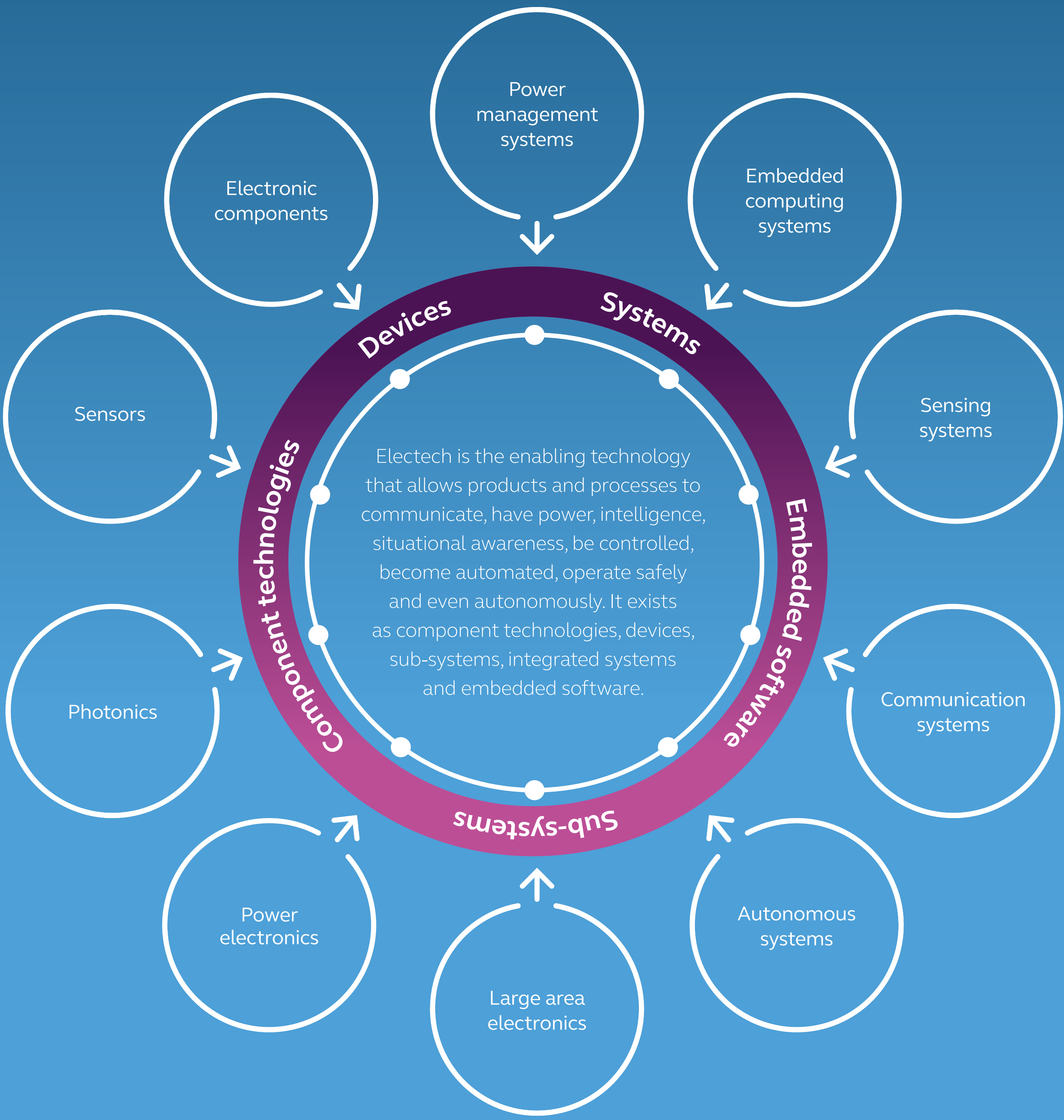
Innovate UK

Electech sector: a roadmap for the UK

Enabling the digital future

September 2019

Innovate UK is part of
UK Research and Innovation



elecTech | TechWorks | GAMBICA | PHOTONICS LEADERSHIP GROUP

SILC SENSING INNOVATION LEADERSHIP COUNCIL | bsi. | technology SCOTLAND | Department for Business, Energy & Industrial Strategy

Contents

Foreword from Innovate UK

Simon Edmonds
Deputy Executive Chair
Innovate UK

Technological innovation is a key pillar of economic growth, national security, and international competitiveness. This roadmap report is centred around enabling technologies and innovations that we collectively call electech. They are indispensable building blocks that enable a wide range of products, solutions, processes and business models. These in turn drive the transformation of existing vertical sectors stretching from automotive to pharmaceuticals and beyond. Electech plays a foundational role in the development of industries and value chains of the future.

Technological advances in electech are enabling changes in the way we live, work, socialise and the way we experience our world. They underpin the digital transformation that affects all firms, industries and value chains. Vertical industries are experiencing game-changing shifts, such as automotive, through electrification, autonomous driving and customer experience. The race to capture future markets has increased automotive manufacturers' reliance on fast-accelerating, continuously evolving electech technologies, most notably specialised hardware to drive artificial intelligence, sensing systems to develop situational awareness, and communications systems to enable networked architectures. The digital transformation of the manufacturing sector is also happening apace, leading to a complete rethink of the way products are designed, produced and deliver value during their lifetime. Electech offers manufacturers new ways to innovate, compete and grow; from cyber-physical systems to monitor and control manufacturing assets and processes through to photonic-based technologies for high-value manufacturing.

This roadmap report was commissioned to produce for the first time a high-level landscape of electech as an enabling sector that drives productivity and growth across virtually all sectors of the UK economy. It identifies strategic electech capabilities that are essential for the digital transformation of industries now and in the medium and long term. The report takes the view that electech's underpinning power to transform and grow industry sectors and its important contribution to the UK economy merit a broader recognition across the UK's research and innovation landscape, from policy development to R&D agendas, industrial initiatives, and associated public and private investments.

The report has been made possible through the contribution and insights we have received from across the electech sector's stakeholders and beyond. I would like to thank everyone who contributed to this important piece of work. Innovate UK recognises the UK's strength in electech. We hope that the report will have a wide appeal across industrial sectors and stakeholder communities. By highlighting the value that can be harnessed from advances in frontier electech technologies and innovations we hope that this report plays a part in ensuring the delivery of that value is maximised.

Foreword from the ElecTech Council

Tony King-Smith
Chief Executive
The ElecTech Council

We live in an age where technology is exerting more impact on every aspect of our lives than ever before. Electric vehicles; artificial intelligence-powered autonomous transportation; robots; ubiquitous high-speed wireless communications: these are but a few examples of technological innovations that have the power to change our cities, to save the environment, reshape society and save millions of lives.

The common thread: they are all enabled by electech technologies and innovations.

The world of electech is incredibly broad, built on the core skills of electronics and electrical engineering, and the embedded software that controls them. The list of products that rely on one or more electech technologies is endless. Yet few recognise its strategic importance to the UK economy.

That is why this roadmap report is so important. We want all industries to recognise that they can gain significant commercial advantage by making electech a key part of their strategies. By investing in UK electech expertise, as do the US, China and Japan, we can make the UK stronger and more globally competitive.

The UK has an amazing history of leading the world using electech, with examples including the world's first programmable computer, television and radar.

Electech is everywhere. We often talk about the "multiplier effect" of electech. It adds value and is fundamental to virtually all sectors. For example, almost every mobile phone today is powered by silicon chips using UK-designed processor, graphic and video technologies. Electricity infrastructure, electric vehicles, sensors, lighting, television, broadband and so much more are based on electech. We rely on electech and are surrounded by it in almost every aspect of our smart, connected lives.

But that is also why the electech sector has struggled for recognition. As a "horizontal" sector, it employs more than 1 million people in the UK in more than 45,000 businesses, generating revenue of around £100 billion. It is not seen as a key industry sector in itself because it is always built into the products of vertical sectors – health, aerospace, manufacturing and retail to name a few.

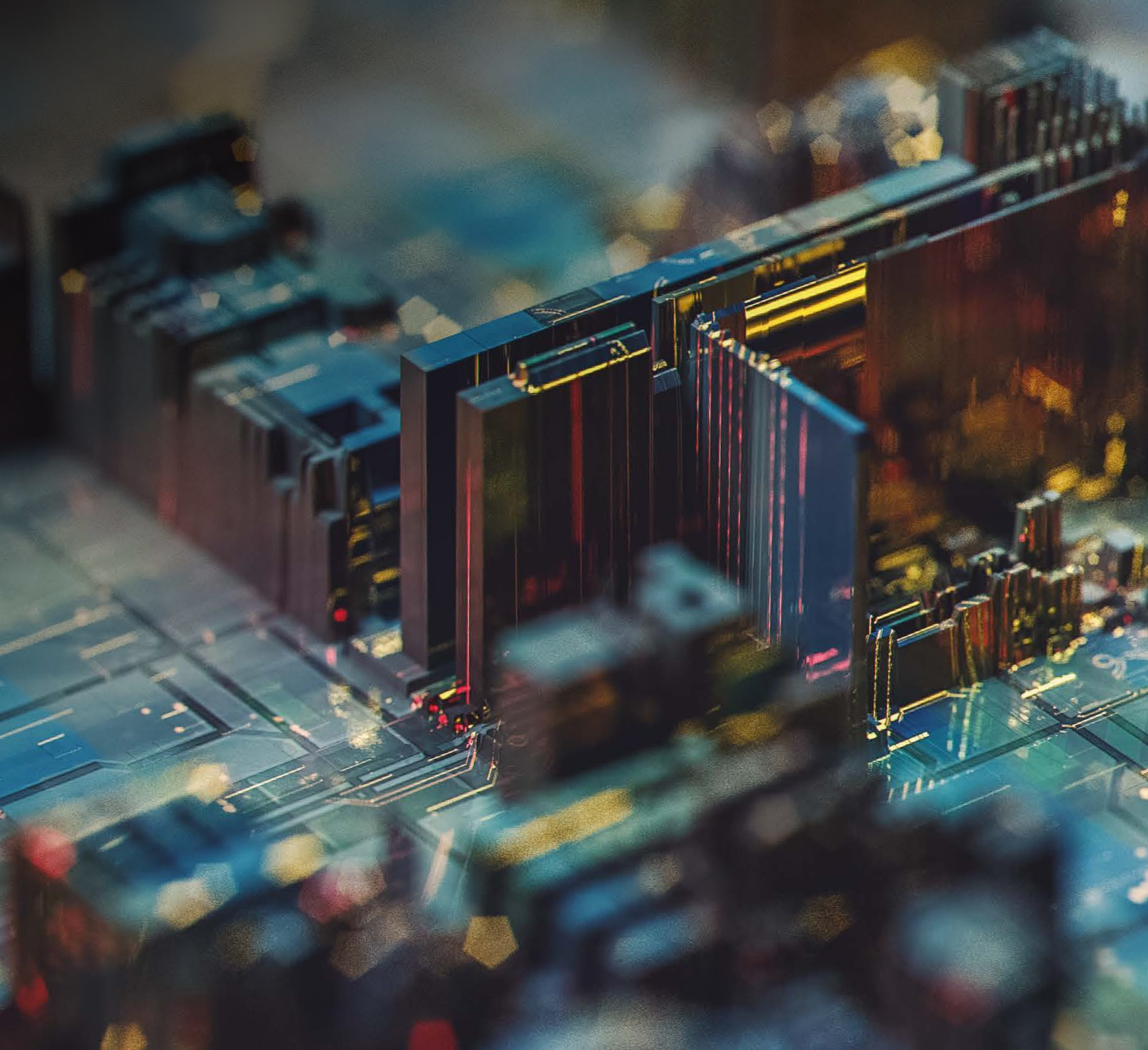
We must invest in the skills that make electech: electronics and electrical engineering, photonics engineering, nanotechnologies and other electech-related disciplines; the associated trades skills; and the embedded software engineering that makes everything work. We must also recognise that the UK's role as a leading innovator in electech standards allows our companies to build global businesses in areas such as certification, compliance testing and advising others.

Every industry sector in every region of the UK will benefit from a highly skilled and adaptable workforce created by investing in degrees and trade qualifications in electronics and electrical engineering and in electech-related disciplines such as material science, quantum physics, photonics and nanotechnologies. The importance of informal training such as industrial placements and cross-functional experience should also be recognised.

I hope this roadmap helps those who care about innovation, productivity, global competitiveness and economic resilience to recognise the importance of electech in building the future of the UK. We need teachers, parents and business leaders across the UK to realise that we must invest far more in encouraging electech-led businesses and in training people in electech skills. All our futures depend on them.

Executive summary

Electech is the enabler of all things digital



1 Executive summary

Electech is the enabler of all things digital. It is the hardware and embedded software that allows products and processes to communicate, have power, have intelligence and situational awareness, be controlled, be automated and operate safely and even autonomously. It is the electronics, photonics, electrical, optical technology and embedded software that enables and controls complex systems. Electech provides capability in the form of component technologies, devices, sub-systems, integrated systems and embedded software.

The electech sector is a collection of horizontal technology-focussed sub-sectors that provide technical solutions and capabilities to vertical sectors such as health, transport, energy, manufacturing, agriculture, built environment and defence and security. There is no recognised measure of the size and economic footprint of the sector. Work undertaken by sub-sectors does, however, suggest that electech is worth more than £100 billion a year to the UK economy.

Electech often lacks recognition and investment at a sector level by industry and government. It needs to present a more compelling case built around the critical importance of integrating constituent technologies to address wider industry and societal challenges. Electech technologies can help to meet all the grand challenges in the UK government's Industrial Strategy and make a significant contribution to economic growth.

This report and its roadmap have grown out of wide consultations with the sector. It is the result of extensive analysis, workshops and interviews with representatives from key companies and industry organisations. More than 100 people contributed directly to the roadmap content.

A vision for the sector

Our vision is for an electech industry widely recognised for its impact and investments in innovation and supply chains and for its ability to solve the big 21st-century challenges in health, energy supply, productivity, security, mobility and sustainability.

The challenges

Electech companies face many challenges. Addressing these challenges would help realise electech's full potential to unlock significant growth and job creation across the UK economy. The challenges include:

- lack of recognition, particularly from wider industries that depend on electech technologies
- electech companies focussed on sector-specific applications rather than being driven by the crosscutting capability of technologies
- fragmentation and focus on specific technologies when wider industry wants integrated and qualified solutions
- lack of early adoption of new technologies by end-users of electech
- long product cycles in industries such as aerospace, which require long-term support of aged yet still-needed technologies
- lack of capital investment in large and expensive pilot-line and manufacturing facilities
- lack of investment to help scale up electech start-ups and spin-out companies
- attracting private investment when development timescales are long or when financing capital equipment
- the Industrial Strategy's focus on challenge-led investments rather than a focus that includes electech-oriented investments
- translating university research to industrial use in developing products and services
- shortage of skills and slow evolution of education and training to meet the industry's changing needs

The roadmap

The roadmap demonstrates the need to invest in enabling electech technologies by providing a high-level view of the sector's breadth and importance and by showing clear links between electech technology and the industries and future applications they will enable. It is organised into 4 main layers – trends and drivers, application areas, system level capabilities and enablers – which are projected along short-term (3 years), medium-term (5 years) and long-term (10 years) time frames. The higher layers drive the ones below. For example, a future application will demand certain system level capabilities that will in turn require specific technology developments to be realised across time. Other important considerations must be taken into account such as framework conditions, standards development and other cross-cutting technologies. Improved price/performance ratio in electech components and technologies driven by one application will in turn enable new capabilities and drive demand in other applications.

Roadmap analysis – highlights

A wide range of electech stakeholders contributed to the development of the roadmap. The key findings are grouped into the following themes:

- the digital future of all industry sectors is vitally dependent upon electech. These sectors provide the smart **application areas** of personalised health and smart diagnostics; renewable energy and smart grids; transport and smart mobility; smart manufacturing; smart cities and communities; sustainable food production; and agile defence and security

- electech technologies are delivered as and within systems. The key **system level capabilities** that form the building blocks of future digital solutions are: sensing systems; embedded computing systems; power management systems; communication systems; and autonomous systems. Every one of these systems is of importance in every one of the application areas mentioned above

- **technologies** from across electech underpin the system level capabilities. Many of the electech sub-sectors will recognise themselves in these technology areas, which include: electronics components and sub-systems; large area electronics; photonics; power electronics; and sensor sub-systems

- vertical industry sectors require solutions that enable them to offer digital products. This demands **integration** of technologies through sub-systems and systems with ever increasing degrees of complexity but also increasing value added in end use. Electech innovation is built layer upon layer, and the wide application potential acts as a multiplier of the impact of any investment

- electech's ability to provide digital solutions is supported by a number of **enablers**. These include other technologies, for example artificial intelligence, edge computing, system-on-chip and key capabilities such as cyber security, validation and verification, interoperability, human-machine interfaces, standards and the availability of suitably skilled people

Recommendations

The following recommendations are supported by the roadmapping activities and consultations with industry and their representative bodies.

