issue affecting the sector.

Energy costs are a very significant consideration for power semiconductor manufacturing. Today the UK is at a significant disadvantage in this respect. Steps need to be taken to protect UK-based Power Electronics component manufacturers from poorly-regulated energy pricing.

In addition to the common issues identified on page 22, the workshops found that UK strengths, weaknesses, opportunities and threats in this sector were:

Strengths

- Innovative technology and manufacturing from both industry and academia

- Legacy of analogue and Power Electronics design expertise
- Legacy of UK semiconductor wafer fabrication facilities
- Resourceful SMEs.

Weaknesses
- Inadequate and too short-term funding of academic research
- Fragmented support infrastructure (grants etc)
- High energy costs
- Faltering supply chain.

Opportunities
- Legislation to support the adoption of efficient Power Electronics
- Promote the UK as a high-value/high-quality location for the sector
- The control of currency exchange rates allows an element of management for competitiveness.

Threats
- UK energy costs substantially impact manufacturing costs in this sector
- The perception both overseas and within the country that the UK is not a manufacturing nation can influence inward investment
- Low-quality may become acceptable if the trend to a ‘throw-away society’ persists.

Industrial drives

An industrial drive in the context of Power Electronics is simply a motor together with a Power Electronics-based converter which directly controls the motor shaft position, speed or torque. It usually also contains a large number of auxiliary control, sequencing and communications functions to allow it to be used to optimise the operation of not only the motor but also the machine or process in which it operates, either autonomously or as part of a larger factory automation scheme.

The market

The world market for industrial drives is over £8.5 billion (excluding motors and systems integration). For the past 30 years growth has been between 2% and 5% ahead of the industrial average, driven by two primary sources:

- The growth of industrial automation, itself driven by the demands for quality, productivity and - interestingly - factory management information from the production line

- Energy saving - driven mostly by cost-reduction opportunities and increasingly supported by regulations such as the climate change levy.

Of the total market, £7 billion relates to low voltage (up to 690V ac) supplies, and £1.5 billion on medium voltage (between 2kV and11kV) supplies.

The market is highly diverse. If a controlled motion is required anywhere in industry, it is likely that an industrial Power Electronics drive is in control. The market also includes non-industrial applications such as commercial and domestic building services (eg elevators, air conditioning). The market is made up as follows:

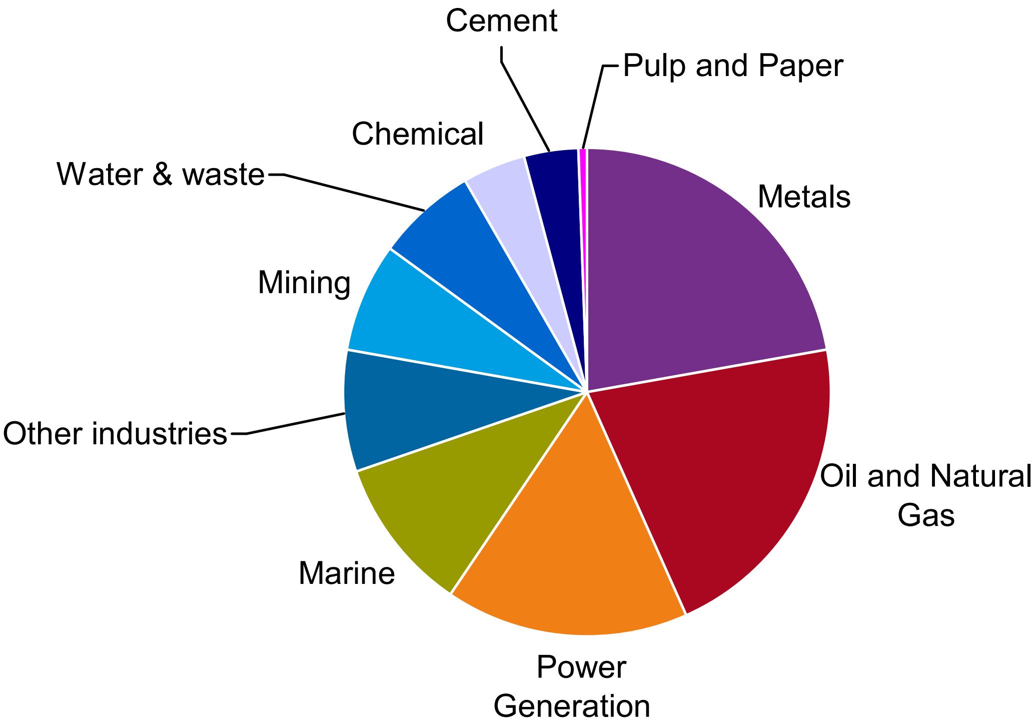


Figure 3 – The market from an industry perspective[28]

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[28] Source for Figures 3 and 4, 2009 report by IMS Research plus Emerson – Control Techniques data

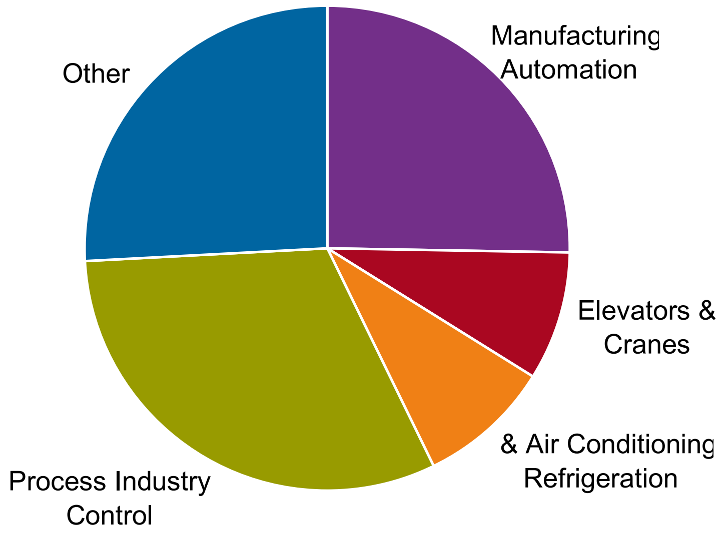

Figure 4 – The market from an application perspective

The market is highly diversified in application and functional requirements. High-volume manufacturers address this with very flexible products, but there is still an opportunity for smaller manufacturers to provide specific products to niche markets.

