Technology Strategy Board
Driving Innovation

Electronics, Photonics and Electrical Systems

Key Technology Area

2008-2011

The vision of the Technology Strategy Board is for the UK to be a global leader in innovation and a magnet for innovative businesses, where technology is applied rapidly, effectively and sustainably to create wealth and enhance quality of life.

Our three-year strategy for 2008-2011 is to drive innovation by **connecting** and **catalysing**. To achieve this we are focusing on three themes: challenge-led innovation, technology-inspired innovation and the innovation climate. For more information on the overall strategy see **www.innovateuk.org.**

We have identified a number of key application areas and key technology areas on which to focus, and for which we are developing specific area strategies.

This document presents the strategy for the key technology area of **Electronics, Photonics and Electrical Systems.**

The Technology Strategy Board would like to thank the electronics, photonics and electrical systems community for their help in preparing this strategy document.

Foreword

The Technology Strategy Board is a new organisation with a new vision and ambition to make the UK a global leader in innovation. Our job is to ensure that the UK is in the forefront of innovation enabled by technology.

Our task at the Technology Strategy Board is to "Connect and Catalyse". As part of our challenge-led approach to innovation we treat societal and economic challenges of the future not just as threats but as opportunities for innovative solutions that enhance the quality of life and increase wealth.

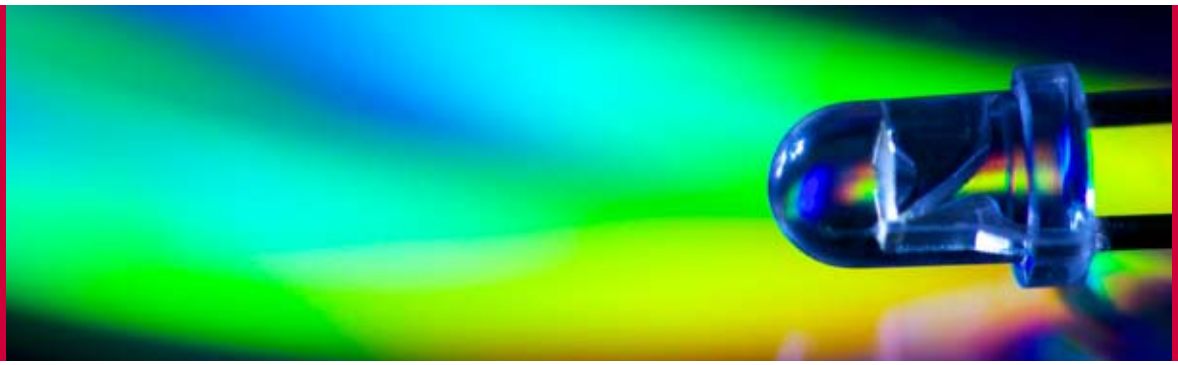
The world is changing. Globalisation, digital communications and the growth of emerging economies present profound challenges to UK business sectors. Yet where there are challenges there are also opportunities. Open access to global supply networks and emerging markets is easier than ever before; the highly skilled UK workforce, world class science base and open-market philosophy also puts us in a strong position.

Electronics, Photonics and Electrical Systems technologies underpin products and services across the economy, and enable wealth generation in a wide range of markets and applications such as transport, healthcare and energy. Our analysis has shown the UK is in a strong global position, but more needs to be done. We see opportunities in areas such as reducing energy consumption, enabling intelligent environments, improving communications and exploiting the promise of plastic electronics.

This strategy identifies technology themes which will help UK businesses to collaborate and exploit their world-class capabilities. I welcome its technology-inspired approach, focused through key challenge areas. I also recognise the substantial value of a system level approach, where individual components and associated supply chains combine into a solution that meets the end-users' purposes.

This document closely aligns with our Information and Communication Technology strategy; both are part of our wider technology portfolio, and will provide the foundations for our work in this area in the 2008-2011 period. We are looking forward to working in partnership with key players in innovative businesses and making our contribution to wealth creation in the UK. Most importantly, I am excited by the technology opportunities for UK businesses in Electronics, Photonics and Electrical Systems.

Iain Gray
Chief Executive, Technology Strategy Board



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Executive summary

The availability of electronics and electrical systems has changed the way that society conducts its everyday life, from computers through to electric motors. This ability to harness the potential of the electron is now being matched by the control of light in the field of photonics, from general lighting itself through to lasers in DVD players and supermarket checkouts. It is a common misconception that these industries have disappeared from the UK, especially from a manufacturing perspective, but this is not the case; they have just evolved.

Whether through power supply, sensors, invisibly embedded systems, lasers or displays, the Key Technology Area (KTA) of Electronics, Photonics and Electrical Systems (EPES) underpins activity in all industrial sectors and throughout the consumer market. Global markets for electricity ($1.2 trillion), electronic products ($2.0 trillion) and photonics products ($0.6 trillion) all continue to expand strongly. $260 billion of this is accounted for by semiconductors, with 900 million transistors being produced every year for every man, woman, and child on Earth. The UK is well placed to profit from these markets, as it benefits from a strong science base and a long tradition of inventiveness in the uses of electricity and light.

UK business – at a glance:

- EPES manufacturing employs more than 330,000 people in 14,000 UK businesses, with £42 billion turnover. This is 10% of UK manufacturing industry.
- EPES distribution, wholesaling and retail adds £73 billion and electricity transmission and distribution a further £55 billion.
- The value added by these activities totals 4% of GDP, with telecommunications adding a further 2%, and EPES technology underpins activity throughout the remainder of the economy.
- The UK boasts nearly a third of Europe's silicon design companies – three times as many as either France or Germany.

The Technology Strategy Board recognises the importance of these technologies to the UK economy, and will continue to champion a sector that received over £114 million of investment from the Technology Programme during 2004-8. The economic benefits (the goal of the UK's EPES strategy) can be achieved by developing ideas from the science base into industrially relevant new EPES technologies, and onwards to become products in the marketplace; but they can also be achieved by the adoption of existing technologies into new applications in the healthcare, transport, energy, retail and environmental sectors. This benefits both the technology providers in the device industries and the technology adopters in the end-use markets.

The EPES sector should always be looking for technology with an identifiable route to market. Those areas, where technology push and market pull are both evident, are of particular interest and provide persuasive arguments for Technology Strategy Board intervention.

This UK strategy has identified five technology pillars for investment, where Technology Strategy Board involvement will have a significant and lasting impact on the UK economy:

- Control systems and power engineering
- Plastic and printed electronics
- Data and image acquisition
- Communications
- Systems design and integration.

Control systems and power engineering

Management of electrical power consumption across the EPES spectrum brings benefits to the energy sector, to users of electric power and to the environment [1]. Improvements in device efficiency and system design have a part to play, such as low voltage "solid-state" lighting technologies that promise new levels of efficiency and versatility. In addition, sensing and electronic technologies can provide the intelligence to coordinate electricity demand and supply throughout industrial, commercial and domestic environments.

The Technology Strategy Board will:

- encourage the development of ultra-efficient lighting technologies and the deployment of products based upon them;
- apply expertise from the EPES Key Technology Area to the challenges within the Low Impact Buildings and Low Carbon Vehicles Innovation Platforms and more generally, for example to reduce power consumption in manufacturing environments; and
- promote transfer of energy efficiency technologies between industrial, transport and built environment sectors.

Plastic and printed electronics

The UK has a world lead in organic semiconductors and the creation of circuits on flexible materials, and this may lead to new generations of display and lighting technologies as well as electronic devices created on demand, so cheaply that they are high volume commodity items. The challenges ahead include the development of scalable manufacturing technologies and construction of a value chain that retains wealth creation opportunities in the UK.

The Technology Strategy Board will:

- act as a focal point for analysis of the plastic and printed electronics value chain, and for identifying the opportunities for wealth creation in the UK;
- link technology providers in the sector to end users, business leaders and creative designers, to provide a joint understanding to ensure exploitation of market and product opportunities; and
- having identified the barriers to UK wealth creation, stimulate innovation to overcome them.

Data and image acquisition

The UK boasts a wealth of expertise in sensor, imaging and laser technology. Combined with the UK's considerable design expertise, these enable increased functionality and underpin wealth creation in diverse sectors of the economy. As examples of the future opportunities, the integration of location sensing into transport systems, logistics and mobile devices will lead to new services and operational models, whilst the networking of context-aware devices leads to 'smart environments' that are responsive to user needs and offer services and capabilities that are impossible today.

The Technology Strategy Board will:

- ensure that the potential of existing sensing and imaging technologies are promoted to potential end users;
- maximise the potential of these underpinning technologies by stimulating cross-sectoral links between application domains and the fusion of complementary sensing elements; and
- encourage the development and exploitation of location-based technology for consumer and business applications, including the challenges set by the Intelligent Transport Systems and Services Innovation Platform.

Communications

The ever increasing demand for fixed line and wireless bandwidth at a cheaper user cost requires further innovation and integration of hardware and software, as well as the development of regulatory and business models that are supportive of infrastructure investment. The rewards on offer are an information-rich society, with immersive learning and leisure environments, continuous connectivity and informed decision processes, all enabled by developments in photonics and high-frequency electronic power systems.

The Technology Strategy Board will:

- champion the benefits of high bandwidth Next Generation Access (1Gb/s and beyond), to position the UK as a world leader in the forthcoming communications revolution, and act to ensure that UK technology is available to support its low-cost deployment; and
- encourage development of systems and services based on wireless communications technologies to enable smart environments.

Systems design and integration

The pull of technology-intensive end-use markets, such as transport and healthcare, needs system-level design for applications that transcend traditional areas of specialism, and requires cooperative development of hardware and software. For example a laser guidance system builds on the enabling photonics and electronics for drive and control to provide a packaged solution that can cope with harsh environments and work at the push of a button. The UK is a centre of such design knowledge, and with Technology Strategy Board investment is well-placed to leverage this and embed new capabilities into a wide range of products.

The Technology Strategy Board will:

- promote a systems engineering approach to product design;
- inspire electronics and software designers in the UK to lead the embedded systems industry in Europe;
- bring the UK's hardware and software capabilities together to address the challenges in fields such as robotics and automation; and
- promote an integrated approach between electronics, photonics and control systems for the use of lasers in industrial applications.

Business framework

This UK strategy builds on previous strategies in this area [2] to further a business framework that encourages all players to cooperate to the best advantage of the UK economy. Planning of the knowledge and material supply chain to maximise value, and networking to establish the contacts and collaborations to realise it, are crucial to success of innovative businesses within a global market.

The Technology Strategy Board will:

- operate Knowledge Transfer Networks covering the EPES strategic priority areas, to further improve engagement of UK businesses with each other, international partners, the academic base and government;
- ensure that the interventions it targets at the EPES sector are accessible to SMEs as well as larger organisations;
- connect the EPES businesses to the UK science base using Knowledge Transfer Partnerships, including short duration KTPs which will support the more immediate requirements of SMEs; and
- identify and signal requirements for metrology, standards and regulation.

Working with branches of government and with major stakeholder groups in industry is essential to the success of this UK strategy. The EPES team works with DIUS (the Technology Strategy Board's sponsor), with the Research Councils to ensure alignment of science and technology development strategies, with BERR on the business and regulatory environment, with the Regional Development Agencies and the Devolved Administrations to coordinate national and regional policy and investment, with UKTI to encourage inward investment and to attract and protect value in the UK, and with other government departments to investigate technology synergies and sector overlaps. Technology Strategy Board will also work within Europe to represent UK interests, influencing the EU research agenda of the ICT and NMP portions of Framework Programme 7 and ensuring that EU funding complements national programmes. The industry sector also provides its own voices in the form of the Electronics Leadership Council and the Photonics Leadership Group. The EPES team will work with these, linking up the technology and innovation agenda with those of industry leaders, Trade Associations, Skills Councils and others.

1. Background and context

The recent Review of Government's Science and Innovation Policies by Lord Sainsbury [3] made many recommendations for the innovation space within the UK. These broad themes are reflected in the Technology Strategy Board's "Connect and Catalyse" document [4]. The purpose of this UK strategy for EPES is to highlight the market and technology opportunities within the Key Technology Area and identify routes for the UK to exploit them and generate wealth.

The EPES sector should always be looking for technology with an identifiable route to market and those areas where technology push and application pull are both evident will be of particular interest. Sector overlaps are fertile ground, and in such cases the economic benefits are felt not only by the technology providers, but also by the end users in the form of operational improvements.

It is important to recognise where the UK is currently positioned to define the future opportunities and how they can be realised. Analysis of the other sectors' requirements can be used to identify market opportunities in underexploited applications. The necessity to build cross-sector knowledge and material supply chains to access such markets provides a persuasive argument for Technology Strategy Board intervention.

A particularly important cross-over is with the field of software, as more and more intelligence is being driven into new products. For a more detailed view of the software space and its links to this strategy, see the UK's Information and Communication Technology (ICT) Key Technology Area strategy document [4].