The electech sector should:

- improve promotion of enabling electech technologies to all UK industry sectors as a way to deliver innovation, increase productivity and competitiveness in a skills-scarce environment
- orchestrate its sub-sectors to work more closely together, frame their long-term individual and collective interests in a common vision
- develop a comprehensive measure of its composition, scale and economic impact, both nationally and regionally
- work more closely with universities and further education colleges for the design and delivery of higher education courses to address skills gaps and encourage students to enhance their skills and employability through work placements and relevant projects

UK industries should:

- consider innovation in electech technologies when drawing up their strategies and roadmaps and when seeking support from government
- invest in realising the cross-cutting benefit of electech technologies in new application areas
- ensure acceptance of UK electech in international markets through continued UK influence in development of international standards that support safe data exchange, communication, interoperability, compliance and testing

Government should:

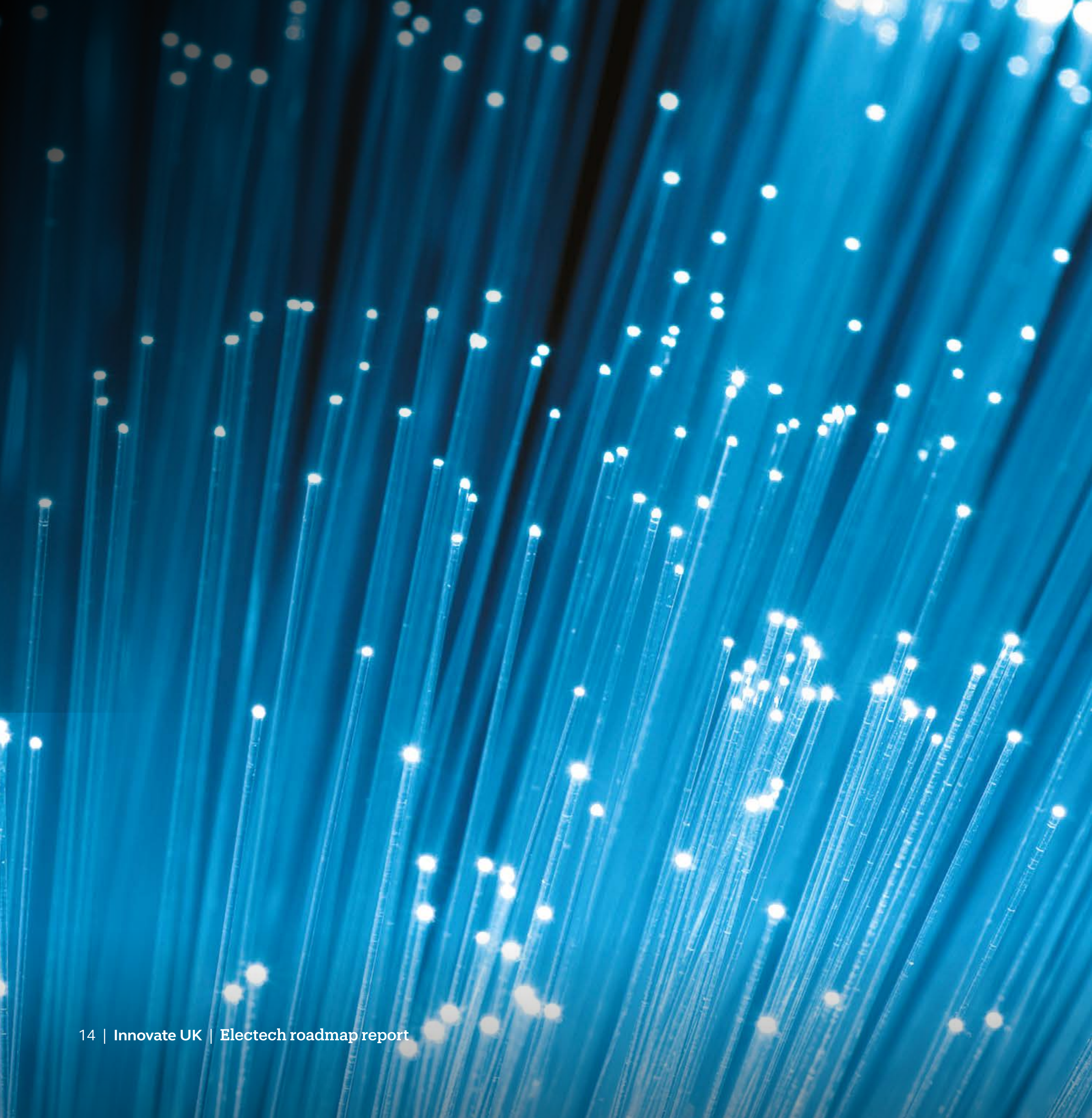
- recognise the cross-cutting role electech technology will play in delivering the Industrial Strategy's grand challenges and the associated Industrial Strategy Challenge Fund programmes
- support research and development in electech to meet the challenge of integrating technologies into systems, of providing demonstrator and test facilities and of developing longer term programmes for new strategic electech capabilities that will have wider applicability across UK industry sectors
- promote UK excellence in electech abroad to support exports and international collaboration in research and innovation
- develop ambitious public-private partnerships to invest in capital intensive plant facilities and advanced manufacturing processes using the compound semiconductors cluster in South Wales as an example
- work with the electech sector to address skills shortages by promoting and extending activities that encourage more young people from more diverse backgrounds to study electech science and engineering disciplines and to pursue engineering careers in the sector

“”

The electech sector should improve promotion of enabling electech technologies to all UK industry sectors...

Introduction

Electech is a wide spectrum of technologies with cross-cutting application



Electech is a wide spectrum of technologies with cross-cutting application. It's perhaps best understood as a collection of building blocks from which solutions are made. Electech is the enabling technology that allows products and processes to communicate, have power, have intelligence and situational awareness, be controlled, become automated, and operate safely and even autonomously. It's the electronics, photonics, electrical, optical technology and embedded software that enables and controls complex systems. Electech provides capability in the form of component technologies, devices, sub-systems, integrated systems and embedded software. It encompasses everything from the smallest electronic chip to the largest electrical motor or power station and the software that controls it.

Electech is a common thread when we seek solutions to society's great challenges, such as in healthcare, transportation, environmental sustainability, communications, advanced manufacturing, and cybersecurity. Without continuing innovation in electech there is no artificial intelligence, no Industry 4.0, no Internet of Things (IoT), no autonomous vehicles and no smart, affordable and connected diagnostics for healthcare.

Electech technologies combine to create systems that build solutions for industries such as aerospace, manufacturing, energy and health. Electech also allows these industries to develop and deploy novel processes, services and business models that keep them competitive and improve productivity. However, electech has a low profile despite its ubiquitous nature across industry and society.

2.1 The electech sector

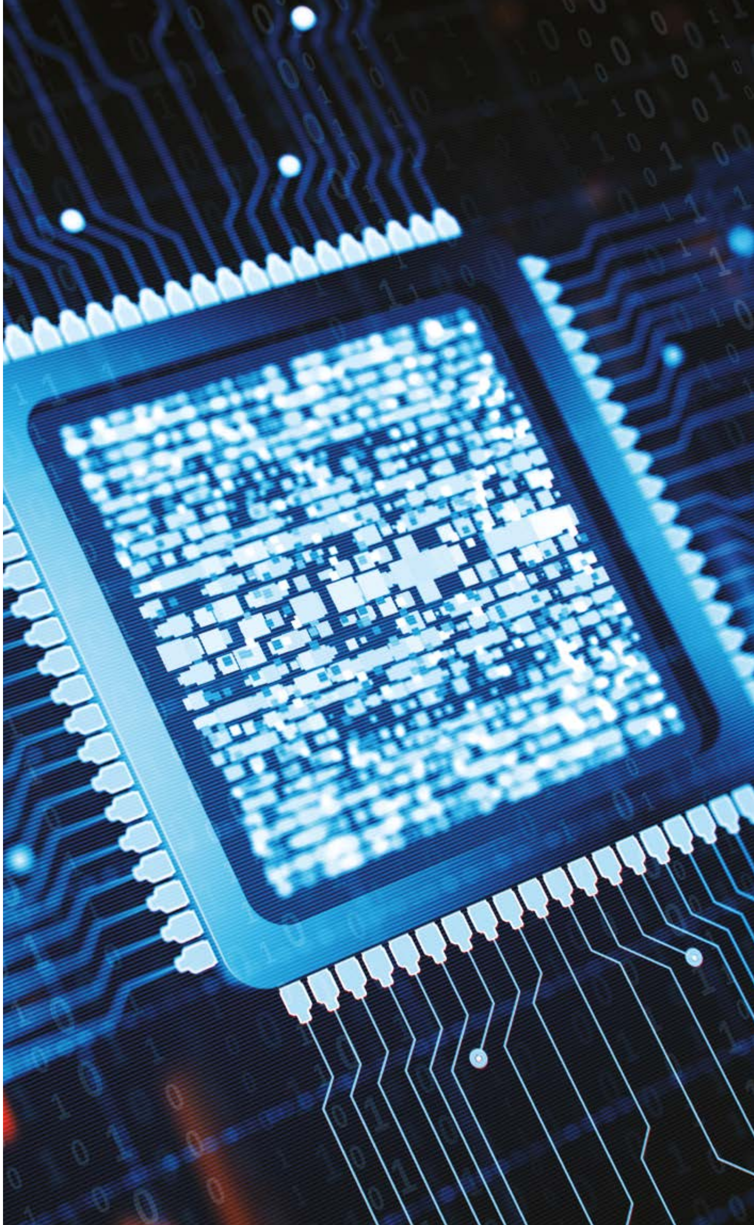
The electech sector includes the companies, academic and industrial research institutions, representative bodies that collectively design, develop, manufacture and integrate electech technologies and innovations. It consists of several technology-focussed sub-sectors that may partially overlap each other, but also complement each other. Each of these has its own historical identity, self-identifying membership and industry representation. There are regional clusters and strengths but also nationwide distribution of capabilities in these sub-sectors.

Many companies still associate themselves with their key application sector rather than with the whole electech sector. The technologies are widely applicable across vertical sectors, making the overall market in the UK and beyond very significant. Increasing integration of electech technologies is driving closer collaboration between technology suppliers from the sub-sectors and highlighting the sector's scale and economic impact beyond a simple key enabling role for other industrial sectors.

2.2 Size of the sector

There has been no comprehensive measurement of the size of the electech sector as defined in this report. There have, however, been several attempts by different groups to measure their sub-sector and its impact (Figure 1 on pages 18-19). The methods and categorisations used vary considerably. They suggest electech contributes more than £100 billion a year to the UK economy. The data in Figure 1 is provided only to illustrate that the electech sector is very significant in size and that there is both regional and national level recognition of its importance. The sector needs to develop a more definitive and rigorous measurement of scale and impact so all its sub-sectors can be represented as a more cohesive unit.

The Department for Business, Energy and Industrial Strategy (BEIS) annual business survey [1] in 2017 shows that the electronic systems sector alone accounted for at least £52 billion of turnover. BEIS analysis also shows that this sector supported more than 926,000 jobs in more than 53,000 companies by the end of 2017. The UK photonics industry 2019 data shows that it contributes £13.5 billion to the economy a year and employs 69,000 people in at least 1000 companies [2].



926,000
JOBS
supported by the electronic systems sector

69,000
JOBS
in the photonics industry

> **"Electech encompasses everything from the smallest electronic chip to the largest electrical motor or power station and the software that controls it"**

2.3 Sector-wide consultation

The sector is represented by a range of trade associations and other industrial stakeholder groups covering different technologies and a broad geographical area. They are acting to join up the sector and have provided input to this report and helped to encourage the wider industry to have its say.

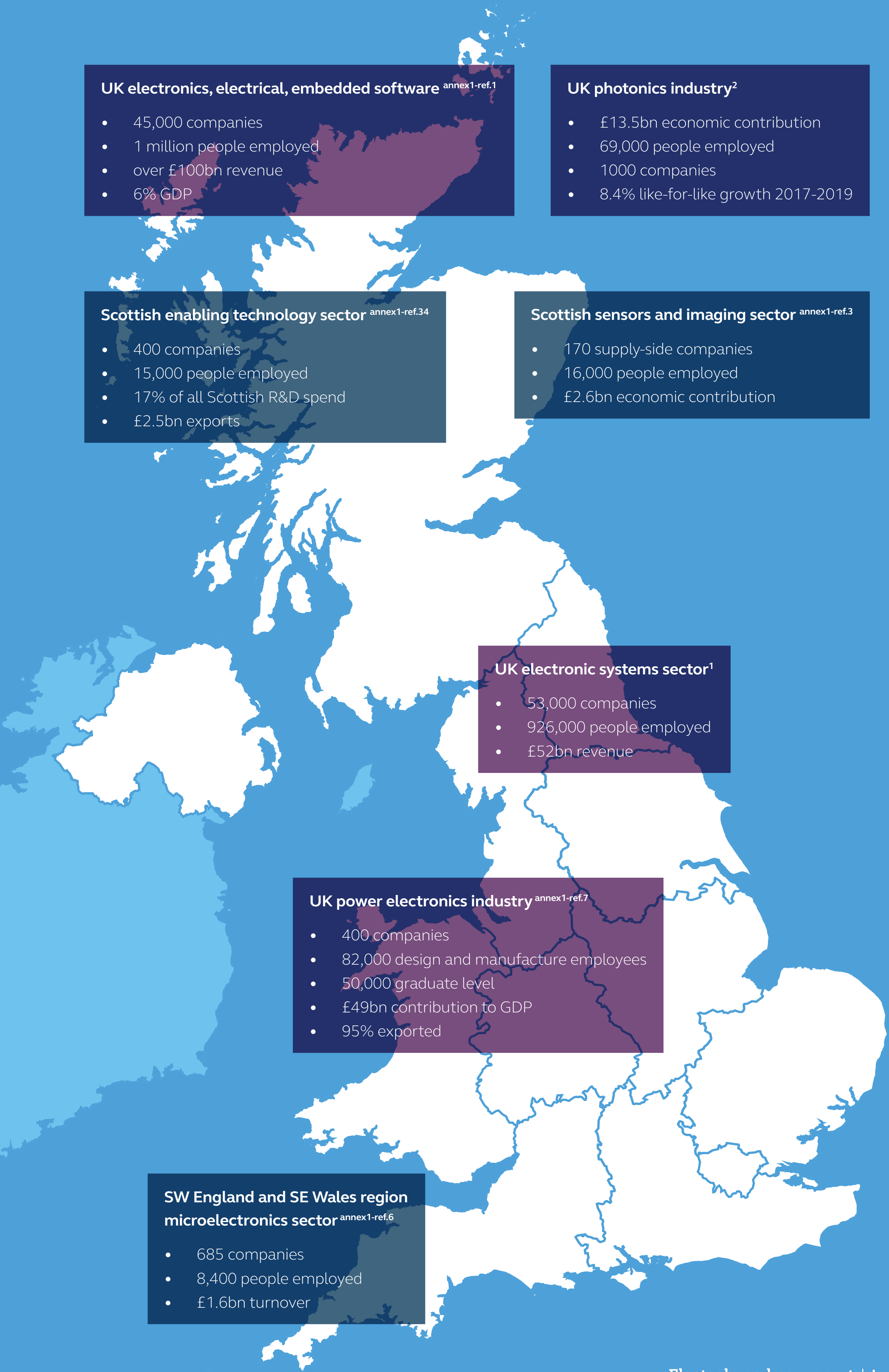
Stakeholder organisations include: the ElecTech Council, BSI (the UK's national standards body), GAMBICA (the trade association for instrumentation, control, automation and laboratory technology), TechWorks (including PowerElectronics UK, the Automotive Electronic Systems Innovation Network and the Internet of Things Security Foundation), Photonics Leadership Group, Sensing Innovation Leadership Council (SILC), CENSIS (innovation centre for sensor and imaging systems and Internet of Things), BEAMA (representing manufacturers of electrical infrastructure products and systems), Technology Scotland, Compound Semiconductor Applications Catapult, the Institution of Engineering and Technology, and the UK Electronics Skills Foundation.

This report and its roadmap have grown out of wide consultations with the sector and the stakeholder organisations. It is the result of extensive analysis, workshops, interviews with representatives from key companies and industry organisations. More than 100 people contributed directly to the roadmap's content.

Figure 1: The size of the electech sector and sub-sectors

UK instrumentation, control, automation and laboratory technology industry annex1-ref.2

- 40,000 people employed
- £6.9bn turnover
- £3.7bn exports
- 9.3% combined growth in 2017



UK electronics, electrical, embedded software [annex1-ref.1]

- 45,000 companies
- 1 million people employed
- over £100bn revenue
- 6% GDP

UK photonics industry[2]

- £13.5bn economic contribution
- 69,000 people employed
- 1000 companies
- 8.4% like-for-like growth 2017-2019

Scottish enabling technology sector [annex1-ref.34]

- 400 companies
- 15,000 people employed
- 17% of all Scottish R&D spend
- £2.5bn exports

Scottish sensors and imaging sector [annex1-ref.3]

- 170 supply-side companies
- 16,000 people employed
- £2.6bn economic contribution

UK electronic systems sector[1]

- 53,000 companies
- 926,000 people employed
- £52bn revenue

UK power electronics industry [annex1-ref.7]

- 400 companies
- 82,000 design and manufacture employees
- 50,000 graduate level
- £49bn contribution to GDP
- 95% exported

SW England and SE Wales region microelectronics sector [annex1-ref.6]

- 685 companies
- 8,400 people employed
- £1.6bn turnover

2.4 Why electech is important

Government should recognise the importance of enabling technologies in its policy-making. European recognition of the key enabling technologies has been driving research and innovation policy since 2009. Electech technologies are specifically seen as strategic and indispensable to innovation and economic growth.