It is important to note that, in many market sectors, industrial drives are purchased by machine builders, OEMs or system integrators who often have little or no interest in the energy use of their equipment. This is an area where legislation, in the form of a requirement for an energy declaration on machinery and systems, could encourage greater consideration to be given to lifecycle costs.

The UK supply chain

Whilst this market sector is dominated by large global industrial electrical and electronics engineering companies, no one company has more than 25% of the overall sales. Smaller companies remain competitive in niche areas of the market, usually offering a product tailored to the specific needs of a particular market, machine type or customer.

The product used in each market sector is essentially the same, with customisation typically in software (control) functionality, and in some cases in the power circuit configuration and/or method of cooling.

It is important to note that no fewer than six of the top ten global market leaders in the industrial drives market have design and/or manufacturing facilities in the UK (Emerson–Control Techniques, Converteam, Siemens, Parker (SSD), ABB (Baldor) and Yaskawa). It provides employment for over 12,000. Over 3,000 jobs are directly involved in industrial drive design and manufacture in the UK, with a similar number of other jobs involved in the supply chain, and more than 5,000 involved in systems integration of the industrial drive product. The contribution to GDP is in excess of £1 billion.

Case study	
Emerson / Control Techniques	Henry Denny & Co produces a range of pies, sausage rolls, pasties and cottage pies at its site in Portadown, Northern Ireland. Its 20 chilled rooms hold these and other food products for distribution, with a large ammonia compressor maintaining very carefully-controlled temperatures. When the company was forced to replace a soft starter for the compressor, the decision was made to change to a variable speed AC drive. Control Techniques, part of the Emerson engineering group, was its preferred supplier and duly provided a compact 315kW unit, just 400mm wide, that Henry Denny's staff installed in 2006.  The Power Electronics solution ensures holding the temperature "pretty well bang on our target of -10°C as well as cutting our energy bill by around 50%," according to the company's electrical engineer Ciaran McSherry. And Emerson-Control Techniques' President Mark Bulanda says that this result is not atypical. "Better control, easy installation and a payback of six months is great, but not exceptional. A low-carbon world will increasingly need applications like this, and we have 500 UK workers at plants in Newton Powys and Telford dedicated to make it a reality." www.controltechniques.com

The technology base

The critical technologies in an industrial drive embrace Power Electronics (including thermal management) as well as analogue and digital electronics, motor control, and applications control. In total, industrial drives can be considered a sub-system, and the integration skills are vitally important.

The technology is advancing rapidly, and new technologies in components and customer requirements need to be embraced quickly to maintain competitive advantage. This is achieved internally through the creativity of employees, but disruptive technological change requires support from both universities and specialist research centres. A number of UK universities have an international reputation in aspects of industrial drives, including power circuit devices and topologies, machine modelling, structural analysis, thermal management and application simulation.

Many challenges lie ahead including adding new functionality, improving efficiency (in Power Electronics as well as the overall system), reliability and condition monitoring, and increasing power density. Underlying all of this is the drive for lower costs.

Analysis

In addition to the common issues identified on page 22, the workshops found that UK strengths in this sector were largely based on an established heritage in the design of industrial drives. This heritage has provided considerable, hard-earned experience of the necessary design processes, many of which have been captured in internal design tools within the leading companies. In such a situation, disruptive technologies are a substantial threat and so many of the leading companies undertake significant research, internally and with leading universities, to monitor and prepare for significant changes in technology. The systems nature of the product design gives some protection against disruptive component technologies but not against transformational customer solutions, and here insight into customer problems is important. This business model depends on highly-competent, highly-trained and well-motivated staff in research, design and marketing functions.

People also drive the strong position in manufacturing of industrial drives in the UK. Success here depends on process knowledge but also commitment and flexibility: a culture where productivity and quality are central to everything. Good support infrastructure exists in the UK to help in this regard. For example The Manufacturing Institute (TMI) assists in providing direction and support in process and people development. The good transportation infrastructure is also important.

The major threat to the UK's strong position in this sector comes from the poor availability of good engineers. This is not simply an issue in relation to the highly qualified/experienced engineers who drive innovation, but is an issue at all levels including technicians.

Strengths

- Six out of top ten global suppliers have UK based design and/or manufacturing

- The industrial drives sector is profitable and capable of funding non-disruptive innovation

- World-class university research and undergraduate teaching.

Weaknesses

- Time to market/response time to market is too slow - global companies are setting up other design teams as the sector cannot recruit enough engineers in UK
- Industrial drives are not recognised as a key enabler for a low-carbon economy
- A lack of support for activities relating to international standards.

Opportunities

- An expanding global market
- The possibility for small companies to enter the market, perhaps by branding their product for electrical wholesalers
- Industrial drives play an important role in factory automation schemes, and a significant element is directly relevant to the challenges of renewables and the smart grid. Quality regulations will result in more innovation and increased use of industrial drives.