2. Industry and market overview

2.1 Industry structure

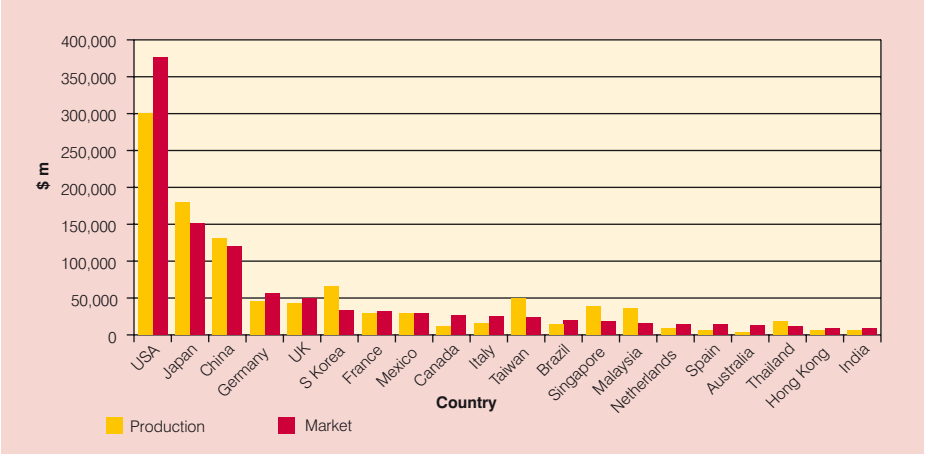
2.1.1 Trends in the global market

In many industry sectors, low-margin cost-driven manufacturing has crossed the globe to reduce capital or labour costs and to seek favourable regulatory and tax regimes, whilst clustering for proximity to component and sub-assembly supply chains. These economic pressures may have led semiconductor production to relocate towards the Far East, but they do not apply to less mature technologies, those with knowledge-intensive materials and manufacturing requirements, or automated production with low labour overheads. In these cases, logistical pressures may drive to co-location with end-use markets or with centres of expertise and R&D.

The geographic breakdown of global electronics markets and production facilities in Figure 1 shows that the well-documented outsourcing of chip manufacture from the US and Europe towards Taiwan, Korea and Malaysia has led to only a minor distortion to the dominant trend, which is for production capacity to be located near to markets. The UK has the world's fifth largest market for electronic goods, and the seventh largest production base, a close second in Europe to Germany.

A second international trend, affecting knowledge-intensive fields such as Electronics, Photonics and Electrical Systems (EPES), is driven by a need for flexibility in the use of highly skilled manpower. For corporate businesses innovating in multiple, fast-moving technology markets, overhead and risk can be reduced by subcontracting specialist functions such as technology development to outsourced service providers and consultancies. Thus, in the 'open innovation' business model, the development of ideas into technologies and products is pursued with a mix of in-house and outsourced R&D workforce. This has led to the decline of vertically-integrated multinational corporate businesses, and a proliferation of business models reliant on exploiting a knowledge base and an intellectual property portfolio. In the 'fabless' business model, design expertise is retained, but manufacturing is outsourced to specialist providers and 'foundries'. The smaller size of the agile businesses now operating in the EPES space can mean that the industry is much less visible, even though it is as vibrant as ever.

Figure 1 – National electronics production and markets 2003 [6]



2.1.2 The UK Electronics, Photonics and Electrical Systems industry

Electronics, Photonics and Electrical Systems manufacturing employs around 330,000 people in more than 14,000 UK businesses, and accounts for 10% of all UK manufacturing. Distribution, wholesaling and retail of EPES-enabled goods then account for a further 235,000 employees, plus 100,000 in electricity transmission and distribution and 200,000 in telecommunications. It is difficult to quantify the additional contribution of EPES design businesses, as official figures do not distinguish clearly between types of engineering consultancy, but it will be seen below that the UK has particular strength in this area.

The competitiveness of the UK electronics [6, 8] and photonics [9, 10] industries has been studied previously. Table 1 summarises the economic contribution of these activities, plus those associated with the ICT sector with which EPES has considerable overlap. Taken together, EPES and ICT directly account for some 10% of the UK economy, but also underpin a much broader base of activity, being an essential and valuable part of industrial processes, vehicles and transport systems, business processes, consumer products and many more. Core EPES and ICT functions are highly skilled and high added-value activities, with Gross Value Added (GVA) per head for electricity transmission and distribution reaching five times the national average.

The EPES and ICT sectors span wide variations in business profile. Those dealing with national-scale telecoms and energy infrastructure are typically large companies, with high turnover and staff numbers into the hundreds or thousands. Manufacturers and retailers adopt an intermediate position, and at the opposite extreme are software, IT and design, which tend to a consultancy model with as few as six employees in an average business.

The economic contributions of these three groups, however, are comparable and they all merit attention in this strategy.

Of the UK EPES manufacturing businesses, more than 98% are below the 250-employee threshold that defines them as Small or Medium-sized Enterprises (SMEs), and around two thirds are 'Micro' enterprises with less than 10 employees. These SMEs account for around half of the workforce and turnover; in photonics it has been estimated that the 92% of companies that are small or micro employ 24% of the workforce and generate 19% of the wealth [9]. A breakdown of the aggregate employment by subsector is shown in Figure 2. This is typical of UK manufacturing – there is no evidence that EPES industries have followed an abnormal trend. Larger manufacturing companies are therefore still a substantial proportion of the sector, and the UK should aim to encourage existing capabilities and corporate technical centres.

One area of UK strength is instrumentation and control, which covers an extremely broad and diverse area. Estimates of the world market vary enormously but are in excess of £100 billion. The UK industry is the world's fourth largest and its significance for the British economy far outweighs its turnover of £12 billion, through enabling and leveraging other activities [11]. It is possible to pick out from Figure 2 the significance of these small and medium-sized instrumentation businesses, and contrast it with medium-sized electricity control and distribution specialists and relatively large corporate manufacturing centres for domestic appliances or pumps and compressors.

This manufacturing capacity, however, forms only a part industry's strength. The UK boasts nearly a third of European silicon design companies [12], more than twice as many as its nearest rival, Israel. This makes it a global centre for innovation; independent design and consultancy businesses are increasingly where technologies are developed.

Table 1 – The UK EPES and ICT Sectors [7]

		Total				% of UK Economy			Average Enterprise		
2006 data	SIC(2003) Code	Number. of Enterprises ('000)	Turnover (£M)	Gross Value Added (£bn)	Number. of Employees ('000)	Gross Value Added	Employees ('000)	Enterprises ('000)	GVA/Head (£k)	Employees	Turnover (£M)
UK economy	all			1,299	31,412	100.0%	100.0%		41.4		
Agriculture, Fishing, Production, Construction, Distribution and Service Industries	A-O	1,888	2,604,719	789	23,973	60.8%	76.3%	100.0%	32.9	13	1.4
All manufacturing	D	151	484,199	151	3,116	11.6%	9.9%	8.0%	48.5	21	3.2
EPES manufacturing	29.12, 29.71, 30-32, 33.2-4	14.5	42,477	16	329	1.2%	1.0%	0.8%	47.1	23	2.9
EPES wholesale, retail & repair	51.43, 51,84-6, 52.45, 52.72	17.5	73,464	11	235	0.9%	0.7%	0.9%	48.4	13	4.2
Electricity transmission & Distribution	40.12-13	0.5	55,580	21	100	1.6%	0.3%	0.02%	210.2	220	122.4
Telecommunications	64.2	4.8	60,050	26	203	2.0%	0.6%	0.3%	126.0	42	12.4
Software & IT	72.2-4, 72.6	95.8	58,583	35	540	2.7%	1.7%	5.1%	65.5	6	0.6
All technical design & consultancy	72.1, 72.5, 74.2	69.3	39,416	21	413	1.6%	1.3%	3.7%	50.1	6	0.6
All EPES &ICT		**202**	**392,570**	**130**	**1,820**	**10.0%**	**5.8%**	**10.7%**	**71.2**	**9**	**1.6**

Figure 2 – The shape of the UK EPES Manufacturing Industry in 2007 [7]

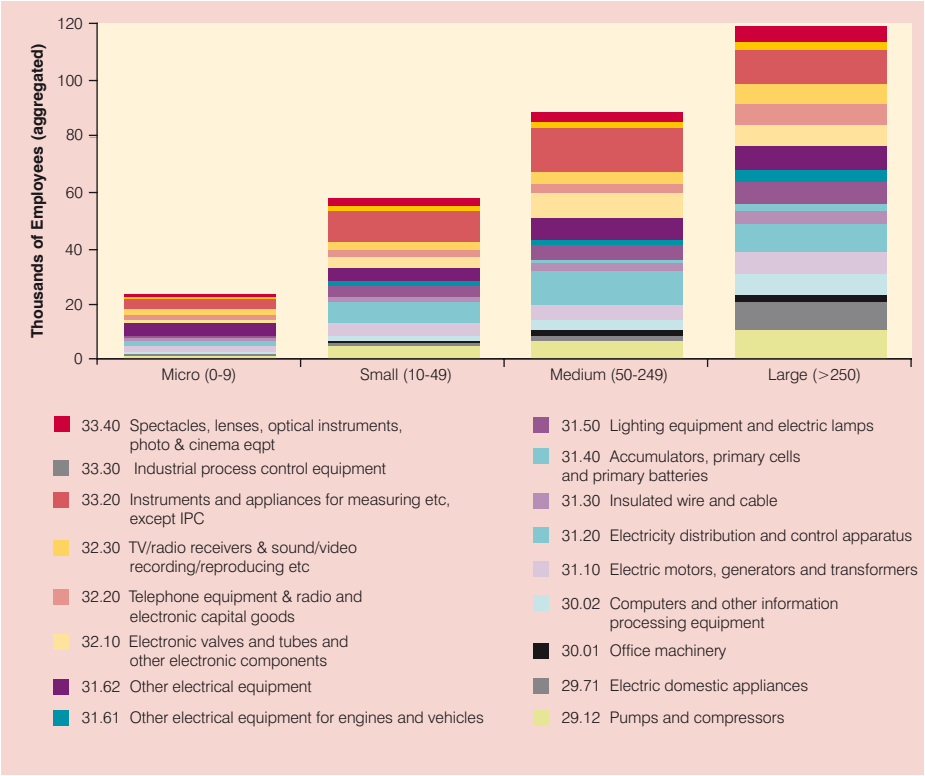
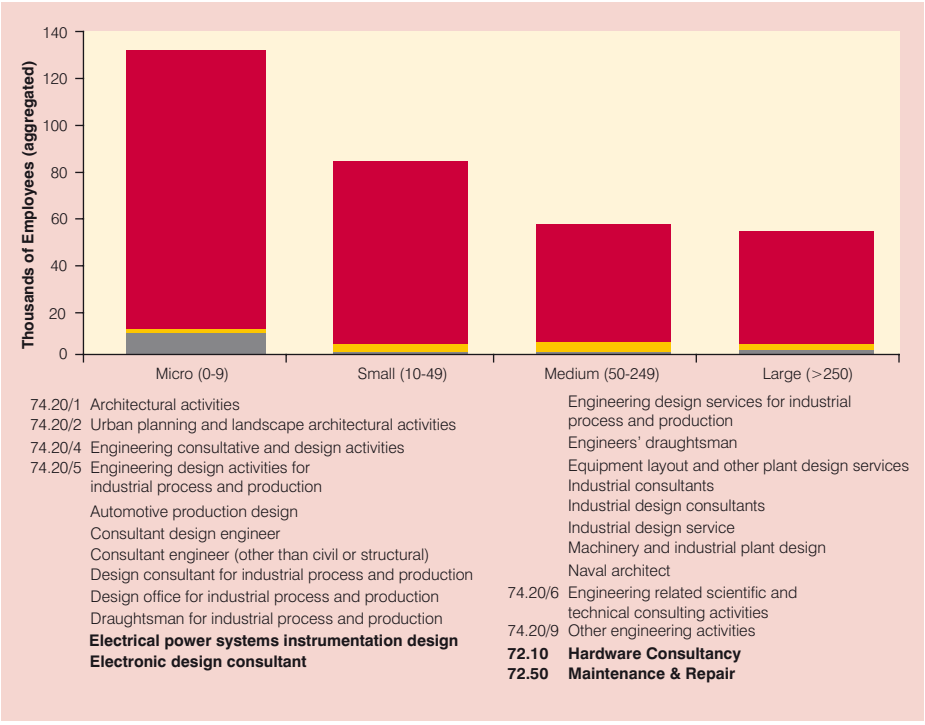


Figure 3 – The shape of the UK EPES Design & Consultancy Industry in 2007 [7]



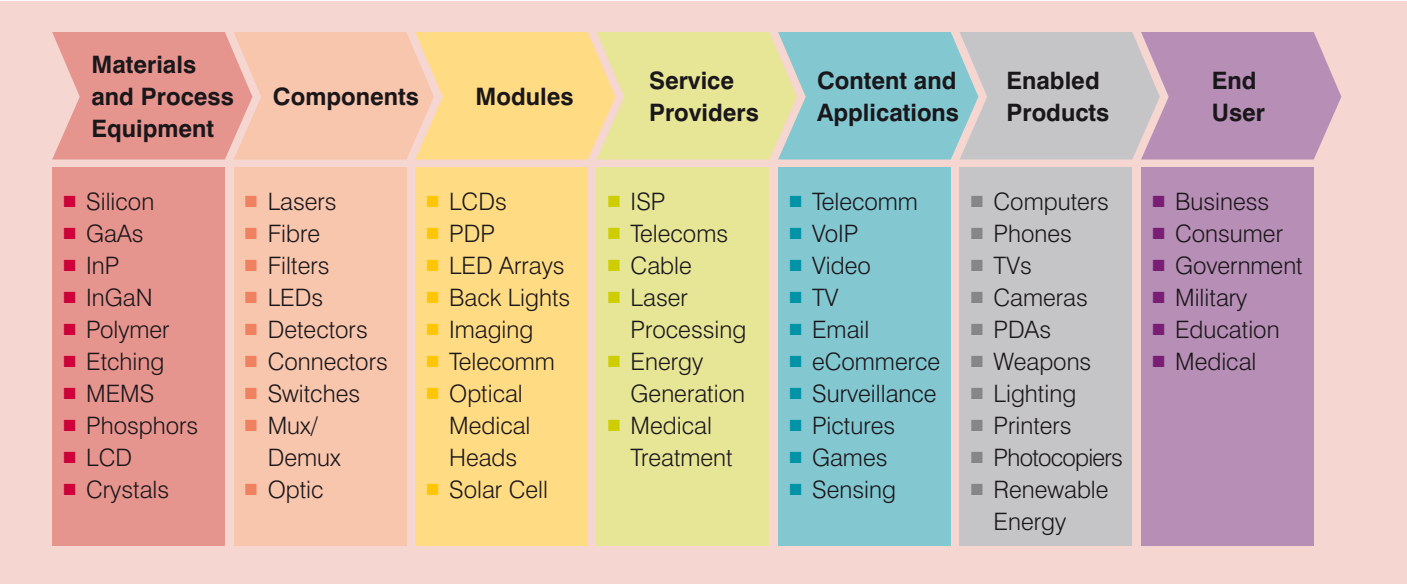
Their demographics are represented in Figure 3 (although the SIC codes unfortunately conflate electrical and electronic design houses with architects and automotive designers). Around 70% of such design sector employment is in small and micro-scale businesses, a pattern typical of design and consultancy in the wider economy, e.g. in software or management consultancy. These companies are solely reliant upon innovation for their success, whereas manufacturing companies can add value through processing activities. In deciding priorities in the UK Innovation Strategy, of which this document forms a part, the many small companies in the design sector have particular significance.