Investment in industry-driven innovation projects, such as pilot lines or large-scale demonstrators, is supported by the Electronic Components and Systems for European Leadership (ECSEL) Joint Technology Initiative [3]. The Electronics Components and Systems Strategic Research Agenda [4] is a key pan-European industry-driven effort to align research and innovation priorities across technologies and applications and inform ECSEL's strategic priorities for investments.

Photonics is also seen as a key enabling technology with a research and innovation strategy driven by Photonics 21 [5], a public-private partnership developing future research and innovation priorities that drive investments as part of the Horizon 2020 Framework Programme.

Dedicated and sustained investments in both electronics components, systems and photonics are deemed essential for Europe's competitive leadership in an era of technological disruption and global change. Key enabling technologies and their evolution are expected to have continued recognition in the next EU Framework Programme for Research and Innovation, Horizon Europe.

The recently launched Defense Advanced Research Projects Agency-funded programme known as Electronics Resurgence Initiative [6] strongly demonstrates US recognition of the underpinning role of the electronics industry. The programme is investing in research and development to fully unlock microelectronics innovation for commercial and defence purposes and to reach levels of performance beyond the limits of traditional increases of the doubling of the number of transistors on a chip every 2 years projected by Moore's Law.

2.5 Electech is an opportunity for the UK

The UK has an opportunity to strengthen its competitive position by similarly recognising, supporting and investing in electech technologies and innovations. A future association model with Horizon Europe is likely to be important in pursuing economic growth through collaborative research and innovation.

Furthermore, the UK needs to develop its export potential to take advantage of global trends towards smart, digital, electech-enabled solutions in all industry sectors but also to stimulate future inward investments.

“ ”

Electech technologies are seen as strategic and indispensable to innovation and economic growth

2.6 A Vision for the sector

Our vision is for an electech industry widely recognised for its impact and investments in innovation and supply chains and for its ability to solve the big 21st-century challenges in health, energy supply, productivity, security, mobility and sustainability.

The UK has a great track record of innovating in electech. It's introduced many world-first underpinning concepts, technologies and electech-enabled innovations. This ingenuity and inventive capability can, however, be better exploited.

We want the UK to be amongst the best places in the world to develop or acquire electech solutions – a great place to start, build or scale a business involved in electech or to gain access to electech supply chains. It is a country that plays a leading role in driving the development of key technologies and the standards and regulation that enable them to be widely adopted. The electech sector should aim to encourage companies that design, manufacture and/or deploy products with significant electech content and capabilities to maximise their collaboration with UK-based electech companies and expertise.

The electech sector should address skills shortages by driving the development of education and training at all levels of the economy, leading to sustained, productive and high-value employment for current and future generations. It should supply the technologies that enable other industries to address productivity when skills are limited and build on the work of the UK Electronics Skills Foundation to encourage more young people to study electech engineering disciplines and to pursue careers in the sector.

We want to engage and excite the young, talented and energetic to rise to society's greatest challenges and enable British industry to make the most efficient use of electech skills.

2.7 UK-led developments in electech

Several UK-led developments across electech have transformed our world, including:

Early computing machines and underpinnings of computer science – University of Cambridge

Breakthrough developments that paved the way for programmable computers and laid the foundations of digital computers.

Thermionic valve – University College London

Seminal development in the history of electronics that transformed radio communications.

Cavity magnetron – University of Birmingham

Underpinned the realisation of radar and is inside every microwave oven.

Fibre-optic communications – STC Standard Telecommunication Laboratories

Ground-breaking technology that transformed the way data is transmitted globally and is the backbone of the modern internet age.

Packet switching – National Physical Laboratory

Breakthrough concept that forms the foundation of digital networking underpinning the global internet.

Computed tomography (CT) scanner – Thorn EMI Central Research Laboratories

Transformed medical diagnosis in hospitals and found applications in diverse areas that require imaging capabilities.

Erbium-doped fibre amplifier – University of Southampton

Pioneering work that enabled optical fibre data transmission over long distances and is at the heart of modern telecommunication networks.

2.8 Challenges

Electech companies face many challenges. Addressing these challenges could unlock significant growth and job creation. This section presents a collection of views on those challenges gathered from industry interviews.

Lack of recognition

The sector suffers a lack of recognition, particularly from the wider vertical industries that depend on it. Enabling technologies are not always obvious in the finished product, even when their function is vital. This lack of recognition is exacerbated by the way wider industry generally organises itself by vertical sectors that become the focus for government attention and investment to stimulate growth and employment. Companies, particularly SMEs, that develop and deliver electech tend to associate themselves with a sector-specific vertical and corresponding supply chain. This often steers them away from realising the full cross-sector potential of their capabilities as they find an application area and concentrate on maximising their market share there. Scale-up of these innovation-based companies is limited by the opportunities in their chosen sector. Their niche focus also means they do not have the volume to meet the significant year-on-year cost reductions expected by integrators and further limits opportunities to join many supply chains.

Greater industry recognition of electech as a key enabling sector supported by stronger representation in government policy is needed.

Fragmentation

Electech is a fragmented sector. Many companies are focussed on specific technologies and applications. The sector includes lots of highly innovative SMEs working with high levels of technical complexity and an ever-increasing pace of change. There are, however, challenges in taking these technologies to higher level manufacturers in vertical industries. Many SMEs struggle to persuade risk-averse systems integrators to adopt these new technologies and struggle to demonstrate measurable benefit in applications where these technologies are only part of solutions.

The end-user industries are generally only interested in integrated and qualified solutions, something that is beyond the capabilities of most SMEs.

Supply chains in many cases have become hollowed out. SMEs willing to progress up the supply chain need to invest in manufacturing capability, but often find this difficult. On the other hand, large companies increasingly tend to buy subsystems rather than develop their own technology. However, more modern complex products make it likely that these large companies would require hundreds to thousands of components, both hardware and software. It means systems integrators need early access to technologies as they are being developed, further complicating supply chain relationships.

Lack of early adopters

Many users of electech are conservative adopters of new technologies. Innovative UK companies developing electech often go to places such as the USA and Asia in search of a market of early adopters, only returning later to address the interests of the UK market. The sector is global in outlook and, as the UK does not lead in all industry verticals, companies need to work with the best, wherever they might be. It's often critical to find customers capable of getting involved in development.

UK electech excellence needs promoting internationally. Nevertheless, the whole UK-based supply chain will benefit from greater and closer collaboration on everything from components to systems expertise. Close geographic proximity, language and cultural values have repeatedly accelerated innovation, for example in Silicon Valley, Tokyo and Shanghai.

Long product cycles

Agility and rapid product development is not always the challenge. In some sectors, particularly aerospace, there are very long product cycles and extended times to market. This can also lead to problems of obsolescence and a need for long-term support of aged yet still-needed technologies.

Capital investment

Many innovative companies are small and nimble and able to develop incredible technologies with relatively little capital investment. However, some great electech innovations are built on highly advanced manufacturing processes that require expensive and widely accessible manufacturing plant facilities. This is particularly true of semiconductor plants, which must be viewed as a long-term investment to support a local ecosystem of users. The UK has shown world leadership in chip design but has not exploited the potential in manufacture. The trend to system-on-a-chip makes this a missed opportunity.

There is some progress, for example in compound semiconductor technology. Investment in a South Wales cluster, including the Institute for Compound Semiconductor Technology, the Compound Semiconductor Centre and the Compound Semiconductor Applications Catapult, will help to develop products and skills and provide support to attract companies and build supply chains.

Investment

Electech start-ups and spin-out companies struggle to attract investment to allow them to scale sufficiently. This is a particular issue where there is a need to finance capital equipment or to deal with long development timescales. More 'patient capital' is needed. There should also be a greater understanding of the enabling nature of electech companies and that wide-ranging application opportunities should be sought rather than a single profitable niche. The Government's Patient Capital Review [7] and its recommendations are welcomed as recognition of the gap in providing large-scale investment to highly ambitious capital-intensive businesses.

Research funding

UK universities are great engines of innovation, often at the forefront of new discoveries that can revolutionise the world of electech. Academic-industry collaboration has grown in recent years. However, without stronger lead from vertical sectors using electech, there is a concern that the movement of government focus to Industrial Strategy-led challenges may reduce investment in enabling technologies and the opportunities to translate the investment in university research to industrial use.

Training and skills

The electech sector is highly skilled at all levels. High levels of education and training are as important in technician-level manufacturing roles as in postgraduate-level research and development roles. The skills acquired are often widely transferrable and are highly sought after by companies. The sector must continue to promote technology as a career path to address overall skills shortages as demand for suitable graduates outstrips supply.

A survey conducted by the CBI revealed that 46% of employers reported a shortage of STEM graduates [8]. Only 3,330 UK students enrolled on first degrees in electronic and electrical engineering in 2017, less than half the number enrolling on mechanical engineering degrees.

22% **of employers in this sector have reported problems in recruiting engineering graduates**

There are also specific skills gaps where knowledge and capabilities required by industry are not being sufficiently addressed in education and training. There are notable shortages of hardware engineers and software engineers in the electech sector. Systems engineering skills and an ability to focus on systems solutions rather than just hardware or software is also much in demand. Data scientists are also in particularly short supply.

These skills shortages and gaps, coupled with concerns about access to global talent, are an ongoing challenge for the industry. Many companies want to see a clear skills-based immigration policy. There are opportunities to improve the gender balance and draw more talent into the sector. Industry needs to work with universities and colleges to help them to better reflect changing needs in their courses.

2 Introduction

2.9 Investing in electech

Electech needs greater sector coherence and a stronger voice to achieve the vision. It's important to demonstrate the significance of electech to innovation, competitiveness, productivity and the achievement of companies' strategic objectives. This will also improve cooperation across different technology areas in electech and promote more integrated solutions. Greater recognition by the constituent industries will help to develop electech's relationship with government and its alignment with the Industrial Strategy.

Investment in technologies with wide application across many vertical industries will greatly increase the impact of the electech sector. Coordinating this investment across multiple electech technology areas will harness the collective strengths of each sub-sector, unlocking even greater levels of impact on innovation and productivity.

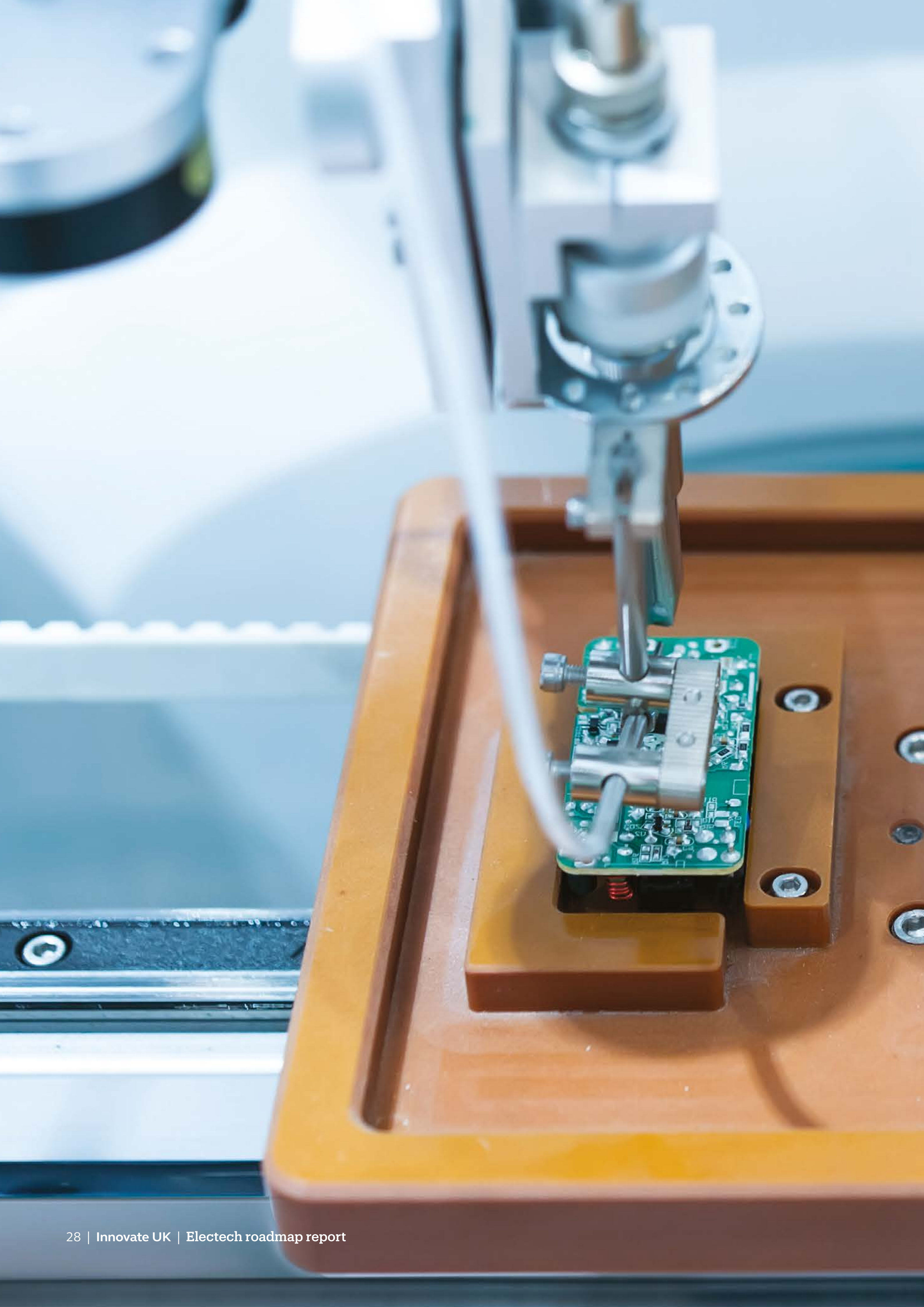
Electech and the Industrial Strategy

The electech sector can play a big part in delivering the UK government's Industrial Strategy [10]. The strategy is built around the 4 grand challenges of artificial intelligence and data, ageing society, clean growth and future of mobility. Electech technologies will play an underpinning role in delivering the innovations across all the challenges – whether it is the smart systems that help to drive and power autonomous vehicles of the future and to run a cleaner electric grid, or the sensors and diagnostic systems that will help us to live longer, healthier lives.

Greater private investment in electech innovation supported by appropriate government investment and a strong UK contribution to international standards will lead to significant and more rapid sector growth. It will also generate rapid growth and improve productivity in all sectors that depend upon electech.

Some sub-sectors of UK electech are already an export success. The UK produces around 10% of total European photonics output and accounts for between 3% and 8% of global photonics production. UK photonics manufacturers export over 75% of their output, with many companies shipping 100% overseas [2]. Moreover, in the electronics industry, the UK has a world-leading expertise in semiconductor design and IP-based business models with companies exporting electech IP internationally. Investment in strengthening UK electech capabilities will strengthen national competitive advantage.

Electech needs to increase the amount of UK-designed and manufactured electech content embedded and used in products made in the UK and to increase the UK content in UK-produced electech systems. This will increase return on investment, strengthen the UK's competitive position and reduce reliance on potentially vulnerable import supply chains. This becomes even more important with the UK's changing relationship with the EU. Efforts to encourage the growth of UK clusters and supply chains around long-term capital investments, for example, the compound semiconductor cluster in South Wales, will help.



Electech roadmap for the UK

The electech technology roadmap uncovers and communicates key technical development areas that map onto a range of future applications

3.1 Why a roadmap?

The electech technology roadmap outlines the key technical developments in enabling technologies required for a range of expected future applications. It does not provide a plan for development because of the sheer range of existing and emerging electech and electech-related technologies. The roadmap aims to demonstrate the need to invest in enabling technologies by providing a high-level view of the electech sector's breadth and importance. Showing clear links between technologies and the industries as well as future applications they will enable.

The roadmap will inform the electech sector and stimulate it to develop a strategic approach by:

- establishing a high-level blueprint of underpinning and enabling electech capabilities, technologies and innovations
- encouraging investment in strategic capabilities with potential cross-sector applications
- promoting private capital investment and stimulating government funding
- encouraging the ElecTech Council and other existing or future sector representatives to establish a strong, consistent and widely recognised presence and to use the sector's dynamics and leading-edge capabilities to drive the relationship with government
- promoting the combination of different electech technologies for rapid sustainable impact in any vertical market challenge

The roadmap will stimulate wider industry and vertical markets by:

- persuading vertical industries to include electech technologies and innovations in their strategies and roadmaps
- informing technology roadmaps with a regional, national or vertical market focus

The roadmap will inform government's research and innovation and broader policy by:

- raising awareness of the electech sector's composition and scope, its enabling power and its significance for business innovation and productivity improvement
- supporting development and effective implementation of the national Industrial Strategy through highlighting the relationship between enabling technologies and their applications
- supporting development of local industrial strategies that build on regional excellence and expertise anchored in electech technologies and capabilities

3.2 Building a roadmap

This roadmap is the outcome of workshops, extensive analysis and consultation interviews with industry representatives from key companies and other stakeholder organisations. More than 100 people contributed directly to the roadmap. We used formal roadmapping techniques devised by the Cambridge Institute for Manufacturing [11]. We captured the collective views of important sector stakeholders such as relevant trade associations and industry groups. The roadmap draws on several published reports and roadmaps covering aspects of the technology or sector for both pre-workshop preparation and post-workshop analysis.