Threats

- Low-cost countries (including China, India and Brazil) are educating large numbers of Power Electronics engineers, making those countries competent and innovative design locations
- For low-volume, high-power products having a relatively low labour content, UK labour costs are not currently a barrier to manufacture. Labour, transportation and taxation cost movements could quickly affect this.

The Industrial Drives sector has great strength in the UK and the opportunity exists to build on that position in the future. There is much that industry and academia must do to improve the environment in terms of collaboration and critically addressing the shortage of engineers as we move forward. Government action and support is necessary too.

Skills in Power Electronics

Even with the existing level of activity in Power Electronics, there is a major challenge for both industry and academia to recruit the necessary skills needed to sustain the sector. Anticipated growth will increase the pressures, as will the need to replace the large cohort of highly-skilled people who will leave the sector through retirement.

Much has been written about the drop in the number of students studying engineering at university, but the position of electrical and electronics engineering, core to Power Electronics, has been dramatic. In 2010 the number of UK students accepting a place to study electrical and electronics engineering in the UK was 41% lower than in 2002 [29]. Not included in these figures is the relatively high number of students entering degree courses who do not graduate. There are many reasons for this, but many claim to find the courses too challenging. It is vital that the standards and quality of UK engineering degree courses are maintained and QAA (the Quality Assurance Agency for Higher Education) and the accrediting bodies (the professional institutions under licence from The Engineering Council, have a responsibility to ensure this.

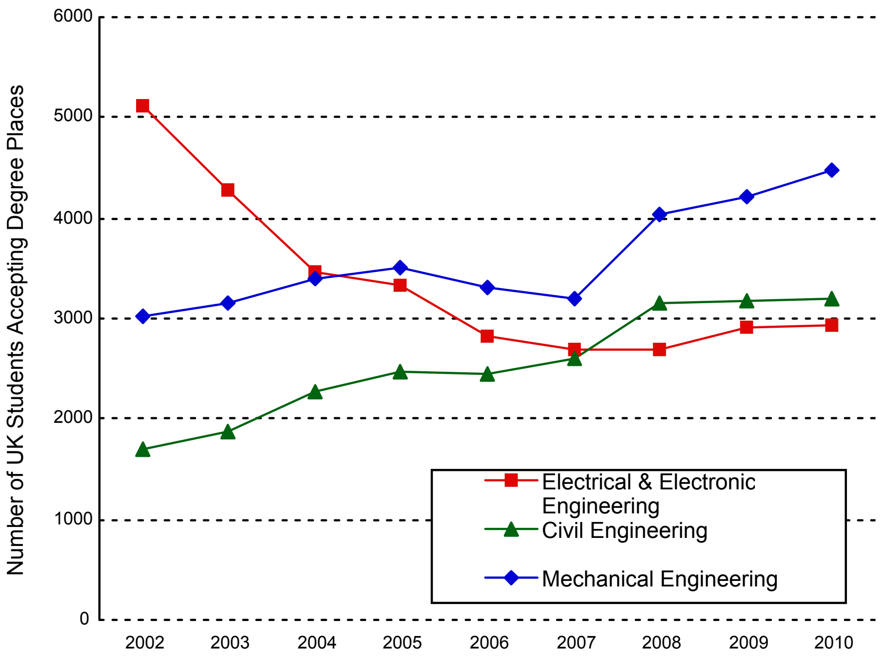

Figure 5: Students accepting degree places

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[29] UCAS

"The big question is what activities can ... all of us in the industry put in place that will attract students to Power Electronics, make them aware that the car of the future accelerates quickly and noiselessly due to Power Electronics, cause them to understand that the wind turbine is producing electricity of high quality due to Power Electronics and that the way to significant energy savings in industrial environments, air-conditioning and home appliances is possible only due to Power Electronics."
Claus Petersen, CEO, Danfoss Silicon Power

It is also clear that the uptake of electrical and electronics engineering university places is moving away from home towards overseas students, and hence the UK is struggling to take full advantage of our world-class teaching and research.

By 2018 there will be 12.9% fewer 15 to 19 year-olds than there were in 2008 [30] and so, if the trend were to continue, both industry and academia would face severe difficulties in recruiting staff. The impact of significantly higher university fees is yet to be seen, but this is likely to add further pressure to engineering student recruitment.

Adding to the problem, 33% of engineering graduates take non-engineering related jobs on graduation [31]. This is in part a result of engineers taking highly-paid jobs in the City, where an engineer's logic and numeracy skills are highly valued.

The problem of skills shortage is not limited to high-level engineers studying for a masters level degree with aspirations to work as a Chartered Engineer [32]. There is also a clear need to improve the supply of engineers studying first degrees with aspirations to work as an Incorporated Engineer [33]. Regardless of this differentiation, it is clear that there is a current skills shortage and that it is already slowing industrial growth and impacting undergraduate teaching.

Public Attitudes to and Perceptions of Engineering and Engineers 2007, published by The Royal Academy of Engineering and The Engineering and Technology Board, provides a useful insight, based on extensive community research, of the issues that need to be addressed in order to motivate students to pursue a career in engineering. Some four years later the issues remain the same.