The structure of the EPES sector brings particular challenges to innovators. One of the biggest barriers facing businesses is the fragmentation and difficulty of knowledge sharing brought about by shifting business models; collaborating, especially on a global stage, makes it more important than ever to protect Intellectual Property (IP). This can often become a barrier to innovation or make companies approach collaboration with scepticism. The large number of SMEs in the sector can also find difficulty supplying to large companies, retailers and consumer groups, who might prefer to deal with companies of a similar size to avoid the risk of a poorly understood single source of knowledge or material, with a low level of financial security. Building trust and collaborations can help address all of these issues.

2.1.3 Supply chains and value chains

Supply chains can be thought of in different forms. In the classical version, illustrated for photonics in Figure 4, raw material or component technologies are procured and then processed or assembled to create a higher value system.

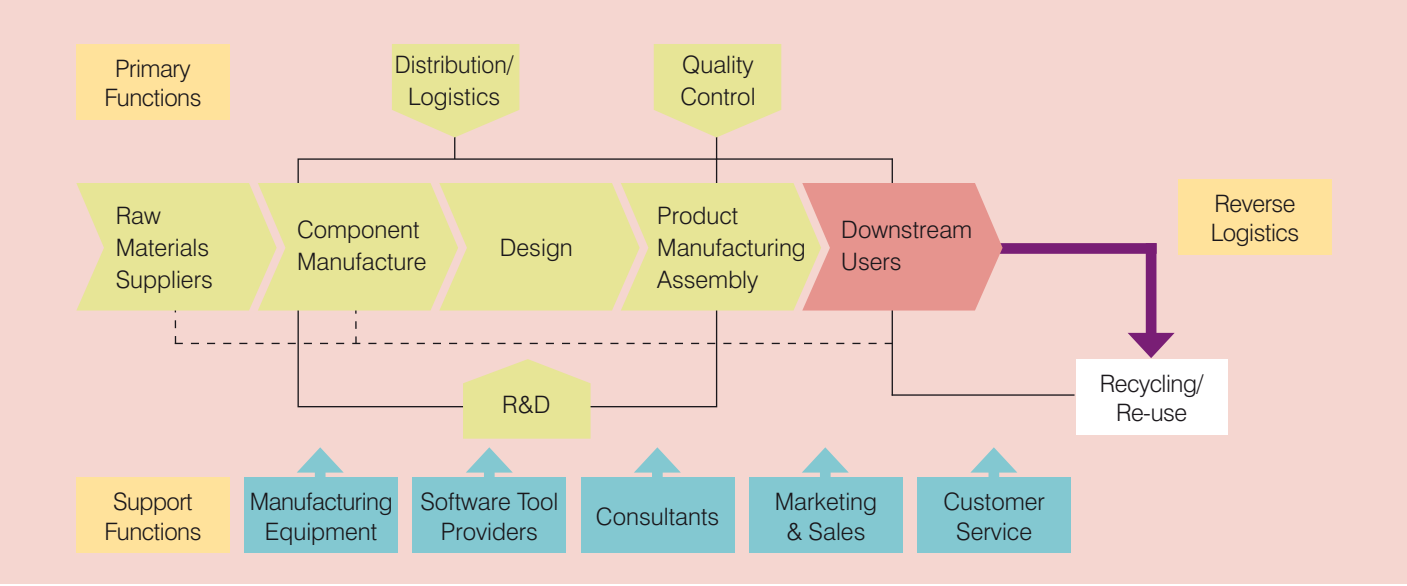
Figure 4 – The photonics component supply chain [9]



When considering innovation, it is also useful to think of the knowledge supply chain, where technological expertise adds value to a product or service, even if the provision of this is in another company or country. An example of the steps and support functions required to generate an electronic product is shown in Figure 5, in a model that could apply to a vertically integrated company or a distributed global partnership.

Networking and supply chain planning are crucial to a successful business model, and decisions such as manufacturing location can have a fundamental effect on profitability and the shape of the value chain. The distribution of the UK electronics and photonics businesses shows noticeable geographic clusters accompanying target markets such as the automotive and defence industries, which have developed to improve the efficiency of component supply. Clusters around academic centres, such as Cambridge University, demonstrate that centres of excellence can also provide a focal point for information and service sharing and for ensuring the knowledge supply.

Figure 5 – The electronics knowledge supply chain [6]

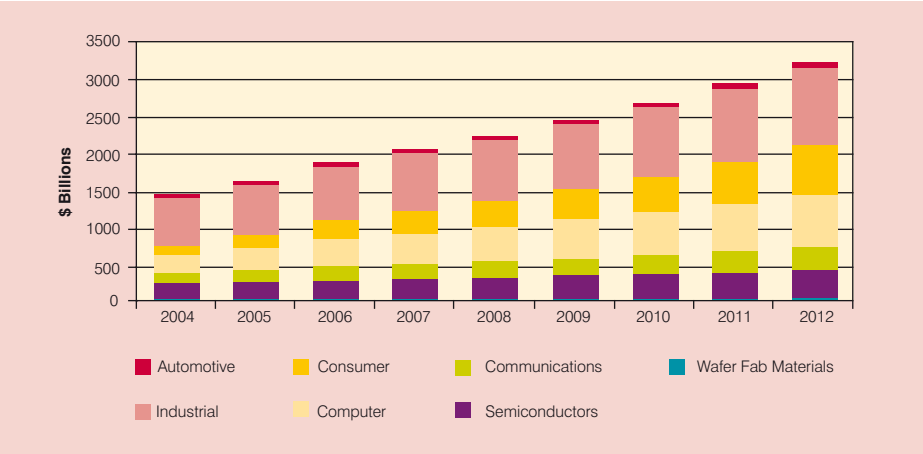


2.2 Global market sizes

Electronics and photonics are underpinning technologies, to be found embedded within a wide range of products, where they often contribute a significant proportion of the production costs. These end-use products then all also require power supply arrangements, making the electrical systems market similarly diverse and underpinning. This makes it difficult to agree a partitioning of value from which the relative market sizes can be agreed and, in particular, to separate the values at chip, component and system levels.

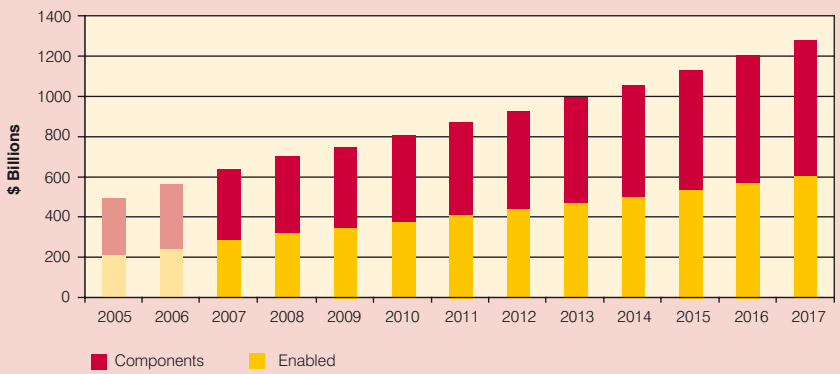
A recent study by BCC Research (Figure 6) places the size of the global electronic products market at $2.0 trillion in 2007, projected to grow at 9.5% compound annual growth rate (CAGR) over the next 5 years. Of this figure, $260 billion is accounted for by the semiconductors themselves, a figure which is also growing at over 7% per year, with 900 million transistors being produced every year for every man, woman, and child on earth [13]. Design represents a substantial contribution to the semiconductor value chain, which is growing as the systems increase in complexity, and further value is then added in the industrial, computer, consumer and communications markets as the chips are integrated and packaged into products

Figure 6 – Global Electronics Market & Forecast [43]



The global market for photonics components and enabled products (Figure 7) in 2006 was worth more than $565 billion, and market forecasts estimate expansion to over $1.2 trillion by 2017 with 7.7% CAGR [14]. This market forecast applies to diverse areas, such as communications, solar energy, medical care and sensors, with consumer displays/TV and computing/ processing showing the fastest adoption of photonics technologies.

Figure 7 – Global Photonics Enabled and Components Markets Revenue and Forecast 2005-2017 [14]



Global electricity demand is $1160 billion (2006), growing at 10.1%CAGR due both to increasing usage (5.6%CAGR) and unit price rises (4.3%CAGR) [15]. On top of this, the International Energy Agency estimates that the world economy will need to invest $20 trillion (in 2005 US dollars) in energy-related infrastructure to satisfy global demand between now and 2030 [16].

2.2.1 End-use market sectors for EPES technologies

End uses for device technologies can be found in almost all industry and manufacturing sectors. But some sectors have a particularly strong dependence on innovations in electronics or photonics and, as such, are of particular interest in this strategy. Table 2 summarises published market data, and identifies key global end-use markets for EPES technologies.

Table 2 – End-Use Markets for EPES Technologies [summarised from Appendix 1]

		Current and Predicted Value					
Opportunity	**Sector**	**Year**	**($ billion)**	**Source Currency (if applicable)**	**Year**	**($ billion)**	**CAGR**
Consumer Electronics & Photonics	Global Consumer Electronics & Photonics	2007	291.0				
Healthcare	Top 30 Countries Total Healthcare Spend	2007	3,500.0				
	USA Healthcare Services	2007	1,800.0				
	UK Healthcare Services	2007	144.0				
	Global Medical Devices	2005	248.0	£			
	UK Medical Devices	2005	7.4				
	Photonic Technologies in Medical Devices				2010	20.4	
	Home Medical Devices	2007	14.6		2010	17.8	6.8%
Transport	Global Automotive	2004	3,004.8	€			
	Global Automotive Electronics OEM industry	2006	106.0		2010	141.6	7.5%
	Safety & Convenience	2006	19.1		2010	25.5	7.5%
	Sensors	2006	10.6		2010	14.2	7.5%
	Powertrain	2006	12.7		2010	17.0	7.5%
	Global Aerospace Market	2006	200.0				
	UK Aerospace Industry Turnover	2006	39.6	£			
Retail & Logistics	Global RFID Market	2007	5.0		2017	25.0	17.5%
	RFID Cards	2007	3.0				
	Self Powered "Active" RFID				2017	6.0	
Security & Environmental	Global Biometric Market	2005	1.5		2010	5.7	30.6%
	Fingerprint Analysis (Laser/Image scanning)				2010	2.5	

Any calculated data such as CAGR or future market size extrapolated from CAGR is shown in blue, and all data have been converted to US dollars using an exchange rate 2.00 USD = 1 GBP = 1.26 Euro.

Table 3 – Technology Market Sizes [summarised from Appendix 2]

		Current and Predicted Value					
Opportunity	**Sector**	**Year**	**($ billion)**	**Source Currency (if applicable)**	**Year**	**($ billion)**	**CAGR**
Control Systems & Power Engineering	Global Electricity Demand	2006	1,167.0		2011	1892.0	10.1%
	Global FACTS & HVDC			£	2015	400.0	
	UK FACTS & HVDC			£	2015	24.0	
	Global Power Semiconductor	2005	10.0		2009	14.0	8.8%
	Global AC Induction Motor, Generator and Motor Drive	2007	30.0				
	Electrical Engineering UK Manufacturing Turnover	2007	30.0	£			
	Global PhotoVoltaic market	2006	10.6		2011	25.1	18.8%
	Organic PhotoVoltaics				2011	2.3	
Plastic & Printed Electronics	Global Organic & Printed Electronics	2007	1.2		2017	48.0	44.9%
	Flat Panel Displays	2006	94.0		2017	200.0	7.1%
	E-paper				2014	4.0	
	OLED				2015	6.0	
	Global Lighting	2006	100.0				
	Solid State Lighting (SSL) devices	2007	0.7		2017	60.0	57.0%
	Automotive Lighting Applications				2014	1.0	
Data & Image Acquisition	Global Instrumentation & Control	2007	200.0	£			
	Global Sensors				2010	61.4	
	UK Instrumentation & Control Turnover	2007	24.0	£			
	Global Pressure Sensors, Transmitters & Transducers	2005	4.0		2010	5.4	6.2%
	Global Proximity & Displacement Sensors	2006	2.2		2013	3.0	4.5%
	Global Sensors based on Nanotechnology	2007	2.7				

		Current and Predicted Value					
Opportunity	**Sector**	**Year**	**($ billion)**	**Source Currency (if applicable)**	**Year**	**($ billion)**	**CAGR**
(contd.) Data & Image Acquisition	Global Distributed Fibre Optic Sensors				2010	1.0	
	Global Image Sensors	2006	7.4		2017	20.0	9.5%
	North American 3D/4D Visualisation in Medical Imaging	2006	0.5		2013	1.4	15.4%
	Global Geographic Information System	2007	4.0		2017	150.0	43.7%
	Global GNSS Products & Services			€		636.0	
	UK GNSS Products & Services			€		38.2	
Communications	Global Telecommunications Revenue	2006	3,000.0		2017	7,000.0	8.0%
	Global Optical Communications	2006	19.0		2017	40.0	7.0%
	Global laser diodes for all telecommunications	2008	3.8	£			
	Global Telemedicine	2007	5.8		2012	13.9	19.1%
	Global Wireless Semiconductors	2007	40.0		2012	80.0	14.9%
Systems Design & Integration	Global Embedded Hardware				2009	78.7	
	Global Dedicated Software Market Supported by Embedded Hardware				2009	3.5	
	Global Robotic Systems				2025	51.0	
	US Surgical Robotics	2006	0.4		2011	2.5	43.0%
	Global Robotics Components				2015	12.0	
	Global Industrial Lasers	2007	6.0				
	Global Fibre Lasers	2005	0.1		2010	0.7	38.8%

Any calculated data such as CAGR or future market size extrapolated from CAGR is shown in blue, and all data have been converted to US dollars using an exchange rate 2.00 USD = 1 GBP = 1.26 Euro.