The workshops helped to develop and establish an understanding of the landscape in which electech operates from both 'top-down' and 'bottom-up' perspectives. The 'top-down' approach considered trends, drivers and the views of a range of stakeholders on society and industry needs over the next 10 years. The 'bottom-up' approach examined the technical building blocks at component, sub-system and systems levels that will meet these needs. We considered key enablers, including essential ancillary technologies, and identified other factors such as standards, skills and collaboration frameworks. We also considered challenges and barriers experienced by industries operating in this landscape.

3.3 The roadmap explained

The roadmap is summarised in Figure 2 on pages 32-33. It is organised in layers (vertically) and timescales (horizontally). Timescales, shown as short-term (3 years), medium-term (5 years) and long-term (10 years), are approximate and highly dependent on investment and integration of effort. Nevertheless, they indicate what is expected in the short term and what is possible in the longer term with the right level of support from industry, the research community and government.

Trends and drivers

The top trends and drivers layer highlights the main industry, market and business trends and the drivers for developments in the electech sector. This layer defines the 'why' and puts the application areas and system level capabilities in context, illustrating why they are needed and why the electech sector needs to plan around them in the future. It also defines the high-level factors that will have an impact on realising the vision.

Application areas

The application areas layer is made up of 7 categories. This layer defines the 'what' – what form the technology-enabled solutions may take and what needs they serve. These applications represent target areas where developments in electech will help to create new products, processes or services and drive innovation and economic growth.

System level capabilities

The system level capabilities layer defines the 'how' by collecting and analysing the technologies required to address the application areas. It organises them into 5 system level capabilities and highlights some of the priority technologies for investment. These technologies are separately identified with different colours as belonging to one of 5 technology areas. This layer allows readers interested in a particular technology area to see the relationship between the evolution of the technology and the evolution of the system level capability.

Enablers

The bottom enablers layer captures technologies and developments that are not directly related to electech but are critically important to delivering electech solutions. These can be other cross-cutting technologies, more general capabilities and a range of other factors that allow electech to be developed and deployed.

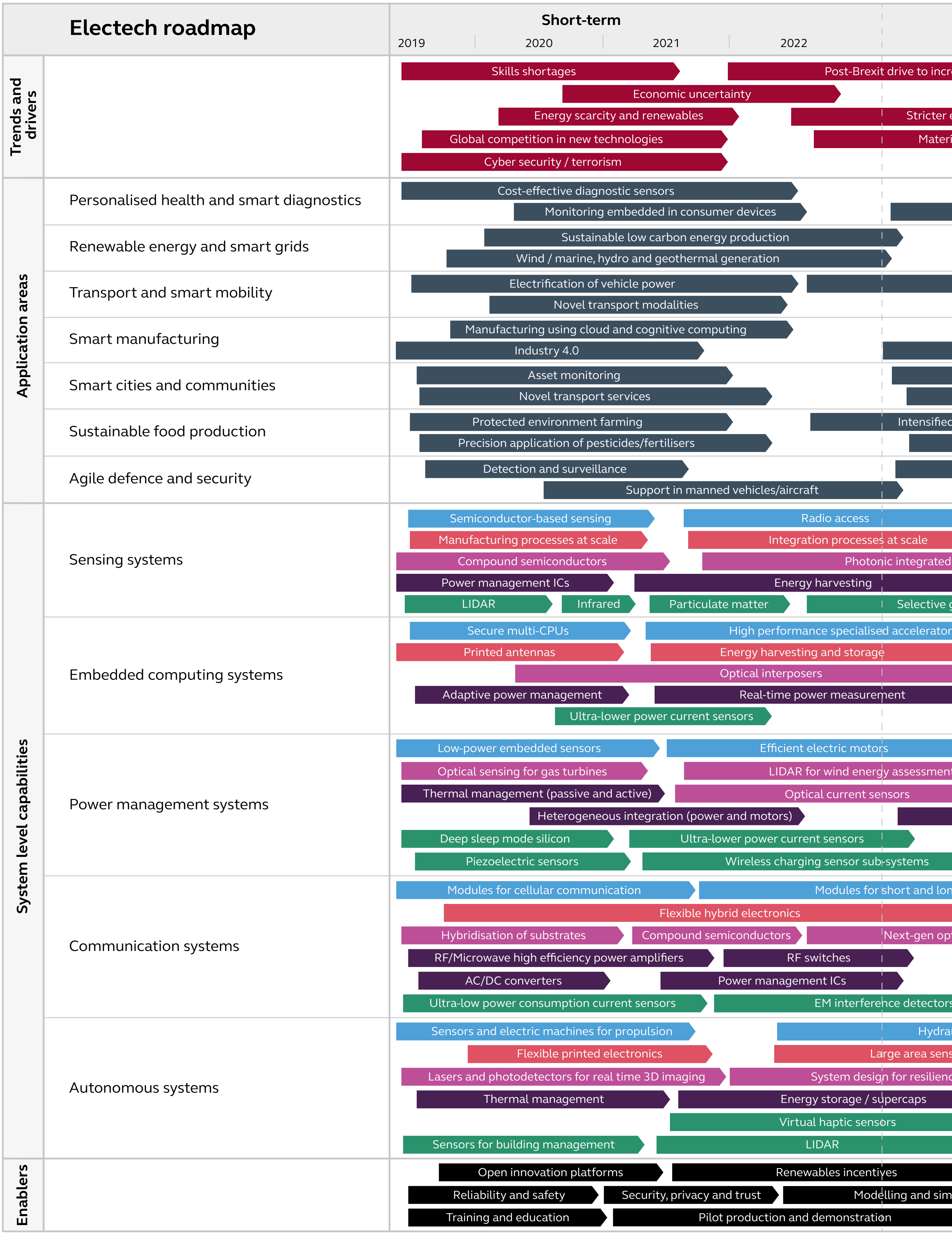


Figure 2: An electech roadmap for the UK.

*Time-scale adjusted for graphic layout purposes.

3.4 Trends and drivers

Industry, market and business trends and drivers influence the development of electech. Trends and drivers influence what products, processes and services industry will choose to develop. The most important trends and drivers include:

Social	Skills shortages, ageing populations, inclusive and reflective societies, social mobility
Technological	Emerging/disruptive technologies such as Industry 4.0, IoT, AI, personalisation and customisation, robotics and autonomy, cyber-physical systems, 5G communications, integrated transport
Environmental	Energy scarcity and renewables, recycling and re-use, materials scarcity and price volatility, greenhouse gas emissions reduction, food security, water scarcity
Economic	Global competition in new technologies, economic uncertainty, fast-changing business models, productivity challenges, product-service systems, availability of investment capital
Political / legal / regulatory	Cybersecurity and resilience, terrorism, potential for international collaboration, drive to increase exports and competitiveness post-Brexit, emissions regulations, emerging UK standards

Trends and drivers reveal that the future is expected to bring societal change, an increasingly uncertain economic world and an increasingly vulnerable environment. Technology capabilities are evolving too, making new solutions and even whole new industries possible. This is the landscape in which the electech sector will be required to operate and innovate.

3.5 Application areas

The trends and drivers drive demand for a wide range of solutions or applications. We investigated opportunities for electech in the roadmapping process. There are many high-impact applications that require some combination of electech technologies for delivery. Our analysis categorises the most important solutions or applications by application area. Whilst the areas described below broadly mirror more standard industry sectors, they are described as application areas to underline that they are specifically electech-enabled.

They show that the products and services of the future will be increasingly dependent on electech for the higher levels of communication, security, situational awareness, intelligence, automation and autonomy required. Electech is a driving force for modernisation of the industrial base, increasing efficiency, driving productivity and expanding export opportunities. It will also be key to the development of entirely new industries.

Within each application area are specific solutions, products or services that will collectively satisfy the specific need. The purpose of this report is not to analyse each of these in turn but rather to highlight the ubiquity of the enabling technologies in delivering them. This will increase the impact of investment in the cross-cutting technologies and capabilities.

Personalised health and smart diagnostics

Healthcare change is increasingly driven by the need to lower costs and improve early detection and diagnosis. This will be supported by cost-effective diagnostic sensors and AI-driven analytics, with data privacy and security being paramount. Patient monitoring will take place inside and outside the clinic to allow timely intervention, reduce pressure on the healthcare system and improve quality of life. Integration of monitoring into consumer electronic devices will aid adoption. Predictive healthcare will reduce later treatment costs. Development of new ways to diagnose disease or illness, including *in vitro* diagnostics and diagnostic imaging, will extend the ability to detect and act early. Remote diagnostics and remote robotic surgery will reduce costs and errors.

Renewable energy and smart grids

Environmental sustainability demands low-carbon energy production. Typical sources for the UK will be wind, solar, marine, hydro and geothermal. Generation, conversion and storage will be required at regional and local levels. Resilient infrastructure and efficient transmission and distribution through smart grids will rely on systems integration expertise, power electronics and sensor systems. Smart grids will allow real-time coordination and dynamic decision-making, ensuring both efficiency and security of supply. Smart grids will also support charging infrastructure for smart mobility and autonomous vehicles.

Transport and smart mobility

Congestion and environmental impact are driving demand for smarter and more sustainable transport systems. This will have an impact in a range of areas from infrastructure and transport modes to operational control of transport, particularly within an urban environment. Location, navigation and communication technologies will play an important part in controlling traffic. Pollution will be reduced by tackling congestion and by on-vehicle technical improvements. Mobility as a service will reduce the need for vehicle ownership and maximise use of fewer vehicles on the road. Coordination of different modes of transport will support efficient and sustainable travel. Connected and automated transport will be found on land, sea and in the air and will include the use of autonomous unmanned vehicles. Electrification will support plug-in hybrids and the transition to fully electric vehicles. More electric motors and ground propulsion systems will improve sustainability of commercial aeroplanes.

Smart manufacturing

Continuing demand for improved productivity, efficiency and sustainable use of resources is driving the trend towards digital manufacturing. This is known as Industry 4.0 and includes the application of cyber-physical systems to the automation of manufacturing using IoT, cloud computing and cognitive computing. It will allow reconfigurable factories to deliver ultra-flexible demand-driven manufacturing and mass customisation. It will rely on manufacturing processes such as additive layer manufacturing. Digital supply chains will have to be highly integrated. There will be extensive use of robotics and smart low-cost sensing. Augmented and virtual reality will be used to plan and to train. Efficiencies and new insights will be achieved in the design, operation and maintenance of processes using digital twins that integrate artificial intelligence, machine learning and software analytics with spatial measured data to create digital models.

Smart cities and communities

Increasing urbanisation requires increased monitoring and management of transport, services, energy, utilities, security access and potentially crowds to make communities operate more efficiently. Connecting the person to their surroundings through wearable electronic devices to monitor, map and inform will enable new services and ways to interact with both objects and others. Connected, smart technology will ease urban congestion and pollution and improve health. Smart cities will also better coordinate and manage the use of resources and reduce the cost of living. Smart cultural and education facilities will be developed for both residents and tourists. The consumer experience will be improved through augmented and virtual reality.

Sustainable food production

Pressures on land, labour shortages and food security are driving change in agriculture. More intensive and sustainable production of food will be enabled through more efficient and targeted agricultural practice. Examples include sensing and robotics for precision application of pesticides and fertilisers, and for greater automation to address acute seasonal labour shortages; remote sensing technologies and platforms (including airborne and satellite-based) and wireless sensor networks for field monitoring and management. New production concepts such as protected environment ('vertical') farming with associated robotics, sensing and automation will increase. Producing a safer and more resilient supply chain and reducing waste will mean increased demand for monitoring and control so food products can be traced and measured – from primary production (soil, seed, chemical, nutrient inputs) through to quality, volume and nutritional value.

Agile defence and security

Evolving threats to security and safety, and cost pressures on defence budgets will drive the demand for more affordable, flexible and able solutions. Detection and surveillance from distance using a range of technologies, from advanced imaging techniques through to wireless sensor networks for sector monitoring, will need to improve significantly. Guidance and control systems will rely on, for example, range-finding techniques such as LIDAR. Navigation systems will require ground, air and space-based infrastructure. There will be increasing demand for driver/pilot assistance and a longer-term trend to unmanned autonomous ground, marine and airborne vehicles. In a connected, digital world there will be a need for innovation in countermeasures to electronic warfare and, underpinning all digital defence and security, will be the need to address rapidly evolving threats to cybersecurity.

“ ”

Electech will be key to the development of entirely new industries

3.6 System level capabilities

Electech technologies are present in different levels, from components and devices through to whole systems. At system level, these technologies provide the cross-cutting technical capabilities that make up the building blocks for solutions in different applications. We call these building blocks 'system level capabilities'. We identified 5 core system level capabilities of strategic importance to the UK: sensing systems; embedded computing systems; power management systems; communication systems; and autonomous systems.

The roadmap outlines the electech technologies needed to create each core system level capability, and the other expertise and technology required to deliver them. This other expertise and technology could include miniaturisation, integration and packaging, for example system-on-a-chip, and the use of advanced manufacturing techniques, for example nano 3D printing, MEMS (micro-electrical-mechanical systems), and additive manufacturing. A system-level approach mirrors the electech supply chain, demonstrates that a technology focus alone is insufficient, and that system integration is a real enabler for electech.

Sensing systems

Sensing systems link the physical world and the digital world. This area includes the sensing element, conversion to a digital signal, signal/data-processing, and sensor fusion. Sensor systems can provide the raw signal data, a processed data stream or alarm/limit detection.

Embedded computing systems

An embedded system is a computer system with a dedicated function within a larger mechanical or electrical system, often with real-time computing constraints. It is embedded as part of a complete device, often including other hardware and mechanical parts. Embedded systems control many devices in common use today. They also provide the intelligence in smart products or systems.

Ninety-eight percent of all microprocessors manufactured are components in embedded systems [14].

Power management systems

Power management systems are responsible for the control, management or conversion of power within systems. They can range in scale from power optimisation in a microprocessor through to power management, conversion and optimisation for grid-based systems. Technologies include energy harvesting, low-power electronics or strategies to minimise power use and maximise battery life.

Communication systems

Communication systems include processing of signals for wire, radio, optical or electromagnetic transmission over distances ranging from millimetres to thousands of kilometres. Examples include 3G, 4G and new 5G technologies and various short and long-range communication systems commonly found in wireless local area networks (based for example on WiFi and Bluetooth); one-way communication systems (based for example on RFID/NFC); and the emerging area of low-power wide-area networks (based for example on LoRa).

Autonomous systems

Autonomous systems are aware and interact with their environment. They include autonomous vehicles, drones, underwater vehicles, machines and robotics and the systems required to enable their autonomous operation and decision-making. Autonomy spans the range from driver/pilot support, where limited functions are autonomous, through to fully autonomous systems with no person required at all. These are underpinned by electrified propulsion, sensors and sensor fusion, communications, imaging and artificial intelligence, motors and energy efficiency (especially for untethered and energy constrained systems).

3.7 Combining system level capabilities to deliver solutions

Figure 3 illustrates the relationship between the application areas and the system level capabilities. Every system level capability is relevant for at least some applications or solutions within any application area. Moreover, it will take combinations of system level capabilities to deliver those solutions.

For example, an autonomous vehicle would be a specific solution within the smart mobility application area. In this case it would require elements of all 5 system level capabilities – sensing systems for the navigation and vehicle performance monitoring, embedded computing systems to process the on-board data gathered at various levels, power management systems to deliver optimum power usage within the microprocessors through to managing the delivery of motive power, communication systems to allow vehicles to coordinate with other vehicles and traffic management systems, and autonomous systems to deliver the higher level control. Some products are likely to need fewer system level capabilities.

Figure 3 presents a high-level view. It provides an indication of the importance of each system level capability in each application area. There is a level of subjectivity in these scores, but they represent the consensus of a significant number of contributors and are included to encourage debate rather than define investment priority.

Figure 3:
The importance of capabilities to application areas

	Personalised health and smart diagnostics	Renewable energy and smart grids	Transport and smart mobility	Smart manufacturing	Smart cities (and communities)	Sustainable food production	Agile defence and security
Sensing systems	1	1	1	1	1	1	1
Embedded computing systems	1	1	1	2	1	2	1
Power management systems	1	2	1	2	1	2	1
Communication systems	1	1	1	2	1	2	1
Autonomous systems	2	2	1	1	1	2	1

1 Of key importance for … 2 Important for …

Figure 4 shows how technologies at the component, device or even materials level can be combined into technology areas and enable a range of specific system level capabilities that are required to develop specific solutions to the challenges in each application area. This figure, moreover, shows how investment in an individual cross-cutting electech technology can have wide impact across industry as it ascends the inverted pyramid and adds value at the technology level, system level, product and service level and at end-market level. Improved price/performance ratio in electech components and technologies driven by one application will in turn enable new capabilities and drive demand in other applications. Innovation builds on innovation as one ascends the inverted pyramid with increasing degrees of complexity and integration. Co-ordination of investment in the right combinations of technologies at the bottom will deliver more capable, adaptable and powerful systems and solutions and a greater return on investment.