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[30] Engineering UK 2011

[31] As 30

[32] See UK Standard for Professional Engineering Competence, Engineering Council (www.engc.org.uk)

[33] As 32

Case study	
Siemens plc	 Siemens plc based in Congleton, Cheshire, specialises in the design and manufacture of industrial variable speed drives. It employs more than 500 workers and, in 2011, will manufacture 1.3 million electronic devices of which 98% will be exported, with China and Germany the biggest markets. The company claims its biggest asset is its workforce. "Over the years we have worked in partnership with The Manufacturing Institute (TMI) to develop our people and to get young people engaged and excited about manufacturing and engineering. Indeed our greatest challenge in years to come will be having people with the applicable skills sets we require, particularly in Power Electronics. So we are involved in the Make It programme, Big Bang Festival, Girls Can Do It too, Greenpower Challenge and numerous activities with local schools and colleges." www.siemens.co.uk

To correct the skills shortage we must take both long-term and short-term action, and cast the net as widely as possible. There is a clear need to encourage individuals to select engineering as a career choice, starting at primary school level, giving genuine widely-publicised emphasis to the science, technology, engineering and mathematics (STEM) subjects throughout the students' education, and offering incentives for studying engineering courses at university and colleges: for example through reduced fees and/or bursaries. Encouragement should also be given to schools to place greater emphasis on the teaching of STEM subjects by highlighting this subject area in the metrics by which a school's performance is measured. Whilst emphasising STEM subjects, the distinction between pure science and engineering and the respective career opportunities also needs to be explained to students.

The CBI's 2011 Education and Skills Survey [34] endorses this, "The Government must tackle skills shortages by promoting science and maths in schools".

In higher education, quotas for engineers should be investigated as a means to ensure universities play their part in meeting the needs of the country. Universities should also be encouraged to involve industry more directly and transparently in the content of their courses, so that they are more vocational and relevant. This should result in a graduate who is more employable and who is not only ready for the demands of a working in industry, but is keen to follow a career in engineering. This could be encouraged if manufacturing and engineering are showcased at the major engineering universities.

"There is no question that one of the very serious problems we have is the image of engineering in the eyes of young people. While there is no shortage of candidates for study in China, India and many other developing countries, there is a decline of interest in Northern America, Western Europe and some other countries, such as South Africa."
Moshe Kam, President and Chief Executive Officer, IEEE

Doctoral training should be encouraged for Power Electronics graduates through schemes supported by the Engineering and Physical Sciences Research Council (EPSRC). Part-time higher education - whilst in employment - could be made easier and less of a financial burden to industry, the university and the employee through incentives, or other benefits. Knowledge Transfer Schemes are to be encouraged, and financial incentives offered to capture EU-based knowledge transfer associates, who do not need work permits and who can be employed in the UK after the period of the scheme.

It is also recommended that a National Skills Centre be set up for electronics engineering, or included within an existing group (if such exists), particularly for vocational training. This Centre would give national cohesion and standardisation to all aspects of further education in the sector. It would ensure that courses delivered by local colleges are available and relevant to industry, and of an appropriate quality for the engineering profession. Building on the existing work of SEMTA (the Sector Skills Council for science, engineering and manufacturing technologies) through the National Skills Academy [35], this could help to generate the skilled technicians and engineers required to work in advanced manufacturing across the sector, and a skilled workforce that is more mobile and can move between businesses.

Whilst the number of engineers is an immediate and urgent issue, it should also be recognised that engineering remains a largely male-dominated vocation. Government statistics show that over 26% of electrical and electronic engineers are female, the highest percentage of any engineering discipline. Nonetheless, this sector of engineering must continue to work on improving the gender balance of its employees. Again, action is

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[34] www.cbi.org.uk/pdf/20110509-building-for-growth.pdf

[35] www.nsa-m.co.uk

needed early in schools to ensure suitable candidates are not diverted from entering the profession.

Recently, the changes to immigration regulations have made it more difficult for UK companies and for academic institutions to employ non-EU staff. This applies to both new graduates as well as more experienced and highly-skilled personnel. The net result is that skills that are being generated by our education system are being taken out of the country. In the short term, unless the immigration regulations are addressed to give some preference for scarce skills, this brain drain will seriously impair the growth of this key sector. Long term it is hoped that UK universities will be able to attract and train sufficient numbers of UK/EU nationals to meet the demand.

The shortage of engineers in Power Electronics is global, but universities – notably in China, Philippines and India - have responded by gearing up to educate many thousands of Power Electronics engineers each year. The UK must act decisively and urgently to attract students to an exciting career in Power Electronics.

In Germany, government and universities have already acted to increase the number of engineering graduates with approximately 9,000 electrical and electronic engineers graduating this year, an increase of nearly 15% compared with five years ago. Despite this, the German Association for Electrical, Electronic & Information Technologies (VDE) estimates a shortage of 6,000 electrical and electronic engineers in 2011, up from 3,000 last year and 1,000 the year before, when the global economic and financial crisis impacted Germany. Further demand for engineers is forecast with dramatic growth seen in the transportation and energy sectors.

Challenges, Opportunities and Actions

The Strategy Group, throughout its discussions and deliberations, has focused on areas where it is considered the UK can continue to succeed in global markets.

Listed below are five specific challenges, beginning with the proposal to form a widely supported 'national forum' to drive and direct the actions needed. The demands of the low-energy/low-carbon economy are discussed next, before considering the implications for design and manufacturing and then the role of education. Finally, a practical approach to get industry and academia to work more closely is outlined.