2.2.2 Market potential of individual epes technologies

Table 3 summarises published market data grouped by technology. Identifying those technologies with greatest exploitation potential is the core of the analysis generating the priorities in this strategy. Appendix 2 covers these areas in more detail but the headline for the EPES sector is that there are many opportunities for growth, ranging from steady (e.g. global proximity and displacement sensors) or dramatic (e.g. solid state lighting devices).

2.3 Market drivers & technology trends

2.3.1 Electrical power usage

The UK government's sustainable development strategy [17] and the Stern Report [1] underlined the necessity to reduce carbon emissions worldwide. The need to reduce electrical power usage drives innovation in electronics, photonics and electrical systems, as these technologies are both the consumers of this power and the agents through which it is controlled.

UK electricity consumption totals around 406,000GWh per year (1,110GW average load) and continues to rise at ~1.0% CAGR. An analysis of this usage can be found in Appendix 3. The European Commission's conclusion [18] is that the greatest potential electricity savings at point of use are available from:

- electric motor systems
- commercial and residential lighting
- domestic appliances (e.g. refrigeration)
- standby power.

In addition, electricity generation and supply account for some 13% of electricity usage, and this presents further opportunities for improvements.

High Efficiency Pulsed Power Source for Industrial Processing – HiPPoS

This collaborative project between e2v, Dynex Semiconductor Ltd and the University of Nottingham, has initially focussed on the mineral liberation process. This project seeks to reduce electrical energy consumption by combining the latest high frequency power converter and power conversion control technology with industrial microwave generators. One example uses microwave or RF energy to assist the mineral comminution process, with potential to reduce the worldwide mining industry's electrical power consumption for this process (420 GWh/year) by up to 60%. This is roughly equivalent to the total UK energy consumption! At the same time as reducing CO_2 emissions, it also has the potential to improve liberation yields, further evidence that saving energy has monetary benefits as well.

The advanced technology element of the project, conducted by the University, is intended to develop the enabling technology to exploit related fields such as the electricity generating and building industries and also future European scientific needs – fusion power generation and the International Linear Collider. The total project investment is £1,407,456, of which £680,406 has been provided by the Technology Strategy Board.

As well as improving efficiency in systems and their use, applying technology in innovative ways is a viable route to reducing consumption.

2.3.2 Regulation and standards

The regulatory environment is a generator of new business opportunities as well as a constraint on the markets. Examples of current EU legislation affecting developers, integrators and users of electronic, photonic or electrical products are:

- **EuP:**
  The eco-design of Energy-using Products, with particular focus on lighting and on standby power [19, 20, 21];
- **WEEE:**
  Waste Electrical and Electronic Equipment directive, affecting design for end-of-life disposal;
- **RoHS:**
  Restriction of the use of certain Hazardous Substances in electrical and electronic equipment (with similar legislation in China and in Korea);
- **REACH:**
  Registration, Evaluation, Authorisation and restriction of CHemical substances; and
- **EMC:**
  Electromagnetic Compatibility, which is of increasing importance with the rise of locally networked RF device communications.

It is important for the development of global markets and supply chains that technology developed in one country should be usable across the world. New technologies and applications generate the need for internationally agreed standards, design rules and operating protocols, especially

in communications and communications-enabled technology markets, and as a reference for procurement to compare new and existing products as they start to enter the marketplace.

2.3.3 Miniaturisation and multifunctionality

There is increasing pressure to expand the range of functionality delivered by devices, whilst at the same time reducing their footprint by co-locating functions onto the same platform. Accompanying this progression, advances are occurring in microsystems technologies (MST or MEMS), where chips with moving parts have enabled pressure and acceleration sensors for the automotive market, optical switching for digital light projection technology and fluid control in inkjet printing. Incorporating materials sensitive to specific chemical species opens up the new fields of bio- and chemo-electronics, with outlets across healthcare and drug development, environmental monitoring and security equipment. Microfluidics will soon generate applications in the biosciences including, perhaps, a "lab on a chip" where picolitre biological samples can be manipulated and analysed.

The increase in functionality of individual devices is accompanied by innovations in their packaging, such as three dimensional integrated circuit (3D-IC), system-on-chip and system-in-package, where density is increased by combining functionalities onto each chip and by stacking and bonding them into a 3D array. The UK has developed strong positions in device- and system-level design and in manufacturing equipment and processes. Whether the devices in question are for data processing, data storage, sensing, actuation, image capture or display, or a combination, such compact 3D structures will require a flow of new design and verification tools and manufacturing processes, and the UK is well positioned to exploit IP in this area.

2.3.4 Embedded intelligence

Over 90% of computing devices now appear not in PCs but in the form of embedded systems inside other products, and this figure has been estimated to be as high as 98% [22]. Over 4 billion embedded processors were sold in 2006, with a forecast of over 16 billion devices worldwide in 2010, more than two per person, doubling again by 2020 [23]. Although rarely acknowledged, embedded processors have become a dominant part of the value of products in fields as diverse as industrial automation (22%), telecommunications (37%), consumer electronics and intelligent homes (41%) and health/medical equipment (33%) [38], as well as accounting for 20% of the value of each car – a figure which is set to increase to 35-40% by 2015.

2.3.5 Communications bandwidth

Global telecommunications revenue is expected to climb from $3 trillion in 2006 to around $7 trillion in 2017, driven largely by the increase in bandwidth required to support surging demand for current and next generation services, with data-intensive applications such as movies, music, and video.

The bandwidth demand for existing services already outstrips the current capacity of DSL broadband. The Broadband Stakeholder Group's review [24] predicts that demand from the most bandwidth intensive UK households could reach 23 Mbps downstream (i.e. when downloading information) and 14 Mbps upstream (i.e. for uploading data) as soon as 2012, beyond the capacity of many current access infrastructures. Cisco [25] is more bullish still, predicting a 46% (52% in Western Europe) per year rise in global internet traffic to over 522 Exabytes in 2012 (i.e. 522 billion Gigabytes or the equivalent of over 130 billion DVDs), including 125% per year increase in mobile traffic. They note that internet video jumped from 12% of consumer traffic to 22% between 2006 and 2007 (not including peer-to-peer file sharing, which accounts for half of all traffic), and predict that video applications will account for 90% of all consumer traffic by 2012.

Increased use of high data rate applications in the wireless industry adds to this load, since wireless data also travels over a portion of the landline network, e.g. base-station to base-station. New solutions will soon be needed in both wired and wireless communications, enabled by electronics and photonics technology, and perhaps requiring a new approach to the infrastructure itself.

3. Technology opportunities

The Technology Strategy Board's investment criteria are:

- **Does the UK have the capability to develop and exploit the technology?**
- **Is there a large market opportunity?**
- **Is the idea ready? (appropriate timeliness and impact)**
- **Can the Technology Strategy Board make a difference? (added value)**

In this strategy, the individual technologies that satisfy these criteria (suggesting an increased prominence in the UK economy over the next five to ten years) are grouped into five technology pillars as shown in Figure 8.

The UK is recognised as a world leader in these areas. It is important that companies are maintained, grown and nurtured to capitalise on the opportunity to exploit a truly worldwide market. Certain enabling technologies such as lasers have a part to play in many of these pillars and it is the aim of this strategy to identify opportunities where their underpinning capability can be developed to satisfy a market pull rather than provide technology push.

Figure 8 – Five Pillars of the Electronics, Photonics and Electrical Systems Strategy

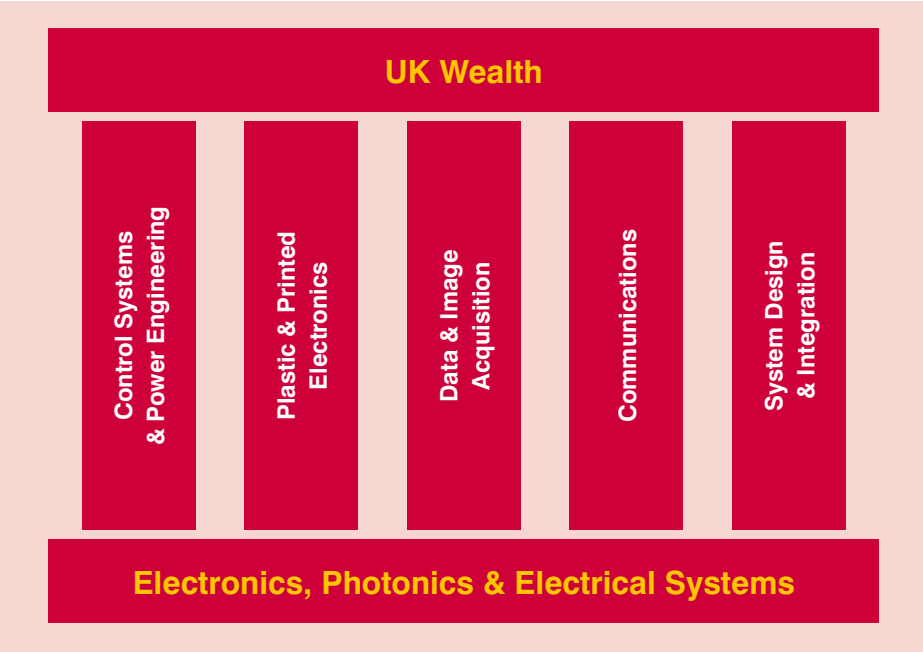


Figure 9 – Challenge Summary for Electricity Usage

	Category	"Always-on" Efficiency Challenge	Control Challenge
Supply	Generation & Transmission	■ Voltage & frequency conversion. ■ Grid infrastructure ■ DC power transmission	■ Active capacity & grid management
	Off-grid electricity management	■ Photovoltaics (incl. organic PV) ■ Microgeneration, e.g. PV, CHP ■ Portable power, e.g. fuel cells, energy scavenging, thermoelectric ■ Generation/distribution in transport ■ Batteries & energy storage	■ Connection of renewable, local and intermittent power sources into the electricity grid ■ Electric braking, storage and rapid recharge
Demand	System-level consumption	■ Commercial & architectural lighting ■ Electric motor design ■ Industrial processing ■ Refrigeration & heat pumps ■ Voltage & frequency conversion ■ Power electronics ■ Subsystem thermal management	■ Variable speed motor drives ■ Consumer demand active management ■ Standby power

3.1 Control systems and power engineering

Most consumption of electrical power falls within the area of Electronics, Photonics and Electrical Systems. This strategy therefore seeks to reduce consumption and improve efficiency, throughout the electricity supply chain, by innovation in particular technologies and processes. It is difficult to assess the impact of such measures in near-market terms; the benefits of innovation and deployment will be felt over time, both by reduced costs to the consumer and to the producer, and in the environmental benefits that come from reduced CO_2 emissions.

Based on the breakdown of electricity usage presented in Appendix 3, some challenges to be addressed are shown in Figure 9. Energy can be saved by improving the efficiency of the device and/or controlling when it is on or off, e.g. switching off items when they are not in use.

3.1.1 Lighting

The lighting sector accounts for up to 20% of national power consumption, and cost/benefit analysis [26] clearly identifies efficient lighting as one of the "easy wins" for carbon abatement. As a first step, a UK voluntary initiative is leading to an increase in the use of compact fluorescent lamps with integral ballasts (CFLi) in place of their less efficient equivalents on shop shelves. Unfortunately, these are not an ideal solution in their current form. Practical concerns include the amount of light, warm-up time, inability to dim, flicker and sparkle, colour appearance and rendition, lamp life, and the availability of suitable luminaires and lamp shades. The use of mercury (up to 5mg per lamp in the worst examples) leads to disposal issue. Breaks in the internal phosphor coating can allow harmful Ultra-Violet emissions, and the poor power factor and harmonic performance of cheaper CFLi bulbs could mean that the power saving opportunity is overestimated.

These issues suggest that more regulation and standards work is required in addition to the technology development in order to solve the problems on the appropriate lighting standards. This would ensure both that replacement bulbs are fit for purpose and that it is easy for consumers to compare new technologies to the previous offerings with which they are familiar, e.g. which product should be purchased to provide the same performance as a standard 60W incandescent bulb.