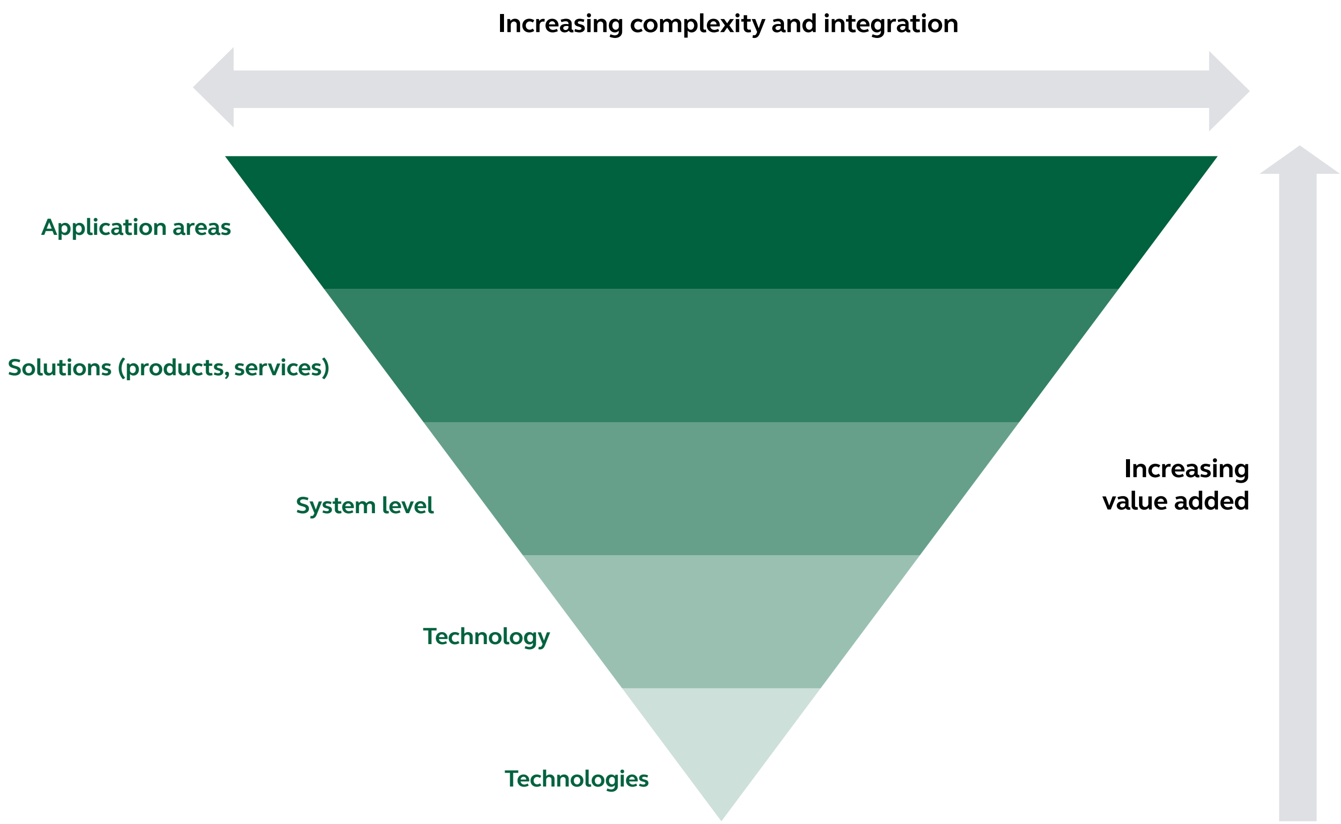


Figure 4: From technologies to applications

3.8 Electech technologies

One of the main drivers for the selection of priority technologies is their potential to advance system level capabilities and therefore enable new combinations and new solutions to be developed, as illustrated in Figure 5. The underpinning technologies can be developed to support more than one of these system level capabilities and they may be dependent on other non-electech factors.

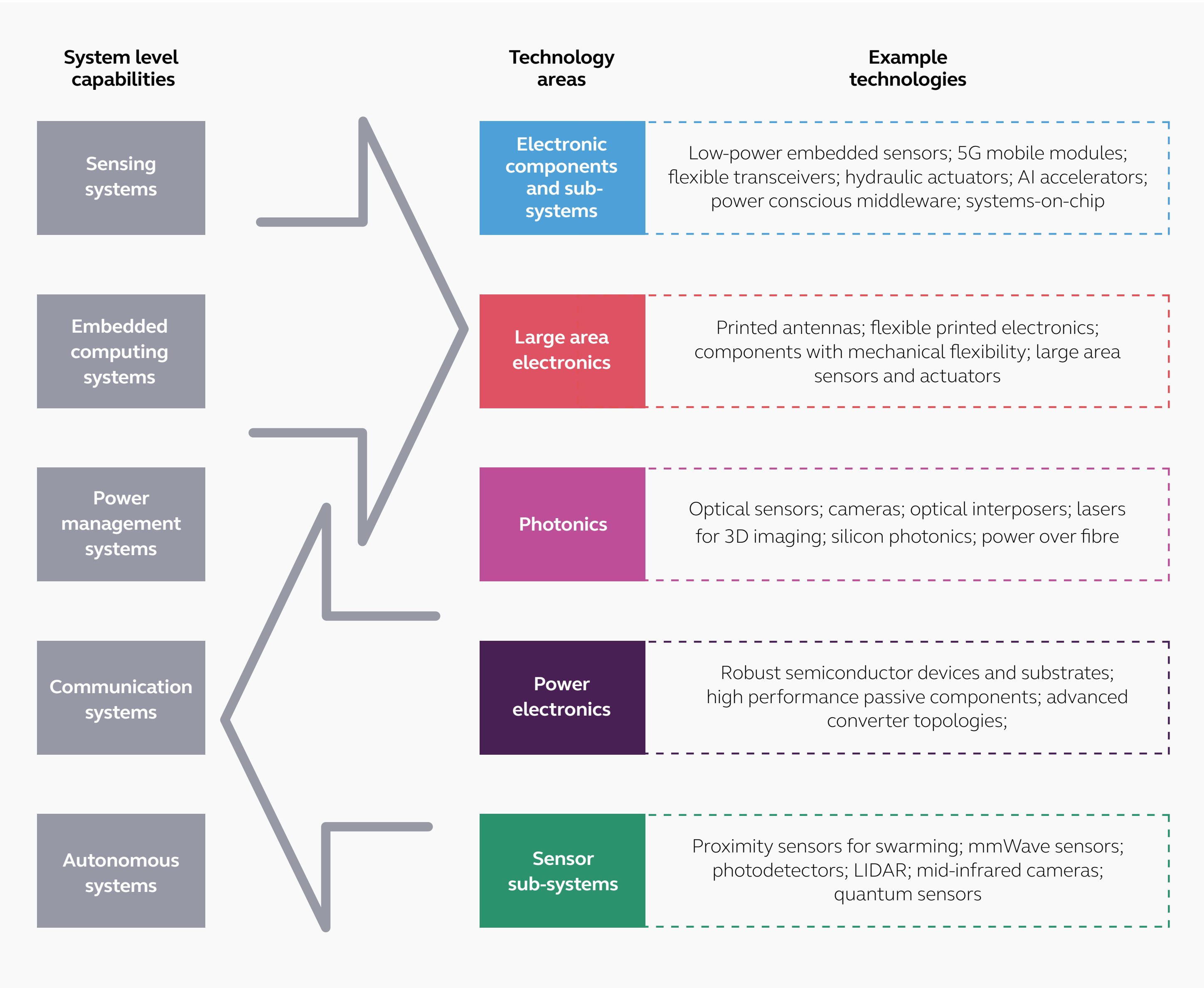


Figure 5: System level capabilities and underpinning technology areas with examples.

3 Roadmap

The following tables describe the priority electech technologies in each of the 5 technology areas with potential to have wide impact across sectors or address significant needs. The analysis is based on the system level capabilities they underpin. The development of each of these technologies at the right time is required in order to be able to deliver against the application areas.

Some of these technologies will develop in the required way due to other applications/drivers, while some will need encouraging specifically to achieve system level capabilities. As deep technical analysis is beyond the scope of this report, references to relevant roadmaps are provided after each table for readers interested in greater levels of detail.

Electronic components and sub-systems			
	Short term (3 years)	Medium term (5 years)	Long term (10 years)
Sensing systems	Semiconductor-based sensing will continue to be used for the foreseeable future.		
	Increasingly semiconductor-based sensing components will be interfaced to support radio access driven by demand for IoT applications. Microsensors and microactuators will be developed to perform miniaturised functions such as active noise cancellation, antenna steering and adaptive optics.	Solid-state scanning gains in importance. By integrating light sources, optical and electrical components and integrated beam steering, for example from MEMS or phased array techniques, integrated 3D sensor systems are realised. Radio access continues to be driven by demand for IoT applications.	Imaging and quantum sensors. Miniature quantum clocks have the potential to provide navigation information in the absence of satellite-based systems for example underwater and inside buildings.
Embedded computing systems	Trade-off remains around increased computing power and reduced power consumption. Operation in harsh environments including high and low temperatures (outside the range -40°C to 125°C) and mechanical stresses (for example vibration and shock) remains essential for various novel applications. Graphics processing units becoming more widely used as a general-purpose parallel processor for algorithm-intense processing.		
	Secure multi-central processing units.	High performance specialised accelerators (including AI, vision, communication and security). High reliability computing at the core of autonomous vehicles, reliable robots and several other systems. System in package, the process of putting a variety of different chips in a small package to make very small, efficient and complete systems. High-speed interchip communication essential element for system in package.	

Electronic components and sub-systems

	Short term (3 years)	Medium term (5 years)	Long term (10 years)
Power management systems	Trade-offs between performance and device areas are increasingly compounded by the considerations of power.		
	Low-power embedded sensors for power management in systems where minimal power usage is required, in both the short and medium term. Efficient electric motors. Power-conscious CAD tools, Supercapacitors and high-energy-density batteries from the short through to the medium term. Power-conscious middleware, followed by power management integrated circuits.	Power efficient data structures are of the highest importance. Reconfigurable power electronics enabled by AI/machine learning increasing in importance on into the long term. Thermal management of passive and active devices, high-power devices and high-speed devices. Wide-bandgap materials for example silicon carbide and gallium nitride show promise.	Neuromorphic chips, which combine very-large-scale integration systems containing electronic analogue circuits to mimic neuro-biological processes.
Communication systems	5G modules for cellular communication to enable very-high-bandwidth data and modules for short and long-range communications. Examples of the latter include 802.11ah (long range) and 802.11ax (ultra-high speed) Wi-Fi; mesh bluetooth and other short-range protocols like Zigbee, Thread, 802.15.4 as used in consumer devices.	Modules for cellular communication to enable very-high-bandwidth data communication and modules for short and long-range communications. Low-bandwidth medium-range chipsets to allow subsystems to connect within homes and business premises in cost-effective ways. Flexible transceivers with good linearity and efficiency. Frequency synthesisers, millimetre wave connectivity and power-efficient data processing.	
Autonomous systems	Emerging applications of autonomous systems, such as connected and autonomous vehicles, have highlighted the need for new regulatory requirements, for example related to liability. Developers and manufacturers must both inform and adhere to these regulations.		
	Sensors such as LIDAR, cameras and radar and robust yet efficient electric machines for propulsion. The main LIDAR challenges in this context are that they must not mutually interfere when operating in the same space, and must be eye-safe and affordable.	Hydraulic actuators gain in importance, although they are superseded by hardware accelerators for AI during this period.	Neuromorphic chips.

Additional roadmaps for consideration: NEREID H2020 CSA Project, Nanoelectronics Roadmap for Europe, 2017 | EPoSS European Roadmap Smart Systems for Automated Driving, 2015 | Electronic Components and Systems Strategic Research Agenda, 2018 | Driving Innovation in Power Electronics Across the UK Community - A Route Map to Success, White Paper, 2017 | European Roadmap Electrification of Road Transport, 2017 | UK National Quantum Technologies Programme, A roadmap for quantum technologies in the UK, 2015

<table>
<tr><th colspan="4">Large area electronics</th></tr>
<tr><th></th><th>Short term (3 years)</th><th>Medium term (5 years)</th><th>Long term (10 years)</th></tr>
<tr><td rowspan="2">Sensing systems</td><td>Manufacturing processes (ranging from vacuum deposition to printing under ambient conditions).</td><td>Sensing components that can be manufactured easily, sensors and other electronics embedded in bulk smart materials.

Textile electronics can fulfil requirements for sports and well-being products, and medical devices for patient monitoring.</td><td>Thin-film active devices; and interconnects.

Improved processability and reproducibility.

Design and modelling tools, in particular for variability in printing, interfacing of hybrid integration of micro/nano-electronics (including thin silicon) and photonics components.</td></tr>
<tr><td colspan="2">Integration processes at scale.

Advanced materials including functional materials, inks, and adhesives to overcome variability issues in printing. Renewed interest in paper due to its low cost and environmentally friendly properties.</td><td></td></tr>
<tr><td rowspan="2">Embedded computing systems</td><td>Printed antennas.

Energy harvesting and storage including printed lithium ion batteries and printed supercapacitors.</td><td>Integrated circuits for edge computing capable of collecting and processing data from IoT devices. Early adopters in manufacturing, utilities, energy, and transportation industries.</td><td></td></tr>
<tr><td></td><td colspan="2">Flexible printed electronics.</td></tr>
<tr><td>Power management systems</td><td colspan="3">N/A</td></tr>
<tr><td>Communication systems</td><td>Flexible hybrid electronics that combine silicon on flexible surfaces and support fully printed RFID/NFC labels.

Non-metallic printed antennas.</td><td colspan="2">Robust in-line metrology and control solutions for traceable measurement of properties and quality of layers and devices during fabrication.

Simplification of the recycling processes for devices to accelerate large-scale adoption.</td></tr>
<tr><td rowspan="3">Autonomous systems</td><td colspan="3">Flexible printed electronics, for example LED displays and flexible batteries or printed solar cells powering systems.</td></tr>
<tr><td colspan="2">Large area sensors and actuators.</td><td></td></tr>
<tr><td></td><td>Adaptive surfaces and adaptive structures with examples including curved displays for automotive, white goods displays and foldable displays in everyday objects such as wearables.</td><td></td></tr>
</table>

Additional roadmaps for consideration: *OE-A Roadmap for Organic and Printed Electronics 7th Edition, 2017 | A European strategy for Organic and Large Area Electronics (OLAE) Vision paper, 2013*

Photonics

	Short term (3 years)	Medium term (5 years)	Long term (10 years)
Sensing systems	3D sensing for facial recognition and autonomous systems and location awareness drive demand. Compound semiconductors. Narrow line-width infrared tunable lasers.	Photonic integrated circuits with non-telecommunication wavelengths. Coatings that go beyond current dielectric performance. New high sensitivity IR sensing materials. New sensors based on 2d semi-conducting materials.	Quantum sensing. Single-photon detection.
Embedded computing systems	Optical inter posers to decrease the distance between the electronics and photonics.		
		Power over fibre, targeting a minimum power of 3.3V at 100mA with conversion efficiency of over 50%.	
		Waveguiding interfaces.	
Power management systems	Optical sensing for gas turbines capable of holding extreme temperatures. Optical current sensors.		
	LIDAR for wind energy assessments. Light harvesting for electrical power generation that is infrastructure independent and with a high capacity for its cost.		
Communication systems	Need for design and simulation tools to cater for next-generation photonic technologies in this area. New mindset and more holistic approach needed for the development of hybrid RF and optical systems.		
	Hybridisation of substrates at wafer level. Optical fibres (such as few-mode and hollowcore that can achieve lower latency and higher bandwidth) and technology. Li-Fi.	Design and simulation tools to cater for next-generation photonic technologies. Silicon photonics, optical signal sensors and optical transceivers with 400Gb/s long-haul bandwidth. Lower energy per bit, higher density and higher capacity characteristics to match the needs of data centres and communications networks.	Holistic approach for developing hybrid RF and optical systems.
	Compound semiconductors and integrated photonics.		
Autonomous systems	Lasers and photodetectors for real-time 3D imaging at distance (for example for LIDAR and time-of-flight sensors), relying on compound semiconductors and advances in integrated photonics manufacturing. System design technologies for resilience and reliability to deploy photonic-based systems in harsh environments.	Wireless optical technologies that address latency requirements. Domains other than aerospace take advantage of installation cost savings and reduced weight typically associated with wires.	Optical CANBus. Plastic optical fibre. Solid state LiDAR solutions.

Additional roadmaps for consideration: *Roadmap of optical communications, Journal of Optics, 2016 | NL Photonics Roadmap, 2018 | The health of photonics, Institute of Physics, 2018 | UK Photonics: The Hidden Economic Engine, May 2018 | Europe's age of light! How photonics will power growth and innovation, European Technology Platform Photonics21, 2018 | UK National Quantum Technologies Programme, A roadmap for quantum technologies in the UK, 2015*

<table>
<tr><th colspan="4">Power electronics</th></tr>
<tr><th></th><th>Short term (3 years)</th><th>Medium term (5 years)</th><th>Long term (10 years)</th></tr>
<tr><td rowspan="3">Sensing systems</td><td>Power management integrated circuits.

Integration of power, sensor and analogue on chip.</td><td></td><td></td></tr>
<tr><td colspan="3">Energy harvesting.</td></tr>
<tr><td></td><td colspan="2">Wireless power transfer becoming applicable to an increasing number of sensing systems, beyond medical implants and portable devices.</td></tr>
<tr><td>Embedded computing systems</td><td colspan="2">Adaptive power management.