<table>
<tr><th>Challenge 1</th><th>To establish a National Forum for the Power Electronics community promoting professional development</th></tr>
<tr><td colspan="2">Approach: The National Forum for Power Electronics will maintain and increase the momentum gained during the preparation of this report, driving through its recommendations and monitoring progress made.</td></tr>
<tr><td>Opportunities</td><td>Actions</td></tr>
<tr><td>The importance of Power Electronics to the environment and the economy is recognised around the world, but the UK could do more to educate and involve stakeholders at home. A multi-disciplinary, multi-organisational approach that influences the public, Government and the education sector is needed.</td><td>The development of this strategy document has involved highly-productive cross-sector discussions of the type required to identify future trends and opportunities. A National Forum should be set up, with a founding Board drawn from the Strategy Group, ideally under the auspices of an organisation such as NMI. A Chairman would co-ordinate the activities of the Board.
The role of the forum would be:
•Driving forward the national strategy
•Enabling cohesion across industry-academia-Government
•Liaison with the wider electronics community
•Ensuring that key PE issues are properly recognised in R&D funding support.
Formal terms of reference for the forum need to be established. Whilst forum costs would be low, a sustainable funding mechanism needs to be established. In the medium-term this would be through a membership</td></tr>
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Challenge 1	To establish a National Forum for the Power Electronics community promoting professional development
	subscription.
In parallel with the outward-looking forum, it is necessary to establish a nurturing ‘home’ for professional Power Electronics engineers, and to promote the culture of professional engineering.	The Institution of Engineering and Technology (IET) is keen to support and embrace Power Electronics, and recognises shortcomings at present in its community programme including its conference/seminar programme and journals. The Power Electronics community should engage with the IET based on a community board comprising senior industrial and academic members. Critical to the community agenda would be mechanisms to engage and inform (through various media including seminars and conferences) all engineers working in Power Electronics. The editors of the associated journals should be involved so as to encourage UK authors and readers. Industry and academia also have a role to play in encouraging staff to engage with the professional institutions, by setting the expectation of membership and registration as an Incorporated or Chartered Engineer.

Challenge 2	To establish the UK as an exemplar low-energy/low-carbon economy – the logical focus of Government strategy on low carbon, renewables, energy efficiency, manufacturing and sustainability
Approach: Foster the reputation of the UK as an exemplary producer and user of Power Electronics technologies. Critical to this is to develop a clear vision for our electricity infrastructure – to define the ‘Smart Grid’. National Grid is in a good position to host such work but would need Government direction and multi-sector support. The National Forum for Power Electronics could identify appropriate expertise in key sectors to support and energise this work.	
Opportunities	**Actions**
A national low-energy/low-carbon approach to energy is unavoidable, and Power Electronics is central to delivering it. There is huge potential	Any serious move to a low-energy economy must ensure that, wherever possible, low-energy solutions are adopted. It is clear that incentives will be necessary to support the widespread adoption of the necessary technology. Such incentivisation has been shown to work, notably in the case of low-energy lighting, and without intervention the take-up of some key technologies will be too slow to meet

Challenge 2	To establish the UK as an exemplar low-energy/low-carbon economy – the logical focus of Government strategy on low carbon, renewables, energy efficiency, manufacturing and sustainability
for the UK to lead on elements of this, and to adopt best practice from elsewhere. With vision, the UK can show real leadership and reap the consequent rewards.	Government targets. For example, to have an energy declaration on all machinery would quickly change the purchasing behaviour of machine builders and system integrators to consider lifecycle costs. The Carbon Trust has proved effective in highlighting carbon reduction opportunities across society, and it seems appropriate that they are given the remit to prioritise action in this area. To maximise the benefit to the UK, projects/initiatives should wherever practicable utilise UK products/systems to provide a showcase for UK design and manufacturing capability. (See Challenge 3)
The 'Smart Grid' concept links all forms of electrical generation, transmission, storage and use. To become a reality it needs leadership and co-ordination. Changes in the core power infrastructure can facilitate this, and the increasing influence of electric vehicles could be a catalyst. A cohesive strategy is needed, not a piecemeal approach.	The 'Smart Grid' cannot be built by any one organisation and so co-ordination and collaboration is key. The Departments of Business, Innovation and Skills and of Energy and Climate Change should act with Distribution Network Operators (DNOs), the automotive industry and National Grid. TSB's consideration of creating a UK Smart Grid Technology Innovation Centre is a very positive step in this direction. Since Power Electronics is the key enabling technology across all elements of the energy map, its engineers need to play a major role informing and establishing the strategy. National Grid appears a logical lead on this activity. The forum described in Challenge 1, could advise on leading experts in the field. Government also needs to ensure that the energy vision takes full account of the place of electric vehicles so as to ensure an integrated approach to transport in general. The EPSRC should be encouraged to examine the current national capability in the Power Electronics research landscape, identifying priority areas in line with their recent 'Shaping Capability' initiative, and ensure that a co-ordinated approach is taken when making significant new investments in this area. It should reflect also the priorities of other agencies' activities, as has been the case with the TSB Innovation Platform for Low Carbon Vehicles.

Challenge 3	To ensure the UK remains at the forefront of innovative Power Electronics design and manufacture
Approach: The key to UK competitiveness in Power Electronics is to drive innovation in both product design and manufacture. We need to foster collaboration across industry sector and supply chain barriers, promoting best practice and access to international standards. Long-term disruptive technologies need focused support through to pre-production.	
Opportunities	**Actions**
In design, the UK competes effectively with the low-cost design teams of China, India and Eastern Europe. But there is scope to increase our share of the global market through innovation and manufacturing excellence.	Innovation is key to the long-term success of design, and the UK is noted for original and novel approaches - notably to systems integration. Hand in hand with innovation is the promotion of good risk management in the design process, as well as the need to dispel the 'fear of failure' which can stifle creativity. In a sector where performance and reliability are key criteria, establishing credibility in the home market is often key to securing export orders. To ensure that the UK maintains leadership at home and abroad we need to be better at pulling innovation through. Test beds need to be established to enable SMEs and start-ups to demonstrate and validate new technologies in both laboratory and controlled test-bed environments that tier 1 companies recognise as being able to deliver reputable evidence of performance. This should also include the standardisation of simulation/interfaces and multi-level functional application models that can provide easy-to-understand quantitative benchmark information. Initiatives such as the Innovative Finance Initiative and Low Carbon Networks Fund to place greater emphasis on supporting and pulling through technologies such as Power Electronics that have greater impact on the control and operation of the electricity supply network. The Royal Academy of Engineering's Visiting Professor in Innovation scheme is helpful in encouraging design in undergraduate and postgraduate courses and should be extended. There is also a role for a wider Power Electronics community to aid the cross-fertilisation of ideas and facilitate continuous professional development; to help inform about and influence international standards; raise the profile of the sector; and promote collaboration between competitor companies and within the supply