A number of ultra-efficient lighting technologies are in development that may offer improved performance and lower cost without the drawbacks of CFLi. These include solid state lighting, based either on inorganic light-emitting diodes (LEDs) or organic electronics (OLEDs), as well as electroluminescent panels (EL) and microwaves. Such new approaches can also add significant features such as area lighting panels or mood lighting, whereby the right colour of light can help people to stay awake on night shifts, at school or on the roads, or to wind down in the evening.

The UK lighting industry is well established at multiple points in the supply chain due to the maturity of the lighting market and has a strong research pedigree covering inorganic semiconductors, printed electronics, lighting fixture design and luminaire manufacturing, which provides a promising environment for exploitation. This includes a wide base in gallium nitride research, as used in white light LEDs, although only a fraction of this effort is directed towards lighting applications. There are also large commercial organisations as well as many SMEs with excellent knowledge, capacity and die manufacturing capabilities based in the UK, along with developers of novel light extraction techniques and major activities within semiconductor and packaging technologies, in high brightness LED, in OLED and in lighting fixtures.

The challenge is to ensure that this well established UK lighting sector successfully transfers production to the new, high-margin technologies represented by ultra-efficient lighting.

Figure 10: Assessment of Lighting against Technology Strategy Board Criteria

Fit against criteria for investment	
UK Capability	Medium
Market opportunities	High
Timeliness & impact	High
Added value	High

3.1.2 Photovoltaics

Improvements in device efficiency can make a substantial difference in organic or inorganic photovoltaics. The lack of agreed standard testing to confirm the efficiency of solar cells is inhibiting growth in this area. However, world-wide capacity is already sold out for the next few years and this in itself could provide an opportunity if a low cost manufacturing solution can be found at the same time as increasing the conversion efficiency. Although several companies are known to be active in the solar field in the UK, either as established players or recent start-ups, a detailed mapping of the entire solar energy sector in the UK would also be helpful to understand the exact landscape of the technology. A rapidly growing area is the low cost but relatively low efficiency PV market where companies are effectively printing PV material. Although they are much lower efficiency, they are projected to have long life, need little maintenance and offer huge area coverage for energy generation at very modest install cost. This technology is of relevance to the Low Impact Building Innovation Platform being run by the Technology Strategy Board [4].

Figure 11: Assessment of Photovoltaics against Technology Strategy Board Criteria

Fit against criteria for investment	
UK Capability	Not Known
Market opportunities	High
Timeliness & impact	High
Added value	Medium

3.1.3 Power conversion and management

Future power conversion and management needs will necessitate greater attention to power quality, power factor and security of supply, which in turn will need new technologies and equipment. Many of these themes are covered in more detail in the Energy Generation and Supply Key Application Area [4].

The electrical engineering sector in the UK is diverse but there are a number of unifying themes. A recent study of the UK companies involved in the manufacture of electrical products and systems identified 19 system companies, 92 product manufacturers, 41 involved with components and materials and 15 in software and services. At least 35 UK universities have specialist groups active in various aspects of electrical technology. Some of these, such as the leading power electronics groups, are highly respected worldwide and, when taken together, represent a higher concentration of resource than in any other EU country [27].

Methods are required to bring power more efficiently to disparate applications at the necessary voltage and frequency, whether this is voltage up- and down-conversion (AC-AC and DC-DC), rectification or frequency generation and conversion. There are additional issues of frequency stability and harmonic purity, given variable load impedances. Thermal management, at general system, package and chip levels, allows increased operating power density without excessive temperature rise, or operation at higher temperature where this improves efficiency (e.g. in micro fuel cells).

There are also efficiency savings to be had through the more intelligent manipulation of heat in the domestic and commercial environment, and in more intelligent planning of electricity distribution, including local power generation technologies that do not require grid transmission. One integrated approach under consideration is that of vehicle-to-grid systems where the power unit in the car (diesel, petrol or fuel cell hybrid) can be linked into the home or grid. This is one of a number of automotive power themes of interest to the Low Carbon Vehicles Innovation Platform, being run by the Technology Strategy Board [4].

Power conversion and management is applicable to the entire transport arena and are not just confined to automotive applications. There will be an increasing move to the use of electrical systems in planes, trains and ships. This is where UK expertise from companies like BF Goodrich, in areas such as variable frequency power systems on aircraft, can be used to generate wealth in the global market.

Some of the most substantial savings, however, may be made by using control systems to switch devices off or ramp them down when not in use, or in response to supply fluctuations and the marginal price of electricity. This requires the coordination of sensor and embedded systems technologies with communications and power electronics, all of which are UK strengths within the EPES arena [11].

Figure 12: Assessment of Power Conversion and Management against Technology Strategy Board Criteria

Fit against criteria for investment	
UK Capability	High
Market opportunities	High
Timeliness & impact	Medium
Added value	Medium

3.2 Plastic and printed electronics

Plastic electronics is an emerging field that is poised to disrupt the world of electronic circuits and flat panel displays and was highlighted as being high risk/high reward by the Council for Science and Technology [28]. The ability to utilise flexible substrates instead of the traditional glass structures will lead to a paradigm shift in capability as well as manufacturing method, with roll-to-roll processing now a real possibility. The development of organic electronics in general is also recognised by the Technology Strategy Board as one of the important aspects of this technology field. As an example, there is the possibility of leveraging this technology to access new methods of lighting, with distributed mood lighting instead of stark point sources.

Plastic Logic Ltd

This company was spun out from Cambridge University in 2000 and has now established itself as a world leader in the production of flexible displays for e-paper, based on its technology for printing the necessary transistors onto plastic substrate materials. In 2007, Plastic Logic raised $100million of equity finance to build its first large-scale factory in Dresden; corporate ownership and development activities remain in the UK. Plastic Logic has been involved in six successful project submissions to the Collaborative R&D programme, totalling nearly £21 million (including over £10 million of Technology Strategy Board investment) and attributes much of its success to the support it has received from government programmes and venture capital investment.

Cambridge Display Technology Ltd

This company is a world leader in display technology based on organic light-emitting elements. Founded in 1992, its technology base is built on patents developed in the Cavendish Laboratory of Cambridge University. In 2007, CDT was acquired by Sumitomo Chemicals, valuing the company at $285million. CDT is still based in the UK, and continues to lead in the global market for OLED display technology. CDT has been involved in 13 Collaborative R&D projects worth over £13.5 million (a total of £7.2 million investment by the Technology Strategy Board) and has acted as lead partner on 9 of these.

The UK has an exceptionally strong academic base, with several 5-star university departments, such as the Cambridge University Centre for Advanced Photonics & Electronics and Cavendish Laboratories, Imperial College and Southampton University having world class research activities. The Engineering and Physical Sciences Research Council (EPSRC) has taken a lead in supporting university research in this area, with several large grants to develop the UK capability. There are also over 30 UK based companies with benchmarked world-class R&D in plastic electronics [28], ranging from home grown companies to multi-national players. UK organisations hold much of the knowledge and critical IP, along with leading positions in developing and marketing early products [29, 30]. The opening of the Plastic Electronic Technology Centre (PETeC) provides an open access facility to allow new companies to enter into this exciting new field and create working prototypes.

The critical challenge for the field is how to make sure that the UK can exploit its world leading position to generate wealth. The Technology Strategy Board will make sure that future public investment is appropriate and able to provide maximum added value. Additional technical challenges which need to be addressed relate to the compatibility between materials (including wet shelf life), device geometry, processing, general issues of developing manufacturing capability and especially the manufacturing proposition, which could well be roll-to-roll.

Figure 13: Assessment of Plastic and Printed Electronics against Technology Strategy Board Criteria

Fit against criteria for investment	
UK Capability	High
Market opportunities	High
Timeliness & impact	High
Added value	High

3.3 Data and image acquisition

Sensors and imaging are underpinning technologies, and there is a great diversity in the applications, from the parameter being measured to the market sector addressed. For illustrative purposes some of these are considered in Appendix 4. It should be noted that sensor developments are especially cross-sectoral: new technology in one area opens up new capabilities in other areas that may initially appear unrelated, e.g. X-ray detectors from high-end science being applied in dental surgeries. The size and scale of the sensor can also vary, even down to the nano-scale, where there can be benefits of having the sensors on a similar scale to the item they are sensing.

The methodologies employed also bind together diverse basic technologies, ranging from MEMS and optical absorption to nanotechnology and advanced materials. This is where bioelectronics meets RF communications and where lasers meet piezoelectrics. Now that it is possible to produce images beyond the limits of conventional vision and video, an opportunity exists to combine the range of technologies together into a defined standard with a modular structure and agreed protocols. This would enable UK businesses to react quickly to a wide variety of future worldwide needs from security (determine if something or someone is harmful, and what threat may be posed) to healthcare (sense at a distance whether a person is healthy, and what may be wrong).

Developing systems that can intelligently gather and make use of data that may be coming from different sensor systems at different locations is important for many industry sectors, and it would be wrong to single out particular examples as strategic priorities. Instead, this strategy will focus on emerging themes of technology development and interconnectedness.

3.3.1 Location sensing, location services and synchronisation

More and more critical infrastructure is dependent on location sensing for key logistics and management operations, e.g. emergency services to co-ordinate responses. There are many opportunities for innovation; taking satellite navigation as an example, this does not work indoors, can perform poorly in city centres and is vulnerable to jamming. Improved navigational performance, resilience and continuous availability may be achieved by integrating satellite location with technologies such as WiFi, mobile phone cell ID, Radio Frequency Identification (RFID), inertial sensors, digital compasses, barometric sensors, dedicated beacons and perhaps eLoran. With the evolution towards "always on, always connected" devices, security issues arise; this is one of several themes explored by the Network Security Innovation Platform [5].

Satellite location is only one of an expanding range of applications where precise timing and synchronisation of signals are critical to success. Both internet protocol communications and financial services (e.g. currency broking) increasingly require precise and validated time stamps on data packets. Synchronising the constituent parts of an increasingly extended, possibly even packet-switched network offers further challenges. Smaller and cheaper accurate atomic clocks operating at microwave frequencies, or very small clocks (i.e. chip-scale), could be useful here. Eventually small clocks operating at optical frequencies could offer improved timing accuracy and stability.

There is strength in the UK across the entire sector from both the hardware and software perspectives. For example, the UK leads the way in "meaning-based computing", used to extract knowledge from multiple unstructured data sources. There are also many opportunities for added content services, which make the sector of great interest to the Creative Industries [5]. Much of what is needed already exists in the UK, or can be developed relatively quickly. But no single organisation possesses all the expertise, so external coordination and direction is required to create the necessary consortia.

Figure 14: Assessment of Location Sensing, Location Services and Synchronisation against Technology Strategy Board Criteria

Fit against criteria for investment	
UK Capability	High
Market opportunities	High
Timeliness & impact	High
Added value	High

3.3.2 Item tracking

RFID 'tags' have already become commonplace in wholesale and retail logistics, for example in smart payment cards such as London Underground's 'Oyster' and for tracking high value items and passports. The primary challenge is currently one of awareness and implementation. 'Smart card' technology, with the added functionality of magnetic data storage, is gaining similar penetration and acceptance. After consolidation of this Automatic Identification and Classification (AIDC) generation of technology, for which a guide has been previously published [31], there are new opportunities where the UK is well placed to play a part:

- Existing silicon-based tags cost around 10 cents (USD) each with readers costing of the order of $1000). The next level of market penetration, where low-cost items are individually tagged, then requires the cost per tag to drop to a fraction of a cent, including its deployment. The UK strength in printable electronics presents an opportunity to capture IP on a new generation of technology, where a unique circuit and its antenna are printed directly onto the item or its packaging, at a fraction of the current cost.
- The integration of RFID tracking with sensors has the potential to create self-powered ('active') tags with an awareness of their environment or history. Early applications may allow tags to report whether they have experienced shocks or temperature fluctuations that may damage the items (e.g. food) to which they are attached. Alternatively they may use the tag simply as a means to transmit sensor data in asset monitoring of high value components such as aircraft parts, with an electronic database to track modifications and upgrades through the product's life, improving configuration management and safety.
- Greater growth potential, however, is not in the tags themselves but in readers and systems to process the data. Although early technologies were pioneered in the UK, product development has since become fragmented and now lacks direction and rallying points. For example, UK expertise in RFID readers is based in the LF or HF bands (typically 13.56 MHz), but new technologies use UHF frequencies above 900 MHz, so that UK RFID businesses need to re-import learning from other application domains. The UK does have an excellent skills base across the radio spectrum, and development of complex UHF RFID reader technology together with algorithms to process large and complex data sets could complement other efforts in both the EPES and ICT domains, such as tuneable (software-based) radio, embedded systems and grid computing.

Several AIDC and RFID centres of excellence are running in the UK, providing an ideal route for new companies looking to explore item tracking to understand what the technology can provide along with the best implementation route for them.

Figure 15: Assessment of Item Tracking against Technology Strategy Board Criteria

Fit against criteria for investment	
UK Capability	Medium
Market opportunities	High
Timeliness & impact	High
Added value	Medium

3.3.3 Sensors and sensor networks

The UK has a strong history in developing new sensing techniques, has vibrant academic activity, and hosts centres of excellence on sensor systems, materials and image analysis; a recent study showed 47 groups at 34 universities active in gas sensors research alone. Some of these have supported roadmapping activities [32] but importantly a good proportion collaborates with industry. Many UK businesses are placed to exploit developments, ranging from large automotive and aerospace suppliers though instrumentation and imaging specialists, and on into a diverse population of specialist SMEs. An example of this diversity was captured in a study of the UK capability in security equipment [33].