Real-time power measurement.

Energy-aware operating systems.

Adaptive voltage scaling applied to high-volume systems such as data centres and wireless base stations, and power constrained portable devices.</td><td></td></tr>
<tr><td rowspan="3">Power management systems</td><td colspan="3">Passive and active thermal management and heterogeneous integration of electrical power and motors.

In situ prognostics and condition monitoring for predictive maintenance providing ongoing dashboard, remote monitoring, failure alerts and critical input.</td></tr>
<tr><td>High voltage motors capable of handling short surges of electrical energy. Reduction of power losses of today's systems by up to 15%.</td><td>Focus on overall powertrain rather than inverter or converter parts.

For grid-scale applications – high temperature superconductors and fault protection systems.</td><td>New Permanent magnetic materials for motors and generators and soft magnetic materials for inverters and power electronics. Need rare earth-free metal options.

Compound semiconductors for smart grid power converters.</td></tr>
<tr><td></td><td colspan="2">Silicon carbide proves its advantages (faster switching speed, lower voltage drop and higher operating temperature) taking a slice from silicon. Gallium nitride and silicon carbide-based power devices capable of combining excessive temperature voltage and frequency (switch efficiency over 99%). High silicon carbide wafer costs addressed.

Grid-scale energy storage to facilitate the transition to efficient, reliable and cost-effective power systems with a high penetration of renewable energy sources.</td></tr>
</table>

Power electronics			
	Short term (3 years)	Medium term (5 years)	Long term (10 years)
Communication systems	RF/microwave high efficiency power amplifiers for cellular base stations.		
	RF switches. Integrated radios that consume less power and smaller area thus offering more functions with better RF performance at competitive cost. RF silicon-on-insulator to continue enabling design flexibility by integrating multiple RF functions such as power amps, antenna switches, and transceivers, as well as digital processing and power management. Fast charging focusing on instant turn-on with a depleted battery, battery run time, charging-path resistance, and thermal performance to support power management for portable systems, for example, wearables.		
	AC/DC converters (passive versus active) and power management integrated circuits.	Network power management techniques, including prognostics and diagnostics.	Hybrid supercapacitors that combine electrostatic and electrochemical energy storage devices by taking advantage of rapid charging ability of supercapacitors with the high energy density of Li-ion batteries.
Autonomous systems	Passive and active thermal management. Energy storage offering higher loading /discharge currents and very high cycle strength at high temperature resistance such as supercapacitors and hybrid supercapacitors.	Prognostics and condition monitoring for predictive maintenance. Modelling for thermal management (for example computational fluid dynamics).	Heterogeneous integration of power electronics and motors.

Additional roadmaps for consideration: *Empowering the Electronics Industry: A Power Technology Roadmap, CPSS Transactions on Power Electronics and Applications, 2017 | PowerAmerica Strategic Roadmap for Next Generation Wide Bandgap Power Electronics, 2018 | Driving Innovation in Power Electronics Across the UK Community - A Route Map to Success, White Paper, 2017 | Automotive Council UK and Advanced Propulsion Centre UK, 2017 Power Electronics Roadmap, 2017 | AESIN UK Automotive Electronics Capability Report, 2018*

<table>
<tr><th colspan="4">Sensor sub-systems</th></tr>
<tr><th></th><th>Short term (3 years)</th><th>Medium term (5 years)</th><th>Long term (10 years)</th></tr>
<tr><td rowspan="3">Sensing systems</td><td>Particulate matter sensors, radiation sensors and light detectors.</td><td>Selective gas sensors e.g. for CO, CO2, NOx and volatile organic compounds.</td><td>Sensor sub-systems with increased functionality, further miniaturisation and cost-efficient manufacture.</td></tr>
<tr><td colspan="2">Camera, LIDAR, infrared and radar for automotive and autonomous applications.</td><td></td></tr>
<tr><td></td><td colspan="2">Non-invasive sensors for pharmacokinetic/pharmacodynamic investigations and biochemical sensors.

Quantum sensors.</td></tr>
<tr><td rowspan="2">Embedded computing systems</td><td colspan="2">Ultra-lower power current sensors (for example to use as a ‘fuel gauge’ for battery power management).</td><td></td></tr>
<tr><td></td><td>Embedded image processing sensor systems for robotics and AI.</td><td></td></tr>
<tr><td rowspan="4">Power management systems</td><td colspan="3">Power management systems operating at mW/microW and lower depend on energy harvesting as well as ultra-low power consumption current sensors (acting as fuel gauges).</td></tr>
<tr><td>Piezoelectric sensors and deep sleep mode silicon systems.

Wireless charging sensor sub-systems.</td><td></td><td></td></tr>
<tr><td colspan="2">Power management sensors aiding in extending a system’s operating time between charges and ensuring that batteries do not overheat when being charged or drained.

At MW generation levels – sensors for predictive maintenance of generator machinery as well as partial discharge monitoring sensors that measure breakdown of insulators in grids.</td><td></td></tr>
<tr><td></td><td colspan="2">Quantum sensors.</td></tr>
<tr><td>Communication systems</td><td>Ultra-low power consumption current sensors (as current gauges).

Electromagnetic interference detectors.</td><td>Millimetre wave sensors and photodetectors for fibre and free space communications.

Acoustic sensors for sub-sea communications and single photon / ultra-high sensitivity detectors with increased range sensitivity and reduced power consumption.</td><td></td></tr>
</table>

Sensor sub-systems

	Short term (3 years)	Medium term (5 years)	Long term (10 years)
Autonomous systems	LIDAR sensors followed by camera sensors and infrared cameras enabling sub £1K sensor packages drive widespread adoption.		
		IR sensors and mid-infrared cameras.	
	Sensors for building management with energy, air quality and temperature as key modalities, followed by humidity sensors for autonomous ventilation solutions to avoid damp – especially in social housing.	Multi-spectral/modal imaging and multiband cameras, where visible and IR reducing size weight and power relative to multiple separate systems. Sensor sub-systems for managing food production environments, including horticulture/precision livestock farming. Tactile sensors and virtual haptic transducers, which are a key enabler for VR and AR applications. Highly-efficient proximity sensors for applications such as swarming, as well as other efficient and reconfigurable sensor processing.	

Additional roadmaps for consideration: *Industrial Digitilisation Review "Made Smarter", 2017 | Electronic Components and Systems Strategic Research Agenda, 2018 | Automotive Council UK Automotive Technology Roadmaps, 2017 | NASA Technology Roadmaps TA 4: Robotics and Autonomous Systems, 2015 | EPoSS European Roadmap Smart Systems for Automated Driving, 2015 | EPoSS Strategic Research Agenda, 2017 | UK National Quantum Technologies Programme, A roadmap for quantum technologies in the UK, 2015*

3.9 Enablers

There are other technologies and disciplines shaping innovation in electech and its use in key application areas. The examples outlined below are critical to realising significant advances in capabilities and performance.

Artificial intelligence and cloud-based computing

Artificial intelligence (AI) linked to electech involves the development of computer systems able to interpret large or complex data sets and make decisions based on them, performing activities that normally require human intelligence. Current deep-learning systems require huge data volumes to be stored and very high computing power found in the cloud. However, pure-cloud implementations are limited by bandwidth and have privacy and security issues. Hierarchies, such as distributed deep neural networks, that involve the cloud and end devices will gain in importance due to the need to develop intelligent robotic systems, autonomous vehicles and consumer electronics.

Edge computing, the trend towards pushing applications, data and computing power away from centralised points, can bring benefits such as faster response time, reliable operations with intermittent connectivity, security and compliance, cost-effectiveness and interoperability between legacy and modern devices.

Cognitive computing combines multiple data streams that identify patterns and provides considerably more context to the existing environments and applications.

System-on-chip and system-in-packaging

System-on-chip architecture and design allows the integration into a single chip of a variety of functions such as sensing (for example MEMS and imagers), actuation, communication, data protection and power management. Similar system-in-package integration best suits embedded memories, analogue and discrete components. Both system-on-chip and system-in-package depend heavily on hardware/software co-design, with design teams having to work closely with intellectual property vendors and foundries.

3D packaging

3D packaging remains a high-end technology that is applicable to datacentres, and some automotive and mobile applications but could potentially benefit other areas. The density of components has increased to such an extent that 3D configurations and/or more advanced nodes are needed. 3D packaging is a key design consideration for electech as it supports the effective integration of many technologies and components.

Additive manufacturing

As additive manufacturing goes mainstream, it is increasingly possible to manufacture fully functional electromechanical parts, opening the door to new possibilities in electronics design, production, and use. Polymer additive manufacturing, more commonly known as 3D printing, enables fast prototyping of customised structures and packages adapted to component dimensions and specifications. Lower material waste and part weight, which are key in sectors such as aerospace, motorsport and consumer electronics, absence of harmful chemicals and simplified assembly are some of the benefits. Entirely new products could be developed, for instance, by printing electronics in nanoscale and using newer materials such as graphene and other 2D materials.

Cyber security

The importance of cyber security cannot be stressed enough. Data integrity is vital in establishing and maintaining trust throughout the value chain. The proliferation of AI-based systems and services emphasises the importance of security and data protection. In some promising developments, next-generation key distribution and research in quantum computing and data transmission challenge current approaches to cryptographic algorithms – see *Quantum technologies: Blackett review* [12].

Validation and verification

Validation and verification – often complemented by visualisation – offer many potential uses without high associated prototyping costs. The development of systems engineering methods, tools and techniques will help to create better understanding between systems and systems of systems in complex scenarios. The quality assurance processes vary across sectors with medical, military, automotive and civil aerospace applications requiring electech products of very high integrity that can ensure reliability and functional safety under demanding conditions.

Human-machine interfaces

Human-machine interfaces will continue to play a major role because the main parts of monitoring and control functions are retained by humans. The focus will move away from user interfaces towards the user experience – how users feel about their interactions. Increasingly though, and as part of system-of-systems approaches, systems will act with a degree of autonomy combined with sophisticated communication to facilitate fast decision-making and response to dynamic situations and environments. The user interface-user experience element of deep technology is expected to be addressed in various initiatives.

“ ” Artificial intelligence (AI) is amongst the key enablers for electech technologies...

“ ”

Standards are key to the electech sector where interoperability is crucial

Standards

Standards are key to any industry, especially for the electech sector where interoperability is crucial. Standards create a common technical understanding and spread technologies through and between vertical industries. For example, this can be for manufacture of a component such as semiconductors or capacitors, allowing international trade and increasing the robustness of global supply chains. It can also be design of a system or provision of guidance on how to adopt a new technology, reducing barriers to entry and allowing smaller players to compete.

Not all new and disruptive technologies need new standards. Existing standards are kept up to date to ensure they take account of new developments. They could address concerns such as cyber security, which are being tackled with electech standards across industries from nuclear plant control and instrumentation to road vehicle communication.

Completely new standards are sometimes needed, for example for drones and the many applications of that technology. Standards are developed with industry and depend on commitment from individuals and employers. Standards help us do more together than we can do on our own. The electech sector needs to:

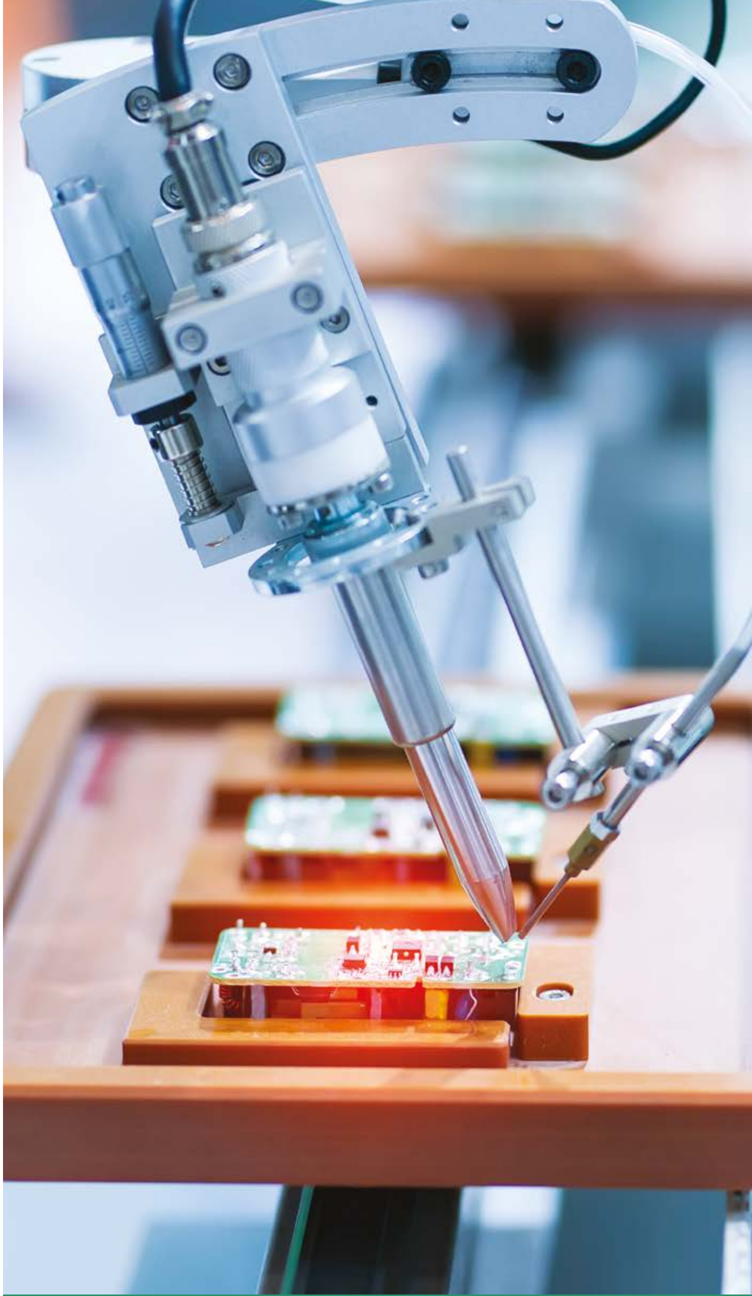
- continue contributing to consensus-based international standards
- ensure clear UK influence on the development of international standards
- grow awareness of the importance of electech standards in all vertical industries
- foster wider understanding of standards on safe data exchange, communication and interoperability as key to future society

Coordinated action is also needed around open source standardised communications protocols and around interoperability of different vendors’ products. This can be supported by establishing testbeds. There is also a need to engage with policy development, for example connecting vehicle electrification with the low-carbon agenda.

Skills

There is long-term demand for suitably educated and trained engineers and technicians in the electech sector. The UK will continue to benefit from the advanced systems and components research carried out at universities both through students finding employment in the sector and through a wide range of collaborative research and development and knowledge exchange programmes between industry and academia. It can take many years for changes in education curricula to work through to the market, so universities, further education colleges and industry must work together to design courses based on emerging needs.

The Engineering Professors Council [13] is already encouraging education innovation to, among other things, address industry involvement in framing skills requirements, preparing for greater crossing of academic boundaries, offering students experience of the workplace and ensuring broader diversity among students. Experienced-based learning through degree apprenticeships to supply job-ready graduates should also not be underestimated. Our changing relationship with the European Union means that it is likely we will need to develop alternative strategies for access to upcoming programmes such as Horizon Europe for UK researchers and businesses where international collaboration on research and development is essential to developing skills.