Challenge 3	To ensure the UK remains at the forefront of innovative Power Electronics design and manufacture
	chain. This would include grasping opportunities for collaborative pre-competitive research.
While there are many examples of excellence in UK industry, many sectors and companies operate their supply chain in 'bubbles', with poor strategic information flow and limited technical and commercial support. This deters the emergence of new entrants/innovation or leads to reinvention of technologies established in other branches of Power Electronics and unnecessary validation (due to sectors not acknowledging empirical data from other sectors as acceptable evidence of performance).	Industrial sectors need to be encouraged to establish good practice in dealing with supply chain networks, in particular with regard to ensuring that the UK retains a strong high-value design and manufacturing capability at all levels in the chain. This may be appropriate to place under the remit of the High Value Manufacturing Technology and Innovation Centre. As appropriate to an open market, forums need to be established to encourage pre-competitive dialogue with competitors and suppliers to discuss and establish: • Map of strategic capabilities – allowing not simply forward-technology mapping, but also exposing opportunities for import substitution. This could be facilitated through supplier open days at tier 1 companies • More cross-sector events that seek to emphasise commonalities and the cross-fertilisation of Power Electronics issues – eg by expanding Universities Power Engineering Conference to include more distinct emphasis on Power Electronics and encouraging greater participation by industry to provide focus. • Encouraging opportunities for collaborative pre-competitive research between competitor companies and within one supply chain that reaches across more than one application sector.
The ability to influence international standards to reflect UK requirements is a strength, but more could be done to improve access to standards-setting and the standards themselves.	Large UK companies and some others through trade associations (eg GAMBICA for industrial control equipment) do get involved in the formation of international standards. The mechanisms for such participation are frequently unclear, and representation if often limited by geographic restrictions. SMEs in particular may find the cost and time involved prohibitive. Greater community focus should clarify the process and opportunity to contribute to and disseminate international standards to the wider UK Power Electronics community.
Some SMEs have leading technology but need help in integrating	Encourage incubators that specifically focus on the creation of high-tech manufacturing-orientated businesses. These centres would be able to provide the support

Challenge 3	**To ensure the UK remains at the forefront of innovative Power Electronics design and manufacture**
their technology into the supply chain – particularly with regard to establishing demonstrations that will be widely-recognised and setting up the necessary business infrastructure to participate in the supply chain.	infrastructure to ensure start-ups and SMEs have the systems in place to gain recognition as a valid supplier. This should also include: •Incubators being able to establish and broker relationships between tier 1 & 2 manufacturers and SMEs/start-ups •Ability to support the creation of pilot production lines. Co-ordinate UK infrastructure operators and tier 1 manufacturers to agree to a universal route to adoption of Power Electronics technologies, such as with renewable power generation today viz bench, 1/10, 1/4, 1/2, 1 scale pilots.
Start-ups and SMEs are recognised as an invaluable source of innovation but often suffer a funding gap between proof of concept and pre-production phases, caused by, for example: •Time to initial market acceptance (typically 3-5 but up to 10 years) •Technology that is inherently capital intensive: typically £5m-£20m investment over 3-4 rounds needed to get to pilot product (too big for early stage venture capital funds, too small for later stage VCs).	Consider how Enterprise Capital Funds (ECF) can be used by disruptive hardware technologies such as Power Electronics with sufficient depth of funds (and time horizon) to support start-ups and SMEs through multiple rounds of investment up to initial production. While Government funding support from organisations such as the Technology Strategy Board is invaluable to pulling innovation through, it can be burdensome and time-consuming to secure. The better use of incentives that encourage larger companies to directly engage and provide financial and in-kind support to start-ups/SMEs through collaborative R&D programmes that qualify for relief (in a similar way to private investment schemes such as the Enterprise Investment Scheme) would increase the availability of R&D funds and accelerate the adoption of new technologies. It is hoped that such support will come out of the work PricewaterhouseCoopers are working on with HM Treasury about changing the R&D incentive in the UK.
For many manufacturing processes, it is vital that high performance infrastructure is available to promote the	The scope for direct Government support in taxation or lower energy costs may be limited at the present time. But support to projects that can act as a catalyst in the adoption of energy-efficient technologies is recommended. We should: •Consider the creation/nomination of Energy Enterprise

Challenge 3	**To ensure the UK remains at the forefront of innovative Power Electronics design and manufacture**
UK as a competitive hub for excellence.	Parks (EEPs) • Encourage on-site electricity from efficient combined heat and power or (proven efficiency) renewable energy sources • Set up test beds and demonstrator projects run from EEP to meet Government emissions targets for low-energy manufacturing or for purpose-built energy efficient facilities. This could be allied to the TSB Innovation Centres. Global design and manufacturing teams rely on a good IT and communications infrastructure in order to synchronise data between locations. Government needs to recognise the critical importance of this in relation to decisions to locate design and manufacturing in the UK.