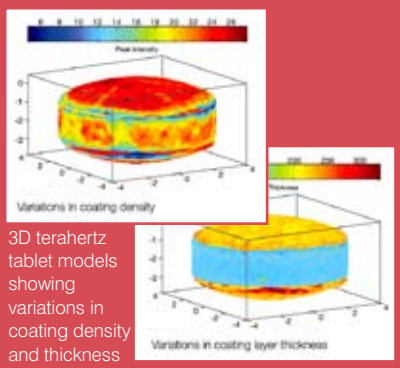
Beyond point sensing, many applications require communications linking sensors across a wider landscape, or connected through near-field communications. Small-scale, low-density sensor networks exist, but there remain significant challenges in scaling them up to large-scale and/or high-density deployments that can comprehensively monitor complex, highly dynamic and, sometimes, harsh environments. This is partly because of the difficulty of assembling cross-disciplinary supply chains that incorporate sensors, power supply, communications, information handling for huge and indigestible datasets (including the security of this information), as well as end users who may have no relevant expertise. This is an issue that Technology Strategy Board is uniquely positioned to help with, as a collaborative effort between the EPES and ICT teams. The convergence of expertise in sensing, instrumentation and imaging technologies, RFID, electronics design, digital communications and pervasive computing gives the UK a unique capability to develop a world lead, both in offering solutions to these challenges and in exploiting their potential. Since the UK already has strength in each of these areas, the opportunity to exploit the convergence of these technologies is vast.

Photonics has a major role both in the sensing and the communication of data. Photonic sensors are particularly attractive in areas where health and safety concerns are paramount, e.g. in the detection of flammable gases. UV and infrared lasers will also be crucial components in networking of sensors and other devices. Large laser sources are currently also the principal means of generating terahertz radiation; if this area of the spectrum is to be a practical option for sensing and communications, smaller sources will need to be developed.

TeraView

Teraview is a good example of a company investing in underpinning laser and sensor technology to exploit new market opportunities. With the support of their collaboration partners they are developing terahertz (THz) sources and sensors, and integrating them into complete data acquisition systems.

The transmission properties of THz waves and their absorption spectra in different materials make them ideal for short-range sensing and imaging applications, without the exposure issues of ionising radiation such as X-rays. Teraview's sensing applications include remote identification of suspicious objects, explosives and drugs that may be concealed on people or within packages, whilst their THz imaging systems can be applied in dental and oncological applications, as well as for real-time quality control of pharmaceuticals on the production line.



3D terahertz tablet models showing variations in coating density and thickness

Over the past four years, Teraview has been involved in five Collaborative R&D projects to develop this technology, totalling £5.8million of research activity with £2.8million of Technology Strategy Board investment. Teraview now predicts a large increase in the ways that terahertz radiation will be used, and believes that with their experience and know-how, and their strong links to the research community, they are well-positioned to exploit these emerging global markets.

There are multiple opportunities to use sensing systems to improve operating efficiency, and even to introduce disruptive technologies, in diverse industry sectors. By establishing cross-sector cooperation, market penetration should follow rapidly after technology solutions. Hence, as well as creating business opportunities for the electronics and ICT businesses in the supply chain, early adopters in the UK should experience the greatest impact on their operational efficiency and consequent competitiveness.

Figure 16: Assessment of Sensors and Sensor Networks against Technology Strategy Board Criteria

Fit against criteria for investment	
UK Capability	High
Market opportunities	High
Timeliness & impact	Medium
Added value	High

3.4 Communications

It is of critical importance to the generation of UK wealth that the UK has a resilient broadband access network, capable of delivering a greatly expanded range and volume of communication-based services. The Council for Science and Technology [28] has noted that "Improvements in bandwidth telecommunications are a vital enabling technology to business and the economy as a whole, across all sectors including the services sectors." The Government has therefore recently completed a review to identify the barriers to investment in such next generation broadband provision [89].

Once again there seems to be an expectation amongst users for more data at a quicker rate, whilst paying less or even nothing, and this perception is possibly the biggest challenge that the industry faces today. In addition to growing consumer expectations, innovative new services like online video games, video and music distribution and user-generated content are set to expand, and infrastructure planning now requires a credible prediction of future bandwidth requirements. Current broadband technology (ADSL2+) based on the current copper infrastructure will support data rates of up to 24Mb/s, although this is not achieved by all users. In order to go beyond this, it is widely accepted that an optical solution is required. Whilst 100Mb/s access would enable the UK to catch up to the rest of the world, 1Gb/s and beyond would enable the UK to "leap-frog" other countries and be a world leader.

The challenge for electronics and photonics technologies is to provide solutions that will allow simple, upgradeable, and flexible installation of cost-effective broadband technology. To provide this technology at a small fraction of the infrastructure installation cost will require UK science and industry to apply their device and materials knowledge in a system level approach, spanning hardware and software, and to provide new communications components and architectures to support bandwidth growth.

Some well proven approaches designed for the implementation of fibre networks in an economical manner ("long reach access") do already exist, but the need to get more for less is only likely to accelerate, since more bandwidth availability in the access network will drive the need for further enhancements such as optical switching in the backbone. Innovation is the only way to find solutions.

Next Generation Access is not only required for fixed connectivity. As various types of base stations proliferate and the bandwidths demanded by mobile users increase, new services will be required, such as cognitive radio, near field communications, software defined radios, ultra wide band, ad hoc wireless networks, 4G networks and beyond. To deliver these services, efficient utilisation of the radio spectrum is essential. The additional issues of data management over these new networks are considered in the UK's Information and Communications Technology KTA [4].

Historically the UK has been very strong in the field of optical communications and impoprtantly, as the market has recovered from the dot com bubble and returned to solid growth, the UK supply chain remains broadly intact, from material suppliers and academic research through to component manufacturers. UK industry and research must firmly focus on the requirements for next generation networks in the wired and wireless domains. The Photonics[21] European Technology Platform [34] provides one opportunity to pursue these interests in a European context.

Figure 17: Assessment of Communications against Technology Strategy Board Criteria

Fit against criteria for investment	
UK Capability	High
Market opportunities	High
Timeliness & impact	High
Added value	High

3.5 Systems design and integration

The Technology Strategy Board favours a holistic approach to design, taking into account both the operating environment and the user experience when determining what functionality is required, and only then moving to the design of sub-systems and components to deliver these capabilities. Across almost all modern technology-enabled sectors, this performance requires cooperation of hardware and software elements. Optimal performance is only achieved when these two underpinning technologies are developed in a harmonious fashion.

The Moore's Law trend since the 1970's has seen the number of transistors on a processing chip increase at around 45% per year, but a chip designers' productivity has advanced at only around 33% per year. This has led to a growing 'design productivity gap', where increasing resource is required to design each chip generation, with cost implications that are further compounded by the 5%/year increase in the cost of employing each designer [35]. The fixed costs of design therefore now account for a substantial and growing proportion of the added value in the semiconductor supply chain. This is just as true for new generations of multifunctional and multicore embedded devices as for historical progression of personal computing. Even for this cost now to stand still requires the repeated development of new hardware and software design tools.

The UK boasts great strengths in electronic systems design [36], with Europe's largest independent electronics design industry hosting nearly a third of its companies [12], together with centres such as the Institute for System level Integration, the Electronics Design Network and University centres in Southampton, Glasgow, Edinburgh and Imperial College. The UK has strengths in analogue and mixed signal electronics, covering many application areas such as wireless communications, as well as world leaders in fabless chip design. For example, ARM designs appear in 90% of all mobile handsets and are the most frequently deployed embedded architecture, accounting for 30% of new projects [37], whilst CSR's command of Bluetooth IP makes it the world leader in this field. These examples encourage the many rising stars amongst the SME population. Increasingly, photonics is also becoming a part of the system solution, designed together with embedded electronics and software to monitor, drive and control it.

It is important that these design solutions are secure and robust against a wide range of scenarios. The UK also has a lead to maintain in the use and provision of design, integration, test and verification tools such as Electronic Design Automation (EDA), particularly in their application to semi-custom designs such as field-programmable gate arrays (FPGAs) and application-specific integrated circuits (ASICs).

To complement this systems engineering approach, the Technology Strategy Board also recognises the value of system integration. Bringing together complementary areas of technology across the hardware and software landscape can often produce a solution that exceeds the sum total of the constituent parts. For example, a novel sensor technology could enable an instrumentation system for industrial, transport or health applications, allow heat and power to be managed intelligently, or improve the performance of an industrial laser or a medical scanner. Such advances offer new challenges and unique performance benefits for the end-user, whatever sector they inhabit, and represent the route to market for all the component technologies discussed above.

3.5.1 Embedded systems

An area underpinned by the cooperation of hardware and software, and which the UK is therefore in a strong position to exploit, is that of embedded systems. These are applications where the enabling EPES technologies are mostly invisible to the user, because custom-designed processors, running bespoke firmware, do their job without the need for explicit programming or interface to the user. Embedded systems are remarkably ubiquitous in modern life, perhaps most notably in vehicles such as aircraft and cars. An army of independent monitoring and control chips operate throughout the system, ensuring its safe and efficient operation and feeding only top-level information back to the pilot or driver. They appear throughout consumer devices such as domestic appliances and toys, and have a strong and growing presence in medical devices and in the built environment.

The evolution of embedded systems relies on intelligent design at system level, encompassing both the semiconductor platform and the software that runs on it. The partition of functionality between hardware and software is a central part of the design challenge. Alongside this is the interfacing of the system to its local environment, for example through sensing capability. The balance between local and central control then determines data communication requirements, and in some cases it may also be necessary to output high-level information to a user. A substantial part of the development process is also in testing and verification of the designs, and UK is also a strong player in these equipment and methods.

These issues are addressed by the European Joint Technology Initiative (JTI) ARTEMIS [38] in which UK is a founding member. ARTEMIS will concentrate on issues of dependability, quality, safety and security and on privacy issues related

to the use of embedded systems; these cross-cutting issues are well served by pan-European cooperation and joint development projects.

Figure 18: Assessment of Embedded Systems against Technology Strategy Board Criteria

Fit against criteria for investment	
UK Capability	High
Market opportunities	High
Timeliness & impact	High
Added value	High

3.5.2 Industrial lasers

Laser technology allows a greater range of products to be made more efficiently through automation and "lights out" manufacturing, more reliably, in a more environmentally friendly way and more cost effectively than other techniques. For example, car manufacturers world-wide use lasers to produce components and body parts with efficient designs that cannot be made by any other process. In the future, laser processing will become ubiquitous as different types of lasers are developed and produced for specific manufacturing processes. Some lasers will become custom engineered for specific tasks, while others will be reconfigurable to enable them to undertake different tasks as required.

There are at least 15 industrial lasers manufacturers in the UK and a similar number of system integrators specialising in fine- and micro-processing; together with an extremely strong research base in lasers and laser processing. The UK thus has the capability of exploiting the growing world interest in laser sources and applications. New technology, such as pico- and femto-second lasers, fibre lasers, direct diode lasers, plus the extension of available, cost-effective, wavelengths into the UV, visible and mid-IR and further, will open up even more applications. In fact, ultrafast (ps-fs pulse) lasers are already finding niche applications in micro-processing, nanoscience, medical treatments and imaging.

Figure 19: Assessment of Industrial Lasers against Technology Strategy Board Criteria

Fit against criteria for investment	
UK Capability	High
Market opportunities	High
Timeliness & impact	High
Added value	Medium

3.5.3 Equipment control and robotics

The UK's strength in sensing and imaging technologies and in system-level design and analysis provide a strong underpinning for activities in control engineering and robotics. According to the European Robotics Platform (EUROP), the major challenges for the 21st century are to develop robotic systems that can sense and interact with the human world in useful ways and to design robotic systems able to perform complex tasks with a high degree of autonomy [39]. The robotics industry has grown significantly in the UK in the past few years and includes around 60 innovative SMEs, supported by a strong population of robotic engineers and cognitive researchers.

More immediate markets for this knowledge lie in automation, for example of industrial processes, where the inclusion of sensing and decision-making functionality can lead to substantial improvements in efficiency, productivity and safety. This is a theme recognised in the Technology Strategy Board's High Value Manufacturing KTA [4]. Specific opportunities include machine vision, where hardware systems such as 3D laser imaging are synergistic with data analysis and decision-making software.

The innovation drivers and barriers in this field cut across hardware and software, and the communities need to work together to provide integrated solutions. In recognition of this point the theme is further explored within the Information and Communication Technologies KTA [4].

Figure 20: Assessment of Equipment Control and Robotics against Technology Strategy Board Criteria

Fit against criteria for investment	
UK Capability	Medium
Market opportunities	High
Timeliness & impact	High
Added value	High

4. Technology Strategy

4.1 The UK Technology Strategy for Electronics, Photonics and Electrical Systems

Figure 8 identifies five technology pillars in the Key Technology Area of Electronics, Photonics and Electrical Systems for the UK to direct its innovation and investment. It is recognised that these are underpinned by component technologies and expertise from across the sector, too numerous to list.

4.1.1 Control systems and power engineering

Environmental concerns demand more effective use of electrical power throughout the UK economy, and innovations in this area are further justified by cost reductions for the user. The aim is to minimise consumption of electrical power throughout the UK economy and to exploit the resulting technology globally. There are, however, barriers to the development and implementation of enabling technologies to be overcome.