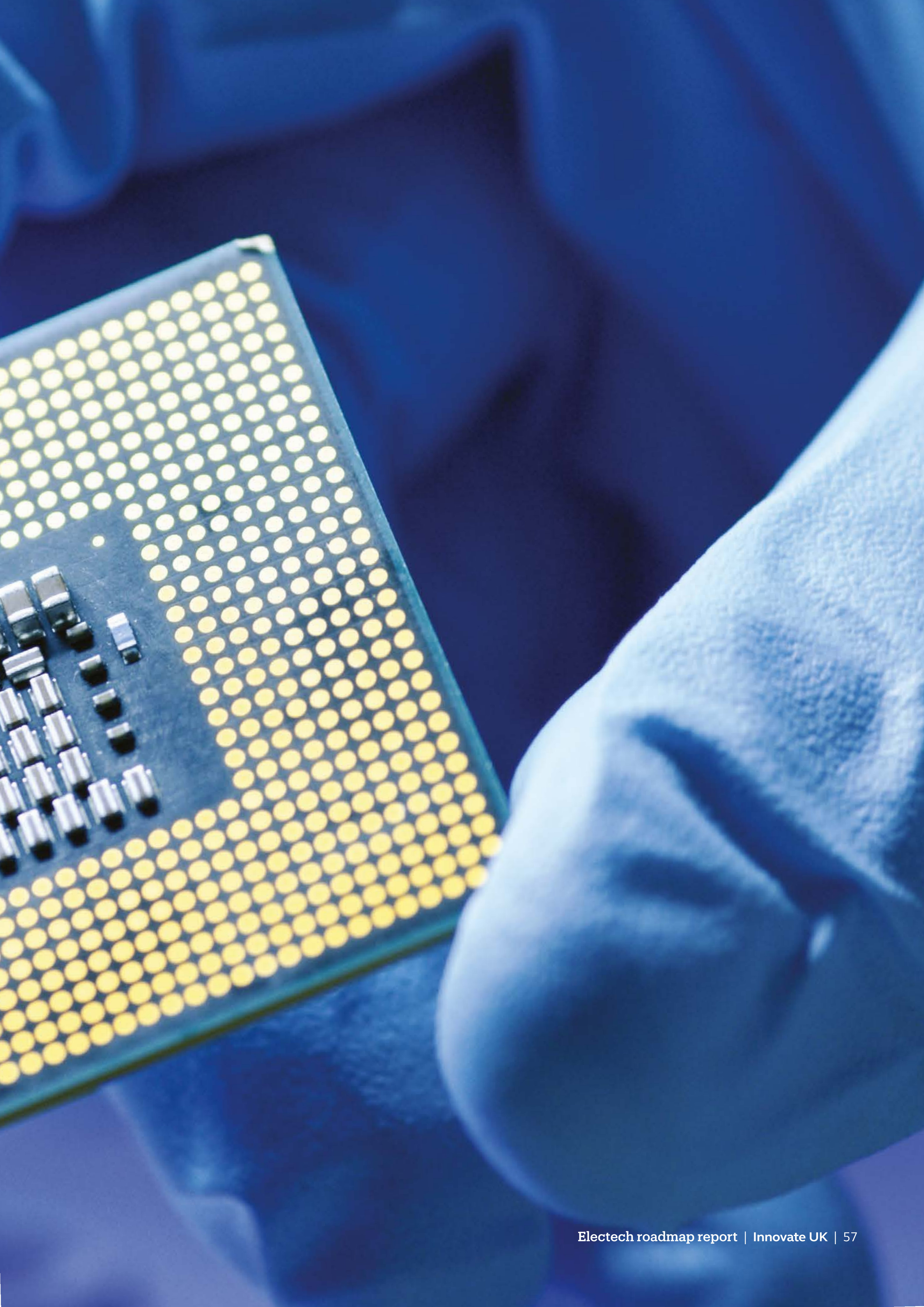


“”

Universities, further education colleges and industry must work together to design courses based on emerging needs

Sector views

This section is intended to help specific industry sectors to navigate the roadmap. It clarifies how each sector is recognised in the roadmap architecture. The sectors are those most mentioned during the consultation process as being critically dependent on electech



4.1 Aerospace

Trends and drivers

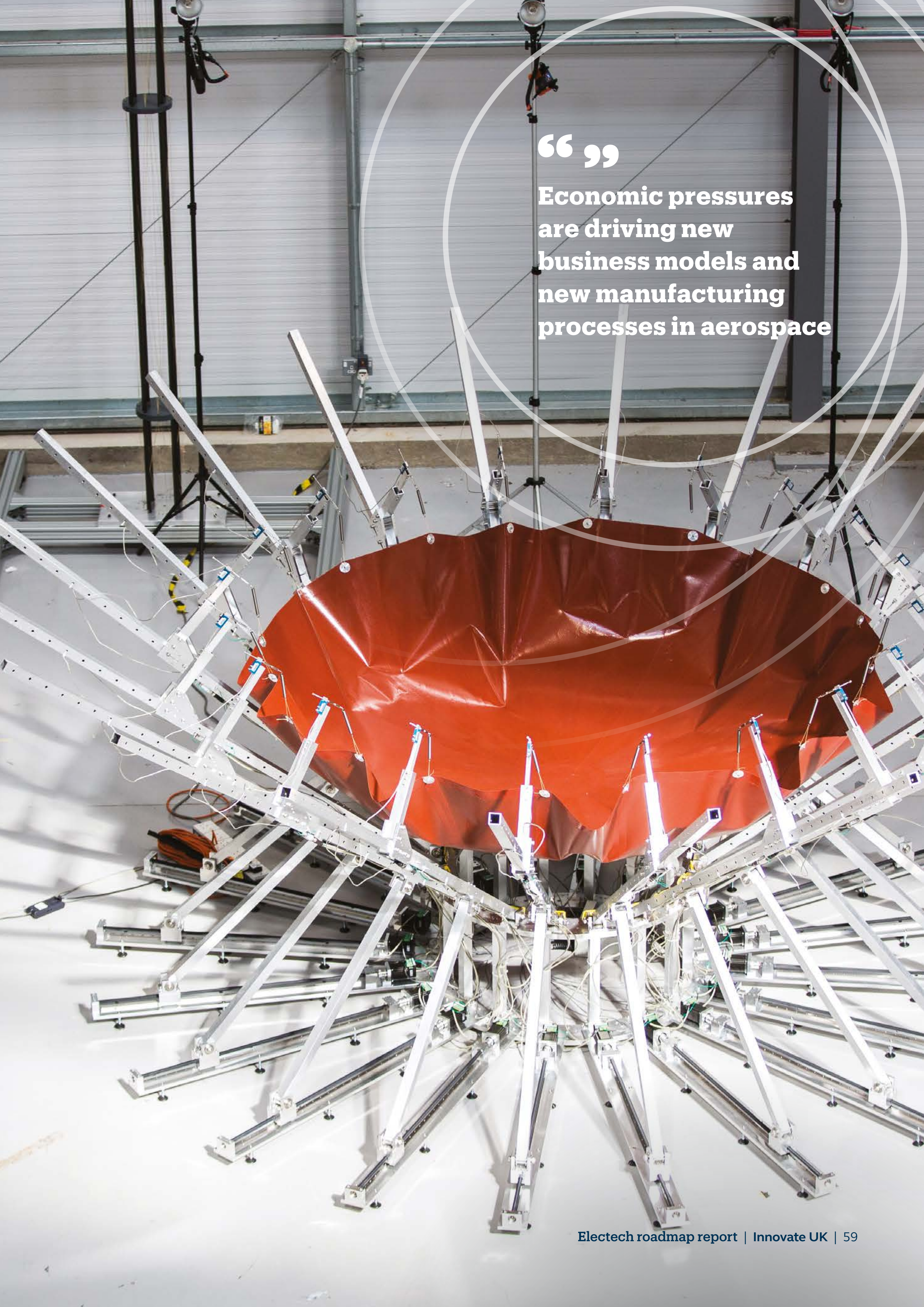
- growing environmental concerns and legislation leading to pressure for less polluting, lighter and quieter aircraft
- economic pressures driving new business models (for example power by the hour) and new manufacturing processes
- technology megatrends such as Industry 4.0, robotics and autonomy will encourage new approaches to manufacturing

Application areas

- transport and smart mobility: manned aircraft and autonomous and man-controlled drones; electric propulsion systems; increased on-board electrification of systems
- smart manufacturing: Industry 4.0/digital manufacturing solutions for more efficient and flexible production
- agile defence and security: advanced navigation, guidance and control systems both onboard and in air traffic control

System level capabilities

- sensing systems: all types from LIDAR to strain sensors for diagnostic data in flight and situational awareness for unmanned aerial vehicles; sensing systems in digital manufacturing processes
- embedded computing systems: data processing and analysis at the edge in wireless sensor networks, reducing the data transmission burden
- power management systems: to optimise consumption of electronic devices enabling longer lasting wireless sensing and data processing; to control and manage power in electronic aircraft control systems; advanced fly-by-wire and propulsion systems
- communication systems: to transmit critical data for a fully monitored aircraft; for interacting elements of a digital manufacturing facility
- autonomous systems: to control aspects of flight and for navigation of unmanned aerial vehicles; robotics in digital factories



"

Economic pressures are driving new business models and new manufacturing processes in aerospace

"

4.2 Automotive

Trends and drivers

- environmental impact, safety and the need to move people in an increasingly congested world
- cost pressures driving increasingly tightly integrated supply chains and manufacturing processes
- technology megatrends of Industry 4.0, IoT, robotics, autonomy and increased integration will have a major impact on automotive vehicle manufacture and operation
- smart and electrified vehicles manufactured using smart technologies and processes and operating in a smart traffic management environment

Application areas

- transport and smart mobility: autonomous vehicles; electric propulsion and battery development; smart transport infrastructure and systems; mobility as a service
- renewable energy and smart grids: vehicle charging infrastructure
- smart manufacturing: Industry 4.0/digital manufacturing solutions for more efficient and flexible production (mass customisation)
- smart cities and communities: connecting people and urban infrastructure with the vehicles of the future

System level capabilities

- sensing systems: for navigation, advanced driver-assistance systems and performance monitoring; for traffic management; for smart manufacturing
- embedded computing systems: to process on-board data that will grow around one hundred fold with greater levels of autonomy; for smart manufacturing; for traffic management
- power management systems: to deliver optimum power usage within the microprocessors and to manage power delivery; for smart manufacturing
- communication systems: to allow vehicles to coordinate with other vehicles and traffic management systems; for smart manufacturing
- autonomous systems: to deliver higher level control; essential for robotics in smart manufacturing

“ ”

Technology megatrends of Industry 4.0, IoT, robotics, autonomy and increased integration will have a major impact on automotive vehicle manufacture and operation

4.3 Healthcare

Trends and drivers

- ageing population and the resulting economic burden on government and society
- need to rethink delivery models and use of technology, including providing services away from hospitals and clinics and people becoming more involved in their own health and wellbeing
- technology megatrends: secure AI-driven analytics; ubiquitous IoT type monitoring; evolution of consumer electronics to deliver very advanced functionality at affordable cost

Application areas

- personalised health and smart diagnostics: significant improvements in monitoring patients inside and outside the clinic; use of technology to encourage healthier lifestyles; cost advantages of consumer electronics developments; longer lasting batteries or energy harvesting technologies; new remote and non-invasive diagnostic sensing approaches; data analytics, for example machine and deep learning for greater insights from data; data security, particularly for wearables and telemedicine; centralised diagnostic imaging and analysis techniques with novel imaging techniques coming from sectors such as high energy physics
- smart manufacturing: mass customisation of medical devices and products and more efficient, reconfigurable production processes; increased use of models and simulation to improve design
- smart cities and communities: smart environments respond to people's health needs in their own homes and in urban areas

System level capabilities

- sensing systems: ranging from basic motion and position sensing devices through to sophisticated medical imaging systems capable of levels of resolution and discrimination way beyond the current state of the art; improved data processing using AI approaches
- embedded computer systems, power management systems and communication systems: improvements to allow efficient edge processing of data and management of information shared with the healthcare system
- autonomous systems: robotic surgery; AI to inform and make more routine diagnostics

> **Technology trends will enable new services for people to become more involved in their own health and wellbeing**

4.4 Manufacturing

Trends and drivers

- cost and efficiency improvements to maintain global competitiveness
- evolution of business models and manufacturing processes
- greater levels of automation and integration of supply chains driving on-shoring and re-shoring of production for companies that would previously have sought low-labour-cost destinations
- pressure to reduce waste and impact and use less energy
- skills shortages hastening the moves to greater automation
- technology trends: increased use of robotics; IoT; computer simulation and digitalisation of production; emerging manufacturing techniques, notably additive manufacturing and its dependence on digital input and control

Application areas

- smart manufacturing: Industry 4.0 or Made Smarter digital manufacturing for more flexible, efficient and profitable production; increased use of data and digital process control; industrial IoT for monitoring, measuring and gathering of vast data sets to provide insights into efficiencies, plant condition and safety; AI and cloud computing to make sense of data; digital control and digital processes such as laser-based marking, welding, cutting and processing; additive layer manufacturing allowing mass customisation of products; reconfigurable processes and digital supply chains to meet flexible demand; robotics; visualisation, modelling and simulation in the form of digital twins for new levels of process and product design, operation and optimisation; safer working through human-robot cooperation and autonomous systems
- other application areas: manufacturing is relevant to all areas of the roadmap that need products including customised low-cost wearable medical devices, autonomous vehicles, electric aircraft engines, military equipment, traceable processed food, and smart packaging; manufacturing of electech components, sub-systems and systems

System level capabilities

- sensing systems: increasingly required to provide data on processes and on equipment condition for control automation, inspection and maintenance; built into products to monitor usage and feed back into future product development; extensive use of networked and wireless sensors for industrial IoT
- power management systems: optimisation of energy use; for greater lifetime either between battery changes or from energy harvesting of ambient sources; cloud computing; visualisation (VR and AR); modelling and simulation
- communication systems: data transmission
- embedded computing systems: intelligent data processing at the node (computing at the edge) prior to transmission to optimise this power-demanding step; chip technologies for cloud computing; visualisation (VR and AR); modelling and simulation
- autonomous systems: advanced robotics to improve production and safety

> Manufacturing will see increased use of robotics, industrial IoT, computer simulation and digitalisation of production

4.5 Consumer and retail

Trends and drivers

- growing ubiquity of smart and communicating devices in all aspects of life and the demand for connection, inclusivity, convenience, entertainment, safety and security from mobile services
- ageing population driving demand for more affordable and easily accessible health and support outside of traditional clinic, including adoption of wearable technologies for measuring wellness and fitness
- environmental concerns driving adoption of smart devices to improve energy and water efficiency
- technology megatrends: new classes of smart products and services including faster and more reliable communications with greater bandwidth; IoT, 5G and optical communications; artificial intelligence; robotics; virtual and augmented reality for improved gaming, online shopping, care, education and domestic help; manufacturing including 3D printing and mass customisation

Application areas

- personalised health and smart diagnostics: wearable smart health and fitness products; monitoring for assisted living at home
- renewable energy and smart grids: smart devices integrated into smart grids to help reduce energy and water use
- transport and smart mobility: consumer devices and services interacting with the vehicles and systems that move them about; mobility as a service with bespoke personal requirements
- smart cities and communities: connections to the physical environment and a virtual environment for entertainment, education and essential services
- smart manufacturing: mass customisation through additive manufacture and smart reconfigurable factories
- facial and 3D recognition for enhanced security and convenience

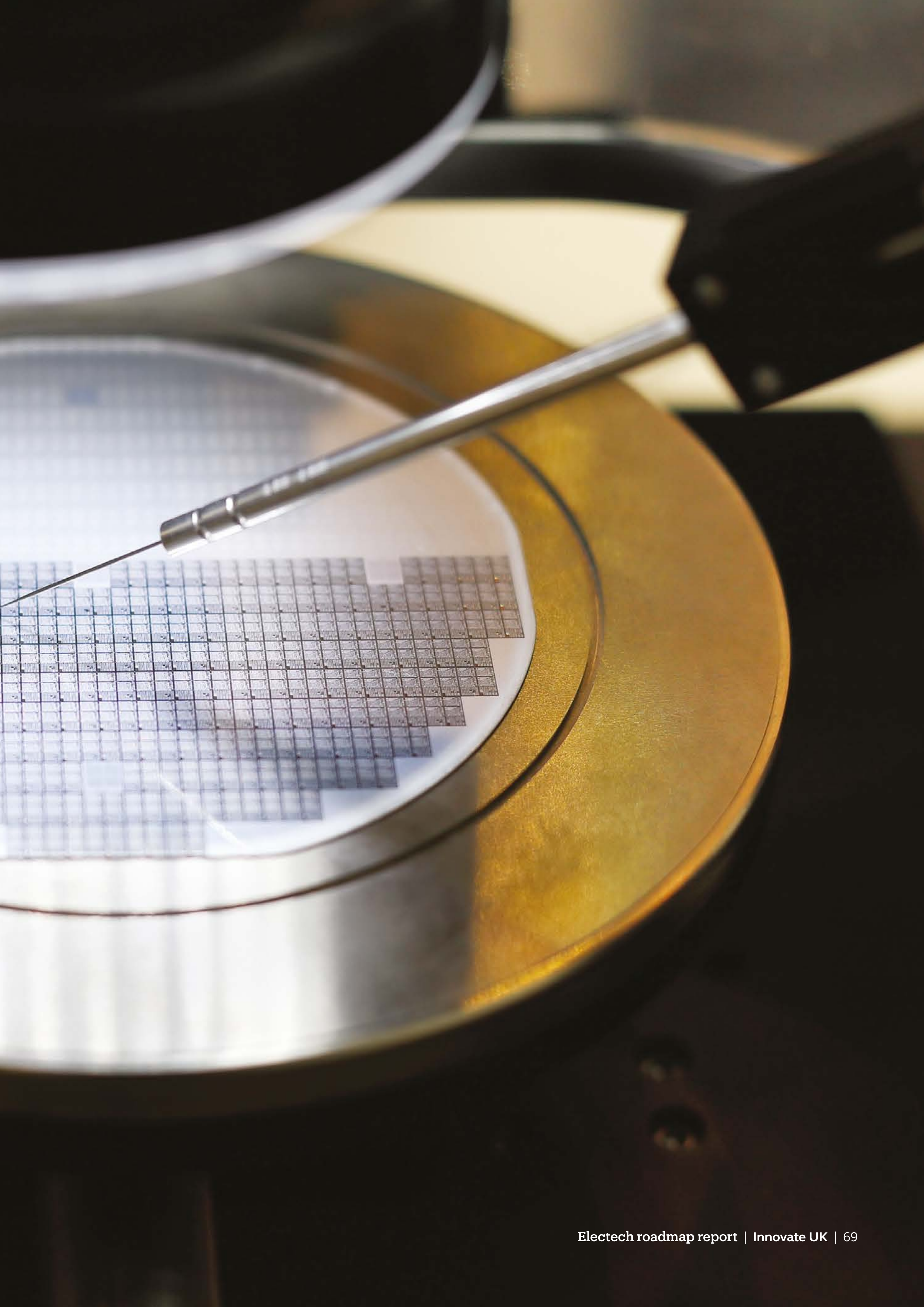
System level capabilities

- sensing systems: health and wellbeing data; location and positional awareness; data on resource usage and on operation of smart factories
- power management systems: optimisation of power use in wireless devices
- embedded computing systems: conversion of data into useful information
- communication systems: optical fibre technologies to connect access points, high-throughput connectivity between and within datacentres and storage; datacentres required to meet challenges of different operating environments and rapid growth
- autonomous systems: human interaction with smart solutions at home, work and play including autonomous vehicles, autonomous robotics, and AI-enabled voice-based digital assistants