Challenge 4	**To ensure a good supply of talented Power Electronics engineers for both industry and academia**
Approach: The National Forum would promote Power Electronics in all areas of education, from primary schools onwards, to maintain a critical mass of competent talent on which the viability and vibrancy of the sector depends. Collaborative industrial involvement is needed. Government has also to play its part, and the strategy proposes a number of zero-cost actions to promote the value of science, technology, engineering and mathematics.	
Opportunity	**Actions**
The status of engineering in the UK has traditionally been lower than in other countries. The prevalence of technology today, however, combined with increased concern about the environment, creates a unique opportunity to project engineering as vital to	Every opportunity should be taken to raise the profile of electrical and electronics engineering in general and Power Electronics in particular as part of a focused continuous effort co-ordinated by the proposed National Forum. Activities should include: • Demonstrating innovation via the low-carbon vehicle initiative; flagship projects; and the encouragement of science centres around the UK (eg Techniquest, Glasgow Science Centre) • The UK Engineering Council and professional engineering institutions taking every opportunity to promote engineering, and providing promotional materials to others

Challenge 4	To ensure a good supply of talented Power Electronics engineers for both industry and academia
the country and an attractive career choice.	• Making the link between Power Electronics and a low-carbon economy, using examples such as the Smart Grid and Electric Vehicles as levers in all appropriate contacts with the media
Schools – both primary and secondary – have the potential to encourage young people to see science and engineering as interesting and rewarding, but they need support from industry.	Place greater emphasis on STEM subjects (science, technology, engineering and mathematics) in school league tables to signal the importance of science to teachers, parents and students. This should be backed up with greater support by professional organisations such as the Institution of Engineering and Technology that already provide teaching aids but could contribute directly to the curriculum. This would boost the good work of the STEM Ambassadors scheme [36]. Re-establish physics, chemistry and biology as the normal subject selection for GCSE students in place of 'combined science', and contextualise science in other subjects. Recognise the importance of teachers with appropriate skills capable of delivering exciting lessons. Ensure an attractive career structure for teachers of STEM subjects. Ensure that Technical Colleges can provide appropriate routes for prospective engineers to pursue Power Electronics. There is concern at the low numbers of teachers with a science qualification in schools. Ways of drawing practising engineers into this formative teaching environment should be developed. Ensure informed careers advice is given to students in secondary education. Professional engineering institutions have a critical role in this respect, perhaps with on-line information streaming. This should be backed up by industry/business involvement in schools and more broadly in the community, for example with factory open days to highlight the breadth of opportunities.

[36] www.stemnet.org.uk/content/stem-ambassadors

Challenge 4	To ensure a good supply of talented Power Electronics engineers for both industry and academia
More vocational routes to engineering qualifications from technician level through to Chartered Engineers need to be promoted to schools and industry.	Apprenticeships offer an alternative route into engineering that leads to well-rounded engineers. Competition for engineering apprenticeships is already higher than competition for top university places [37] by factors greater than 4:1. With universities charging maximum education fees this is expected to rise. Industry and Government need to continue to promote apprenticeships as a valuable route for many people to come into engineering with the best going on to be degree-qualified. While tier 1 companies are investing in apprenticeships, the number on offer needs to increase and schemes that promote and expand the involvement of lower tier businesses to adopt apprentices needs to be developed. Foundation degree courses facilitate good transition between vocational training and higher education. There may be opportunities for greater HEI linkage to company apprenticeship schemes and/or to co-ordinate schemes for smaller companies.
Tertiary education should come to regard engineering and Power Electronics in particular as a key area of growth and influence.	Universities should be given specific targets for engineering undergraduate recruitment (as has been the case for medical students). Degree placements in industry should be encouraged, with increased numbers of industrial sponsorship. Sponsorship schemes - notably the UK Electronic Skills Foundation (UKESF) and the E3 Academy - are proving successful stimulants to attracting students to electrical and electronics engineering courses and should be given increased support by industry. Universities should recognise the value of Incorporated Engineers who represent the backbone of the manufacturing sector as well as playing an essential role supporting design, and celebrate the success of their graduates with bachelors degrees, rather than all aspire to produce prospective Chartered Engineers with masters degrees. Academics should be encouraged to spend time in industry

[37] www.education.gov.uk/inthenews/speeches/a0064364/michael-gove-to-the-edge-foundation

Challenge 4	**To ensure a good supply of talented Power Electronics engineers for both industry and academia**
	with programmes such as the Royal Academy of Engineering Industrial Secondments. Universities should embrace initiatives such as the 'Formula Student Electric' design, build and race project, which encourages a multi-disciplined and practical application of real engineering skills. This is an ideal forum to relate engineering, and critically Power Electronics, to a sport in which the UK has a world-leading profile.
Postgraduate courses and Continuous Professional Development will be increasingly valued to meet the growing – and changing – needs of industry and academia.	A co-ordinated strategy for postgraduate training should be established across the leading academic institutions to ensure that training is in line with national needs. A postgraduate academy in Power Electronics, with support from EPSRC and companies supporting research individually or collaboratively, could be a suitable vehicle for this initiative. EPSRC should be encouraged to work with relevant stakeholders to achieve a strategic deployment of Industrial CASE towards the training of Power Electronics engineers at leading academic institutions and in line with national priorities as identified by the EPSRC in partnership with its strategic partners. Establish a postgraduate academy in Power Electronics with companies supporting research individually or collaboratively. Continuous Professional Development is arguably best driven by the individual, but with the employer recognising the need for ongoing training to keep staff up to date. Recognising that engineering is a global profession, action is needed to facilitate the import of high-quality engineering talent from around the world to enrich UK skills and bridge gaps between supply and demand.
With so much activity in the disciplines related to Power Electronics, it is vitally important that steps are taken to ensure that the high standard of teaching in UK universities is maintained.	Standards must be defended. Whilst the Quality Assurance Agency has a role to play in this regard, it will be the responsibility of the UK Engineering Council, through the engineering professional bodies, to ensure the standards (including the content of degree courses) remain fit for purpose. Some sectors of engineering place importance behind accreditation, which leads graduates to Incorporated or Chartered engineer status, others do not. Industry should recognise and support the multi-faceted