The UK should:

- Innovate to reduce electricity consumption in the built environment, targeting the major issues of:
  - Lighting, including exterior, commercial and domestic applications. There are technology issues to be addressed with these technologies, for example in power and thermal management. In addition to the impact of improved power efficiency, new lighting systems offer new possibilities for innovation in lighting quality and design. There is also a need for metrology, standards and regulation to encourage the adoption of innovative technologies such as solid-state lighting.
  - Barriers preventing the implementation of ICT and sensing technologies for smart environments and electricity metering. These can have a substantial impact by modify usage and behaviour, e.g. by shutting off unnecessary power consumption.
  - Development of affordable and efficient microgeneration, storage and power conversion technologies that allow power to be brought to the point of use from local sources.
  - Electrical systems for heating and cooling in domestic and commercial situations.
- Innovate to address electricity consumption in industrial processes and transport, targeting the major issues of:
  - Electronics and photonics technology for the optimisation and control of processes.
  - Electrical drive systems. There are opportunities for improvement not only in the intrinsic efficiency of the motors and power conversion equipment, but also by addressing the way they are used, for example by installing variable speed drives and power-saving control systems.
  - Temporary energy storage and rapid recharge, for example using fuel cell and battery technologies.

The Technology Strategy Board will:

- encourage the development of ultra-efficient lighting technologies and the deployment of products based upon them;
- apply expertise from the EPES Key Technology Area to the challenges within the Low Impact Buildings and Low Carbon Vehicles Innovation Platforms and more generally, for example to reduce power consumption in manufacturing environments; and
- promote transfer of energy efficiency technologies between industrial, transport and built environment sectors.

4.1.2 Plastic and printed electronics

With the help of sustained government investment and excellent academic underpinning, the UK has developed a technology lead in plastic and printed electronics, which must now be exploited.

The UK should:

- Innovate to develop a sustainable base for wealth creation in plastic and printed electronics, targeting the major issues of:
  - Identifying the applications with the greatest potential for exploitation, bringing together technology providers with the owners of the commercial and technical challenges, and engaging business innovators with the capacity to exploit the opportunities.
  - Analysing the value chain for plastic electronics production, and which parts of this are best sited within the UK.
  - Solving technical issues of manufacturing scale-up, yield optimisation and quality control and device packaging and integration.

- Developing national facilities and a skills base to serve and encourage the emerging industry.

The Technology Strategy Board will:

- act as a focal point for analysis of the plastic and printed electronics value chain, and for identifying the opportunities for wealth creation in the UK;
- link technology providers in the sector to end users, business leaders and creative designers, to provide a joint understanding to ensure exploitation of market and product opportunities; and
- having identified the barriers to UK wealth creation, stimulate innovation to overcome them.

4.1.3 Data and image acquisition

The UK has developed considerable expertise in sensing and imaging technologies through the science base, which will underpin future generations of situation monitoring and context-aware objects. To realise this, however, it is necessary to integrate the data acquisition devices into instrumentation, systems and networks that can manage the data that they generate.

The UK should:

- Innovate to develop systems based on sensing and imaging capabilities, targeting the major issues of:
  - Location awareness. There is a need for platform technologies in both hardware and software, to provide a base on which new service industries and operating methods can be founded. This will require the development of industry standards agreed amongst communications and software suppliers, and their realisation in equipment design. It is also important to address the cultural, cost and information barriers to the adoption and deployment of these technologies.
  - Imaging and remote sensing. There is a continual need for new imaging approaches in security, healthcare and environmental applications, and the strong UK photonics community is well placed to address these high value markets. The fusion and overlay of data from heterogeneous sources represents a particular opportunity, as does the manipulation of this data and the extraction of information from it.
  - Packaging, networking and system-level design. Whilst individual sensing elements may be available to measure a wide variety of parameters, for their commercial exploitation it is imperative to develop beyond this level, to provide complete, integrated and application-specific solutions.

Success in each of these challenges must be founded on knowledge and information transfer and new levels of cooperation between the hardware, software, design and manufacturing communities.

The Technology Strategy Board will:

- ensure that the potential of existing sensing and imaging technologies are promoted to potential end users;
- maximise the potential of these underpinning technologies by stimulating cross-sectoral links between application domains and the fusion of complementary sensing elements; and
- encourage the development and exploitation of location-based technology for consumer and business applications, including the challenges set by the Intelligent Transport Systems and Services Innovation Platform.

4.1.4 Communications

The flow of data is the lifeblood of the 21st century economy. The expansion of applications and services creates a relentless increase in demand for communications bandwidth in both wired and wireless modes, and requires infrastructures to be continually upgraded to keep pace. Although not the only consideration, technology innovation plays a key role in this progress.

The UK should:

- Innovate to encourage national deployment of a Next Generation Access (NGA) network, targeting the major issues of:
  - Development of photonics components and sub-systems that can provide cost-effective technology for Next Generation Access, which should be capable of speeds in excess of 1GB/s.
  - The need for national agreement on network architectures, and for a financing and regulatory model to allow widespread deployment of this technology to business and domestic premises.
  - The stimulation of demand through the development and dissemination of new services and applications, notably in the creative industries.

Regional policy is likely to play a strong role in facilitating this expansion of capabilities, but the UK would also benefit from national scale coordination of this effort.

- Innovate to develop local high-frequency wireless networks, targeting the major issues of:
  - Efficient spectrum usage, including the extension from RF to microwave and even terahertz frequencies for short-range communication.
  - Analogue and mixed signal circuit design.

- Methods for linking mobile and/or autonomous devices, with particular consideration of data security, including encryption and secure line-of-sight links, power management, and the development of adaptive networks that can continually be reconfigured to maintain communication with mobile devices.

The Technology Strategy Board will:

- champion the benefits of high bandwidth Next Generation Access (1Gb/s and beyond), to position the UK as a world leader in the forthcoming communications revolution, and act to ensure that UK technology is available to support its low-cost deployment; and
- encourage development of systems and services based on wireless communications technologies to enable smart environments.

4.1.5 Systems design and integration

Design of both electronics and software are particular UK strengths, and their cooperative evolution is critical to the competitiveness of UK industry, in areas such as robotics, embedded systems, parallel computing and digital communications.

The UK should:

- Innovate to encourage the parallel development of hardware and software, targeting the major issues of:
  - Design of embedded systems tailored to applications in healthcare, transport, the built environment, and industrial and consumer applications. Design rules and tools are urgently required to improve the cost and speed of development, and technologies must transfer readily between these domains.
  - Verification and test of computing system designs, which is a field where the UK can provide a global centre of expertise.
  - Design of robotic and autonomous systems and the interfacing of their sensing, decision-making and actuation functions, including creating an awareness of their location, status and local environment. Of particular interest are industrial and manufacturing applications, where judicious use of such systems for the optimisation and control of processes can result in substantial productivity improvements.
  - Propagating specifications through the design chain, incorporating user issues, interoperability and robustness. For example, it is necessary to develop a skilled population conversant in partitioning functions between chip and software design. System interoperability requires standards and platform technologies to be agreed, and it is important to ensure that hardware and software developments are in step.

Since these innovations require cooperative effort, the approach of the Technology Strategy Board will be to address them jointly between the Electronics, Photonics and Electrical Systems KTA and the Information and Communication Technology KTA. A software perspective on these themes can be found in the ICT Technology Strategy [4].

The Technology Strategy Board will:

- promote a systems engineering approach to product design;
- inspire electronics and software designers in the UK to lead the embedded systems industry in Europe;
- bring the UK's hardware and software capabilities together to address the challenges in fields such as robotics and automation; and
- promote an integrated approach between electronics, photonics and control systems for the use of lasers in industrial applications.

4.2 Fit with other technologies and strategies

4.2.1 Crossover with other Key Technology Areas

The EPES key technology area has interests in common with each of the other Key Technology and Application Areas within the Technology Strategy Board. Such sectoral overlaps are particularly fertile ground for innovation and provide particular opportunities for market-driven investments. Those interested in the technologies in this strategy are therefore invited to explore how these themes are developed in the accompanying UK strategy documents. Similarly, visitors from other Key Technology or Application Areas may find interest in EPES within Table 4.

Table 4 – Overview of Common Interests between Electronics, Photonics and Electrical Systems and other Key Technology Areas or Key Application Areas

Key Technology or Application Area	Common Interests
Advanced Materials	■ Plastic electronics: polymer substrates & organic semiconductors ■ Optical materials, e.g. compound semiconductors and doped insulators ■ Devices materials for harsh environments, e.g. SiC; encapsulation ■ Bio- and chemo-active coatings ■ Electrical & magnetic materials e.g. superconductors ■ Piezoelectric materials e.g. in acoustic wave RF filters ■ Materials for sensors, actuators and displays
Bioscience	■ Sensing systems for agriculture & farming ■ Metrology for industrial biotechnology ■ Biophotonics ■ Biosensors and life sciences instrumentation
Creative Industries	■ Displays ■ Portable devices ■ Human factors & machine interfaces ■ Communication- and Location-based services ■ User-Generated Content ■ Design ■ Aesthetics
Emerging Technologies	■ Currently being investigated
Energy Generation and Supply	■ Renewable electricity generation technologies, especially photovoltaics and micro power generation (micro-photovoltaics, micro-fuel cells & power scavenging) ■ Electricity supply & grid management, including high voltage electronics & electrical systems, DC power transmission, connection of local electricity generation to the grid. Sensors for power systems
Environmental Sustainability	■ Energy efficient lighting and displays ■ Electricity usage efficiency, e.g. in lighting, power conversion & application power supplies; control systems for electricity demand management, e.g. for pumps or domestic power. ■ Environmental monitoring and sensing (water & air quality, meteorological), remote sensing (satellite & land-based) and UV water treatment ■ Sensors and instrumentation for contamination detection, remediation and monitoring
High Value Manufacturing	■ Metrology, control and robotics in manufacturing processes ■ Industrial lasers ■ Power efficiency & power management in manufacturing ■ Manufacture of electronic & photonic components & products: fabs & foundries, manufacturing equipment & processes, assembly & integration
High Value Services	■ Fraud prevention, e.g. using ID chips or biometrics ■ Retail & Transport logistics, e.g. using RFID tagging or smart packaging

Key Technology or Application Area	Common Interests
Information and Communication Technologies	■ Optical communications: optical fibres, communications lasers, broadband & fibre to the premises (FTTP) ■ RF communications, including mobile telecoms & mobile phones ■ Networked RF communications, e.g. in sensor networks ■ Parallel computing and ad hoc computing networks ■ Embedded systems and hardware/software partitioning ■ Context- & ocation-based services and software ■ Verification ■ Robotics
Medicines and Healthcare	■ Sensors & metrology for biological & chemical samples ■ Medical imaging technologies ■ Healthcare products incorporating embedded electronics & photonics ■ Metrology for pharmaceuticals & biopharmaceuticals development ■ Sensing systems for assisted living scenarios
Nanotechnology	■ Nanoelectronics, including advanced CMOS technology and microsystems/MEMS ■ Micro/nano technology (MNT) Centres ■ Next generation devices, e.g. carbon-based electronics ■ Nanostructured materials in sensors and active devices
Transport	■ Sensors, control systems & embedded systems in land, sea and air vehicles. ■ Drive power and ancillary power generation & management ■ Lighting & displays ■ Sensors & control for traffic management ■ Navigation ■ Sensor systems for ageing infrastructure monitoring (e.g. tunnels, bridges, roads)

4.2.2 Crossover with innovation platforms

EPES technologies can help address societal and public sector challenges such as climate change and more efficient use of energy, transformation of healthcare delivery and transport management. These are given special attention by the Technology Strategy Board under the banner of Innovation Platforms. Current examples of these synergies are shown in Table 5. It is expected that further crossovers will become apparent as the Technology Strategy Board expands the Innovation Platform Network.

4.2.3 Next generation EPES technologies

The UK has strengths within the science base in a number of emerging EPES technologies, which may lead to significant market openings at a later date. The Technology Strategy Board maintains a watching brief in these areas, with a view to encouraging their exploitation within the UK economy as the technologies reach maturity and market opportunities emerge. It has not yet been finalised which emerging technologies will be identified for specific investments but some of those discussed here could be relevant.

Approaching opportunities for electronic and photonic 'nanodevices' to penetrate the vast data processing and storage markets are explored in UK's Nanotechnology KTA Strategy [5] and the field of nanoelectronics device development and manufacture is addressed in the ENIAC Joint Technology Initiative (JTI) across the EU [40]. In addition EPSRC continue to support research and development of microelectronic design and silicon technology and have recently published grand challenges in this area [41, 42].

The march of miniaturisation in electronics (Moore's Law) is not thought to be

Table 5 – Overview of Common Interests between Electronics, Photonics and Electrical Systems and Innovation Platforms

Innovation Platform	Common Interests
Assisted Living	■ Sensors and healthcare technologies for use in the home ■ Telecoms-based health provision & services
Intelligent Transport Systems & Services	■ Sensors & control for traffic management ■ Navigation & location-based services
Low Carbon Vehicles	■ Drive power generation & management in electric & hybrid vehicles; ancillary power management ■ Sensors & control systems for emissions monitoring & reduction
Low Impact Buildings	■ Off-grid power generation & management, including photovoltaics, fuel cells, combined heat & power & heat pumps ■ Lighting & domestic power efficiency ■ Tools for 'live' monitoring of electricity, gas and water use, and smart sensors connected to meters and appliances (such as fridges) to manage demand ■ Wireless and wired sensors for smart building control, interoperable building management systems and user focussed control of building management systems
Network Security	■ Embedded systems with inbuilt security ■ Fraud prevention measures, including biometrics for authorisation and authentication ■ Privacy of collected information ■ Resilience and security of critical information infrastructures ■ Trusted computing, especially when building systems from untrusted components ■ High performance (3rd generation) cryptography devices

sustainable with current designs [35], so beyond 2015 there are opportunities for disruptive technologies to enter the market, including carbon-based semiconductor devices (e.g. nanotubes or polymer transistors), quantum electronics (quantum dots and wires) and 'spintronic' devices and eventually perhaps quantum computing. Optical signal processing will be required when electronic solutions have reached their processing limits. To achieve this optical functional elements will be required including switches (spatial and wavelength), wavelength /dispersion management, amplification and polarisation control. The UK is outstanding in the development of all of these ideas.