Internet of Things, 5G, optical communications, artificial intelligence, robotics, and virtual and augmented reality are allowing new classes of smart products and services

Recommendations

The following recommendations are supported by the roadmapping activities and consultations with industry and their representative bodies



The electech sector should:

- improve promotion of enabling electech technologies to all UK industry sectors as a way to deliver innovation and increase productivity and competitiveness in a skills-scarce environment
- orchestrate its sub-sectors to work more closely together and frame their long-term individual and collective interests in a common vision
- develop a comprehensive measure of its composition, scale and economic impact, both nationally and regionally
- work more closely with universities and further education colleges for the design and delivery of higher education courses to address skills gaps and encourage students to enhance their skills and employability through work placements and relevant projects

UK industries should:

- consider innovation in electech technologies when drawing up their strategies and roadmaps and when seeking support from government
- invest in realising the cross-cutting benefit of electech technologies in new application areas
- ensure acceptance of UK electech in international markets through continued UK influence in development of international standards that support safe data exchange, communication, interoperability, compliance and testing

Government should:

- recognise the cross-cutting role electech technology will play in delivering the Industrial Strategy's grand challenges and the associated Industrial Strategy Challenge Fund programmes
- support research and development in electech to meet the challenge of integrating technologies into systems, of providing demonstrator and test facilities and of developing longer term programmes for new strategic electech capabilities that will have wider applicability across UK industry sectors
- promote UK excellence in electech abroad to support exports and international collaboration in research and innovation
- develop ambitious public-private partnerships to invest in capital intensive plant facilities and advanced manufacturing processes using the compound semiconductors cluster in South Wales as an example
- work with the electech sector to address skills shortages by promoting and extending activities that encourage more young people from more diverse backgrounds to study electech science and engineering disciplines and to pursue engineering careers in the sector

“ ”

The electech sector should improve promotion of enabling electech technologies to all UK industry sectors

References

1. Department for Business, Energy and Industrial Strategy. December 2017. ***Analysis of companies involved in the Electronic Systems Community (ESCO)***. [https://www.gov.uk/government/statistics/electronics-systems-community-esco-update-to-bis-analysis-of-companies]

2. Photonics leadership Group. May 2018. ***UK Photonics: The Hidden Economic Engine***. [https://photonicsuk.org/wp-content/uploads/2018/05/UK_Photonics_The_Hidden_Economy.pdf]

   UK Photonics industry data 2019 [https://photonicsuk.org/uk-photonics-output-increases-to-13-5-billion]

3. ECSEL Joint Undertaking. [https://www.ecsel.eu/]

4. Strategic Research Agenda for Electronic Components & Systems. 2018. [http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=50145]

5. Photonics 21 European Technology Platform [https://www.photonics21.org/]

6. DARPA June 2017. DARPA Electronics Resurgence Initiative. [https://www.darpa.mil/work-with-us/electronics-resurgence-initiative]

7. BEIS, 2017. ***Patient Capital Review – Industry Panel Response,*** [https://www.gov.uk/government/publications/patient-capital-review]

8. EngineeringUK. ***EngineeringUK 2016***, page 262. [https://www.engineeringuk.com/media/1472/engineeringuk-report-2016-full-report.pdf]

9. UK Electronics Skills Foundation, 2018. ***Compound Semiconductor Skills Survey***. [https://www.ukesf.org/news/compound-semiconductor-skills-survey-2018/]

10. Department for Business, Energy and Industrial Strategy November 2017. ***Industrial Strategy: building a Britain fit for the future***. [https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future]

11. Institute for Manufacturing, University of Cambridge. [https://www.ifm.eng.cam.ac.uk/ifmecs/business-tools/roadmapping/roadmapping-at-ifm/]

12. Government Office for Science, 2016. ***Quantum technologies: Blackett review.*** [https://www.gov.uk/government/publications/quantum-technologies-blackett-review]

13. Engineering Professors Council, 2018. ***New Approaches to Engineering HE: The Six Facets***. [http://epc.ac.uk/new-approaches-to-engineering-he-the-six-facets/]. ***Experience Enhanced: Improving engineering degree apprenticeships***. [http://epc.ac.uk/experience-enhanced/]

14. Embedded system, Wikipedia [https://en.wikipedia.org/wiki/Embedded_system]

Annex 1:

Supporting documents and links used in the roadmap exercise

1. The Electech Council. [http://www.electechuk.net]
2. Trade Association for Instrumentation, Control, Automation and Laboratory Technology in the UK. [http://www.gambica.co.uk]
3. Centre of Excellence for Sensing and Imaging Systems. [https://censis.org.uk/]
4. Technology Scotland. [https://www.technologyscotland.scot]
5. TechWorks. [https://www.techworks.org.uk/]
6. Department for Business, Energy and Industrial Strategy, 2016. ***South West England and South East Wales Science and Innovation Audit.*** [http://gw4.ac.uk/sww-sia/]
7. Power Electronics UK, 2017. ***Driving Innovation in Power Electronics Across the UK Community***. [https://www.power-electronics.org.uk/]
8. Department for Business, Energy and Industrial Strategy, 2018. ***The Grand Challenges***. [http://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/industrial-strategy-the-grand-challenges]
9. UK Research and Innovation. Industrial Strategy Challenge Fund. [http://www.ukri.org/innovation/industrial-strategy-challenge-fund]
10. Engineering UK, 2016. ***The State of Engineering***, page 262. [https://www.engineeringuk.com/media/1472/engineeringuk-report-2016-full-report.pdf]
11. Electronic Components and Systems for European Leadership (ECSEL), 2017. ***Multi Annual Strategic Research and Innovation Agenda for ECSEL Joint Undertaking***. [https://artemis-ia.eu/publication/download/masria2017.pdf]
12. AENEAS, 2016. ***Strategic Agenda. Guideline for Pan-European R&D&I Co-Operation in the Electronics Value Chain***. [https://www.penta-eureka.eu/downloads/aeneas-strategic-agenda-final-web-low-res.pdf]
13. ARTEMIS Industry Association (for cyber physical systems), 2016. ***Strategic Research Agenda***. [https://artemis-ia.eu/publication/download/sra2016.pdf]
14. EURIPIDES2, 2013. ***Vision, Mission and Strategy***. [https://www.euripides-eureka.eu/vms-form]
15. EURIPIDES2. EUREKA Initiative for Packaging & Integration of µDevices & Smart Electronic Systems. [https://www.euripides-eureka.eu/]
16. EPoSS, 2017. ***Strategic Research Agenda***. [https://www.smart-systems-integration.org/news/eposs-strategic-research-agenda-download]
17. EPoSS, 2014. ***Roadmap Automated Driving***. [https://www.smart-systems-integration.org/publication/eposs-roadmap-automated-driving-2014]
18. Power Electronics UK, 2017. ***Driving Innovation in Power Electronics Across the UK Community - A Route Map to Success. White Paper***. http://nlophitis.info/wp-content/uploads/2017/03/Powerelectronics-UK-Technology-White-Paper-28-03-2017.pdf]
19. ERTRAC, EPoSS and SMARTGRIDS, 2017. ***European Roadmap Electrification of Road Transport***. [https://www.etip-snet.eu/wp-content/uploads/2017/09/ERTRAC_ElectrificationRoadmap2017.pdf]
20. UK National Quantum Technologies Programme, 2015. ***A roadmap for quantum technologies in the UK***. [https://epsrc.ukri.org/newsevents/pubs/quantumtechroadmap/]
21. OE-A (Organic and Printed Electronics Association), 2017. ***OE-A Roadmap for Organic and Printed Electronics 7th Edition***. [https://oe-a.org/]
22. OE-A (Organic and Printed Electronics Association), 2013. ***A European strategy for Organic and Large Area Electronics (OLAE) Vision paper***. [https://oe-a.org/]
23. Journal of Optics, 2016. ***Roadmap of optical communications***. [https://iopscience.iop.org/article/10.1088/2040-8978/18/6/063002]

24. Photonics NL, 2018. ***Photonics Roadmap 2015-2019***. [https://www.photonicsnl.org/]

25. Institute of Physics, 2018. ***The health of photonics***. [https://www.iop.org/publications/iop/2018/file_71498.pdf]

26. European Technology Platform Photonics21, 2018. ***Europe's age of light! How photonics will power growth and innovation***. [https://www.photonics21.org/download/news/2017/Photonics21-Vision-Paper-Final.pdf]

27. CPSS Transactions on Power Electronics and Applications, Vol 2, No 4, December 2017, ***Empowering the Electronics Industry: A Power Technology Roadmap***. [https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8283421]

28. PowerAmerica, 2017 and 2018. ***PowerAmerica Strategic Roadmap for Next Generation Wide Bandgap Power Electronics***. [https://powerAmericainstitute.org/wp-content/uploads/2018/02/PowerAmerica_Roadmap_Final-Public-Version-February-2018.pdf] [https://www.poweramericainstitute.org/wp-content/uploads/2017/01/PowerAmerica_Roadmap_Final-Public-Version-January-2017.pdf]

29. Automotive Council UK and Advanced Propulsion Centre UK, 2017. ***Power Electronics Roadmap***. [https://www.apcuk.co.uk/app/uploads/2018/02/PE_Full_Pack.pdf]

30. Automotive Electronics Innovation (AESIN), 2018. ***UK Automotive Electronics Capability Report***. [http://2pe5rtjld2w41m0dy17n5an1-wpengine.netdna-ssl.com/wp-content/uploads/2018/06/UK-Automotive-Electronics-Capability-Report-2018_July_lr.pdf]

31. Made Smarter Review, 2017. [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/655570/20171027_MadeSmarter_FINAL_DIGITAL.pdf]

32. Automotive Council, 2017. ***UK Automotive Technology Roadmaps***. [https://www.automotivecouncil.co.uk/technology-group-2/automotive-technology-roadmaps/]

33. NASA, 2015. ***NASA Technology Roadmaps TA 4: Robotics and Autonomous Systems***. [https://www.nasa.gov/sites/default/files/atoms/files/2015_nasa_technology_roadmaps_ta_4_robotics_autonomous_systems.pdf]

34. Department for Business, Energy and Industrial Strategy, 2017. ***Enabling Technologies in Scotland's Central Belt***. [http://glasgoweconomicleadership.com/wp-content/uploads/GEL-SIA-main-report-FINAL-201708.pdf]

35. Electronic Systems Challenges & Opportunities (ESCO), 2013. ***Imagine a World Without Electronics. The ESCO Report: A Blueprint for UK Economic Growth***. [http://electechuk.net/wp-content/uploads/2017/08/ESCO-Report-FINAL.pdf]

36. Department for Business, Energy and Industrial Strategy, 2017. ***Industrial Strategy: Sector Deals – Policy Paper***. [https://www.gov.uk/government/publications/industrial-strategy-sector-deals/introduction-to-sector-deals]

37. Electronic Systems Challenges & Opportunities (ESCO), 2014. ***Imagine a World Without Electronics. The ESCO Report: Electronic Systems a Plan for Growth: One Year On***. [http://electechuk.net/wp-content/uploads/2017/08/ESCO-Annual-Report-2014.pdf]

38. The ElecTech Council, 2017. ***The ElecTech Council Response to the "Building an Industrial Strategy" consultation green paper***. [http://electechuk.net/wp-content/uploads/2017/08/ElecTech-Industrial-Strategy-Consultation-v1_1-19apr2017.pdf]

39. Independent High-level Group on Industrial Technologies, 2018. ***Re-finding Industry – Defining Innovation***. [https://publications.europa.eu/en/publication-detail/-/publication/28e1c485-476a-11e8-be1d-01aa75ed71a1]

40. Quantum Technologies Strategic Advisory Board, 2015. ***National strategy for quantum technologies***. [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/414788/Strategy_QuantumTechnology_T15-080_final.pdf]

41. Semiconductor Industry Association, 2015. ***International Technology Roadmap for Semiconductors***. [https://www.semiconductors.org/resources/2015-international-technology-roadmap-for-semiconductors-itrs/]

42. Institute for Manufacturing, 2016. ***High Value Manufacturing Landscape 2016 Interim Report***. [https://www.ifm.eng.cam.ac.uk/insights/national-innovation-policies/high-value-manufacturing-landscape-2016-interim-report-/]

43. Smartare Elektroniksystem för Sverige, 2016. ***Roadmap for Smarter Electronics Systems***. [https://www.smartareelektroniksystem.se/wp-content/uploads/sites/29/2016/03/ECS-Roadmap-2016.pdf]

44. SPARC The Partnership for Robotics in Europe, 2015. ***Robotics 2020 Multi-Annual Roadmap For Robotics in Europe***. [https://www.eu-robotics.net/cms/upload/downloads/ppp-documents/Multi-Annual_Roadmap2020_ICT-24_Rev_B_full.pdf]

45. HM Government, 2013. ***A UK Strategy for Agricultural Technologies***. [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/227259/9643-BIS-UK_Agri_Tech_Strategy_Accessible.pdf]

46. EASE/EERA, 2017. ***European Energy Storage Technology Development Roadmap***. [https://eera-es.eu/wp-content/uploads/2016/03/EASE-EERA-Storage-Technology-Development-Roadmap-2017-HR.pdf]

47. European Commission, 2018. ***Boosting Electronics Value Chains in Europe***. [file:///C:/Users/Derek/Downloads/BoostingElectronicsValueChainsinEuropepdf.pdf]

48. Transport Systems Catapult, 2017. ***Market Forecast for Connected and Autonomous Vehicles***. [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/642813/15780_TSC_Market_Forecast_for_CAV_Report_FINAL.pdf]

49. NEREID, 2017. ***Nanoelectronics Roadmap for Europe***. [https://www.nereid-h2020.eu/system/files/ct_publication/nereid_d7.4_dissemination-plan_final.pdf]

50. European Commission, 2017. ***Study on the dual-use potential of Key Enabling Technologies***. [https://ec.europa.eu/growth/content/report-dual-use-potential-key-enabling-technologies-identification-strategic-areas-eu-0_en]

51. DECISION Etudes & Conseil 2018, publication pending. ***Study on the electronics ecosystem: Overview, Developments and Europe's Position in the World***. [http://www.decision.eu/wp-content/uploads/2016/09/EFECS_DECISION_KeyFindingsrecommendations.pdf]

Annex 2:

Contributors to the roadmapping workshops and consultations

- 2 Insight Ltd
- 4Ax Technologies Ltd
- AESIN
- Alker Optical Equipment
- Alphasense
- Analog Devices
- ARM
- BAE Systems
- BEAMA
- BSI
- BT
- Cambridge Consultants
- CENSIS
- Centre for Process Innovation
- Compound Semiconductor Applications Catapult
- Compound Semiconductor Centre
- Compound Semiconductor Technologies
- Cornucopia Capital
- CRRC Times Electric
- Department for Business, Energy and Industrial Strategy
- Department for International Trade
- DSTL
- ElecTech Council
- Embecosm
- EPSRC
- FTI Communication Systems Ltd
- GAMBICA
- GE Power Conversion
- GRIDSERVE
- Honeywell
- HORIBA MIRA Limited
- Imagination Technologies
- Innovate UK
- Institute for Manufacturing (IfM), University of Cambridge
- Institution of Engineering and Technology
- IQE plc
- Knowledge Transfer Network
- Leonardo
- M2 Lasers
- Manufacturing Technology Centre
- Mitsubishi Electric
- PCME
- Photonics Leadership Group / Harlin
- Plextek
- PragmatIC
- QinetiQ
- Queen Mary University
- Renfrew Group International

- Renishaw
- Riello UPS
- Rolls Royce
- Safran Electrical and Power UK
- Safran Group
- Science and Technology Facilities Council
- SemiMetrics Ltd
- Sensing Innovation Leadership Council (SILC)
- Sensor City
- Sensors Innovation Leadership Council
- Siemens
- SolutionsPT
- Sony
- SouthCoast Science
- SP Energy Networks
- Syngenta University Innovation Centre
- Technology Scotland
- TechWorks
- Teledyne e2v
- Thales
- The Future Photonics Hub
- The Technology Partnership plc
- UK Defence Solutions Centre
- UK Electronics Skills Foundation
- University of Glasgow
- University of Greenwich
- University of Manchester
- University of Sheffield
- Vertizan
- Vodera Ltd
- Zartech Ltd

Innovate UK drives productivity and economic growth by supporting businesses to develop and realise the potential of new ideas, including those from the UK's world-class research base. We connect businesses to the partners, customers and investors that can help them turn ideas into commercially successful products and services and business growth.

We fund business and research collaborations to accelerate innovation and drive business investment into R&D. Our support is available to businesses across all economic sectors, value chains and UK regions.

Innovate UK is part of UK Research and Innovation, a non-departmental public body funded by a grant-in-aid from the UK government.
For more information visit www.ukri.org.

Innovate UK

Telephone: 01793 361000
Email: support@innovateuk.ukri.org
www.innovateuk.ukri.org

Follow us

18.1136.086

September 2019