Challenge 4	To ensure a good supply of talented Power Electronics engineers for both industry and academia
	benefit of degree course accreditation, and seek accreditation for their own graduate training schemes. Future Power Electronics engineers will need to be multi-skilled, with aspects of mechanical and materials engineering also needed for systems-level design. Degree courses need to evolve to reflect this.
Overall, the challenge and opportunity for the UK is to build and retain teams of Power Electronics excellence with the necessary critical mass.	The UK must build on its strengths, with industry and academia leading the way - supported by the proposed National Forum. Government support, where appropriate, should be well-targeted. Research Council spending in Power Electronics should focus on the leading universities and/or researchers. It should be aligned strongly to the priority areas identified in the EPSRC 'Shaping Capability' exercise, focussing on underpinning the core technology areas that are relevant and exploitable by UK industry, whilst ensuring that the national capability in Power Electronics remains internationally leading and scientifically ambitious. Centres of excellence should attract long-term funding to ensure continuity of key research staff, but should also recognise that they provide a source of practical applied training and that (relatively) high staff turnover is symptomatic of success - not organisational failure.

Challenge 5	To improve access to leading technology and to competent engineers, notably bridging industry and universities
Approach: It is necessary to bridge the gaps between universities, start-ups and industry, so that innovation is pulled through in a timely manner. The onus is on all parties to recognise the needs and the opportunities, to make the necessary investment and to create the mechanisms for vibrant relationships.	
Opportunities	**Actions**
Expertise in most areas of Power Electronics exists in UK universities, but better signposting to allow	Establish a Virtual Power Electronics Research Centre/Centre of Excellence linking world-class UK universities with each other and with industry. Whilst it would necessarily be multi-site, a light-touch central management could provide co-ordination and signposting.

Challenge 5	To improve access to leading technology and to competent engineers, notably bridging industry and universities
companies to identify individuals with appropriate experience would be beneficial. This could also allow universities to contact relevant businesses.	This should draw on the EPSRC Research Outcomes Project in order to be able to link across and co-ordinate national research programmes in the area. Mechanisms that promote the effective and timely translation of fundamental research into an industrial context also need to be enhanced, for example through responsive TSB funding or through the Technology Innovation Centres. Produce a web-based/hard copy directory – 'Power Electronics: a guide to UK capability' based on similar guides [38]
Overcome concerns about Intellectual Property by producing simplified agreements.	Universities should be encouraged to develop simplified contractual arrangements for short-term projects. Off-the-shelf/'Boiler plate' agreements would encourage broader and more dynamic industrial engagement.
Stimulate long-term industry/university relationships.	Provide incentives for long-term company-university strategic research partnerships, university-based company development teams (eg Newcastle University/Dyson) and long-term sponsored Chairs.
Encourage all academics to engage in commercial research.	University contracts of employment should ensure that: • Industrial links and funding are included as a formal metric in the performance review of Engineering academics/departments • Researchers are granted some shared ownership of IP for which they are responsible • Researchers have some rights to commercialise IP for which they are responsible.

[38] viz www.nmi.org.uk/assets/files/8027-BERR-Electronic-Systems-Design-WEB.pdf

Sources of Further Information

Carbon Trust www.carbontrust.co.uk

Confederation of British Industry www.cbi.org.uk

Department for Business, Innovation and Skills www.bis.gov.uk

Department for Energy and Climate Change www.decc.gov.uk

E3 Academy www.e3academy.org

Engineering and Physical Sciences Research Council www.epsrc.ac.uk

EPSRC Research Outcomes Project www.epsrc.ac.uk/newsevents/pubs/mags/connect/2011/81/Pages/rocp.aspx

Energy Technologies Institute www.energytechnologies.co.uk

Engineering Council www.engc.org.uk

Engineering UK www.engineeringuk.com

Enterprise Investment Scheme www.hmrc.gov.uk/eis

European Centre for Power Electronics www.ecpe.org

European Power Electronics Association www.epe-association.org

Formula Student Electric project www.formulastudentelectric.de

GAMBICA www.gambica.org.uk

Glasgow Science Centre www.glasgowsciencecentre.org

Industrial CASE awards www.epsrc.ac.uk/funding/students/coll/icase

Innovative Finance Initiative www.unepfi.org

Institution of Engineering and Technology www.theiet.org

Low Carbon Networks Fund www.ofgem.gov.uk/networks/elecdist/lcnf

Manufacturing Institute www.manufacturinginstitute.co.uk

National Skills Academy www.businesslink.gov.uk/bdotg/action/layer?topicId=1085744683

NMI www.nmi.org.uk

Quality Assurance Agency for Higher Education www.qaa.ac.uk

Royal Academy of Engineering Industrial Secondments www.raeng.org.uk/research/univ/secondment

Royal Academy of Engineering Visiting Professor in Innovation scheme www.raeng.org.uk/education/vps/profinnovation/default.htm

Sector Skills Council for science, engineering and manufacturing technologies www.semta.org.uk

STEM Ambassadors scheme www.stemnet.org.uk/content/stem-ambassadors

Techniquest www.techniquest.org

Technology Strategy Board
www.innovateuk.org

UCAS www.ucas.com

UK Electronic Skills Foundation
www.ukesf.org/scholarship-scheme

UK Trade & Investment
www.uktradeinvest.gov.uk

Universities Power Engineering Conference www.upec2011.com

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URN 11/1073