New materials technologies are also poised to penetrate EPES markets. Microstructured optical 'metamaterials' such as photonic crystals are projected to grow from a $14 million market to $666 million by 2013 [43], and "photonic bandgap" applications promise enhanced non-linear optical performance for use in the signal processing applications above. Meanwhile, new nanostructured materials with high surface areas can be applied in established electrical devices markets such as batteries, fuel cells and supercapacitors, and in chemical applications such as sensors and nanomedicine. Quantum dots' tunable spectral signatures have marketable photonics applications, including in sensors and in photovoltaics, where they can substantially boost the conversion efficiency. Nanophotonics themes are developed on the European stage as the MONA theme [44] within the Photonics[21] European Technology Platform (ETP)

4.3 Implementation and delivery

4.3.1 Previous strategy and technology programme investment

The DTI published its Electronics and Photonics Key Technology Area strategy in April 2006. This updated document builds upon these foundations and, in response to feedback on the DTI strategy, the Key Technology Area has now been expanded to include Electrical Systems. From 2004 to 2008 these areas have attracted £105 million of investment through the Technology Programme, and over 100 Knowledge Transfer Partnerships have been granted in EPES.

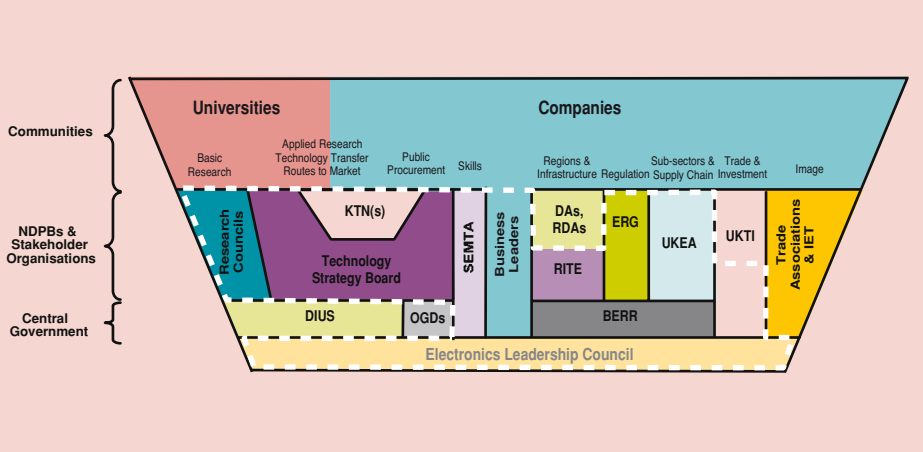
4.3.2 Stakeholder organisations and reports

Considerable progress has been made in bringing the sector together in the recent past, through Innovation and Growth Teams, the Department for Business Enterprise and Regulatory Reform (BERR) Electronics and Photonics sector teams, the EPSRC Electronics sector team and others. The Technology Strategy Board will continue to add value to the EPES Area by building on the good work that is already in progress to tackle the technology challenges that are faced.

The Electronics Innovation and Growth Team (IGT) report 'Electronics 2015', published in December 2004 [6], led to the formation of the business-led Electronics Leadership Council (ELC), bringing together stakeholders from industry, government, academic and funding bodies [45], and now including the Technology Strategy Board. A pictorial overview of the structure is in Figure 21. The ELC continues to provide a route for the collective industry to consider their view of the technical direction [46] and is also a unifying voice for all parties

In parallel with these efforts, a Photonics Strategy Group was set up by DTI in 2005, and published its report 'Painting a Bright Future' in July 2006 [9]. This led the photonics industry along a similar path, with the establishment of the Photonics Leadership Group (PLG) and the Photonics KTN. A pictorial overview of the structure is in Figure 22.

Figure 21 – Pictorial Overview of Electronics Leadership Council Structure in 2008



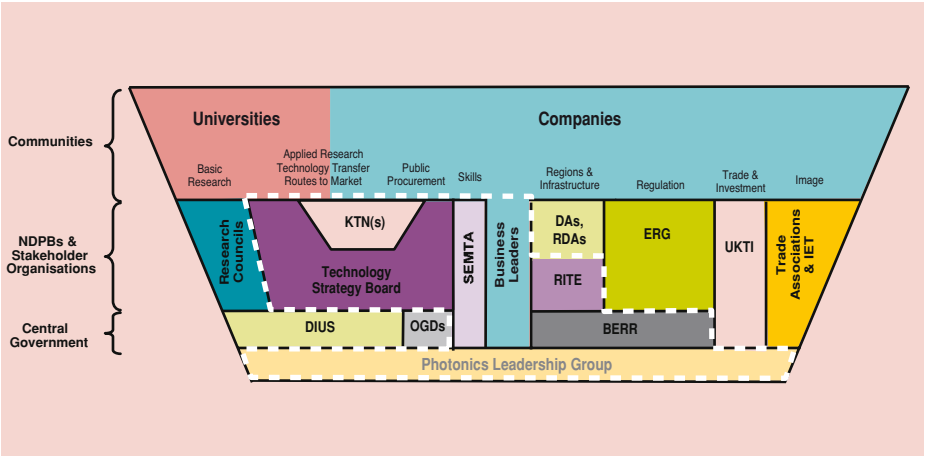
The Technology Strategy Board welcomes the existence of each of these groups, which bring coherence to previously fragmented sectors and provide a hierarchy of opinion through which the collective interests of the industry can be voiced, and looks forward to continuing a strong working relationship in the future.

4.3.3 Knowledge transfer and business support

All of the strands of this strategy require, crucially, good communications: between businesses as they build their knowledge and material supply chains; between stakeholder groups representing the needs of industry and others; and between all of these parties and government. The structure of the EPES industries, and in particular the growth of 'open innovation' models of R&D outsourcing, means that business partnering and networking is of especially high importance.

Amongst the infrastructure available, the Technology Strategy Board invests in Knowledge Transfer Networks (KTNs), to aid these communications. KTNs can help businesses with networking activities and information services, to encourage them to cross-fertilise ideas, construct supply chains and maximise UK wealth creation. The KTNs currently operating directly in the EPES domain are described on the Technology Strategy Board web-site [4] Together their activities seek to span the Key Technology Area. All organisations and individuals who seek to engage with the activities and technologies described in this strategy are urged to join the relevant KTN(s).

Figure 22 – Pictorial Overview of Photonics Leadership Group Structure



Knowledge Transfer Partnerships (KTPs) are a tried and tested method of enabling companies to obtain knowledge, technology or skills which they consider to be of strategic competitive importance, from the further/higher education sector or from a research and technology organisation. The knowledge sought is embedded into the company through a project or projects undertaken by a good quality individual recruited for the purpose to work in the company.

THE UK SHOULD:

- Promote and strengthen the relationships between organisations, by:
  - Linking the extensive expertise in the UK science base to the business challenges that can be solved with this knowledge,
  - Promoting cross-disciplinary and cross-sectoral thinking in the innovation process, encouraging adoption of 'new to me' technologies and resisting the 'not invented here' approach.
  - Networking potential partners along the knowledge and material supply chains. Barriers and challenges include the risks of large end-users dealing with small providers, the need to ensure that the high value (i.e. high margin and high-skill) parts of global value chains reside in the UK, and the role of networks and clusters at regional, national and international scales in benefiting service and component suppliers.
  - Engaging the diverse SMEs of which the EPES sectors are comprised, and implementing mechanisms that are accessible to them.
  - Encouraging new UK businesses to take advantage of the opportunities arising from government procurement.
- Use intellectual property protection, regulations, standards and metrology to the benefit of UK business, by:
  - Identifying when national and EU standards, regulation or legislation are required to widen accessible markets, to create new markets, or as a reference for procurement to ratify the performance of new products.
  - Recognising that metrology is needed to assess compliance and product performance, and ensuring that the necessary techniques are developed. The National Measurement System (NMS) has been established in the UK for this purpose, providing funding to the National Measurement Institutions (NMIs) such as the National Physical Laboratory (NPL). Other centres of excellence, and further services are also available commercially.
  - Developing new metrology techniques to meet new requirements. The electronics and photonics industries occupy a unique situation with regards to measurement science, since they provide the sensing and instrumentation technologies which are its bedrock.
  - Ensuring that businesses are informed of opportunities presented by these issues.

The Technology Strategy Board will:

- operate Knowledge Transfer Networks covering the EPES strategic priority areas, to further improve engagement of UK businesses with each other, international partners, the academic base and government;
- ensure that the interventions it targets at the EPES sector are accessible to SMEs as well as larger organisations;
- connect the EPES businesses to the UK science base using Knowledge Transfer Partnerships, including short duration KTPs which will support the more immediate requirements of SMEs; and
- identify and signal requirements for metrology, standards and regulation.

Appendix 1 – End-use market sectors for EPES technologies

A1.1 Consumer products

The $291 billion global market [47] for consumer electronics and photonics products in 2007 includes items such as:

- TV sales, including flat panel displays, accompanying a marked increase in digital TV sales;
- games consoles;
- digital imaging equipment;
- CD and DVD players;
- portable entertainment, of which a large percentage is MP3 players; and
- portable navigation and GNSS devices.

Much of this functionality is hidden from the user in the form of embedded systems; the average consumer would probably not know how many lasers are in their house, but would answer very readily if asked how many DVD or CD players they own. The true worth of the UK electronics industry is similarly easily underestimated: UK chip designs are an integral part of the iPhone and iPod, of Bluetooth devices and a wide range of other consumer products. The consumer market is also considered further in the UK's Creative Industries Key Application Area (KAA) [5].

A1.2 Healthcare

The world's top thirty countries spend nearly $3.5 trillion per year on healthcare services [48], including over $1.8 trillion for the USA and $144 billion for the UK, and NHS expenditure alone is expected to account for around 9% of GDP in the UK by the end of 2008 [49]. There are expanding opportunities for electronic and photonic technologies in health and pharmaceuticals, often relatively underexploited, including:

- localisation of healthcare, including telecare;
- biosensing and health monitoring;
- targeted interventions;
- equipment for cancer treatment (radiotherapy, hadrontherapy and prototherapy);
- imaging technologies including new developments such as Terahertz imaging;
- tools for animal welfare and veterinary medicine; and
- analytical technologies enabling advances in bioscience, such as tools for drug discovery, or for genomic and proteomic analysis.

Photonic technologies in medical devices alone are forecast to reach $20.4 billion in 2010, within a global medical devices market valued at over £124 billion in 2005, of which the UK has a 3% share [50]. Foresight indicated that the UK could also capture up to $5bn of the market for integrated lab-on-chip systems, which provide a platform technology for multi-diagnostic applications including diabetes treatment, health monitoring, drug targeting and cancer detection. In fact monitors, sensors, and telemetry devices account for the largest share of the $14.6 billion home medical devices market in 2007, which is growing at 6.8% CAGR. This is mainly because of the very large market for home blood glucose testers, estimated at $7 billion in 2007 [43].

The regulatory environment surrounding healthcare technologies can make this a difficult market sector to penetrate, but Technology Strategy Board involvement can help to overcome these challenges, making the UK ideally placed to develop, exploit and export contemporary healthcare solutions. These themes are expanded in the UK's Medicines and Healthcare Key Application Area [5] and other aspects are appropriate to the Assisted Living Innovation Platform.

A1.3 Transport

According to the International Organization of Motor Vehicle Manufacturers, the turnover of the global automotive industry was €1,890 billion based on 2004 data or the latest available figures [51]. The electronics content of an automobile now averages some 20-25% of its production costs and this figure is expected to rise to 30-40% by 2010 due to the application of more sophisticated controls in engine management, drive train, anti-locking braking system, steering, tyre pressure monitoring and many other functions, plus increased sophistication of entertainment, information and navigation systems inside the vehicle. Thus the $106 billion 2006 global automotive electronics OEM industry is projected to grow by 7.5%CAGR over the next few years [52]. Within this, around 18% is spent on safety and convenience [43], with sensors representing a steady 10% [53] of the market, and around 12% is spent on powertrain electronics [43]. Body and chassis electronics are both becoming more prevalent and are predicted to achieve a $6 billion market by 2010.

The global aerospace market is worth $200 billion per annum and the UK aerospace industry is the second largest in the world, with a turnover of £19.8 billion in 2006. It comprising more than 3,000 companies and supports, directly and indirectly, some 400,000 UK jobs [54]. It is the UK's second largest manufacturing sector and adds, on average, £2.5 billion per annum to the UK's balance of trade [55]. Around 25% of the sector is associated with aero-engines. The global aerospace market is set to have total sales of around $2.6 trillion over the next twenty years, including some 15,000 single-aisle aircraft worth $1 trillion [56].

There is a need for control systems and power engineering to support the growth in both hybrid electric and full electric transport, which may use 300V or variable frequency systems; managing the power here is of critical importance. The operating conditions in a car, ship, train or plane can subject the electronic and photonic devices to high temperatures, corrosive environments, high accelerations and vibration; the design for such harsh environments is a significant challenge. Advances in device technologies, for example using MEMS sensors, or high-visibility non-planar displays, or innovative communications schemes to streamline the control systems, often first find a receptive market in the high value aerospace sector. From there find a route into the high volume automotive market. This strategy aims to identify these technologies and foster their adoption in both sectors.

Transport infrastructure and planning also has multiple requirements for sensing technologies, ranging from condition monitoring of bridges and motorways to traffic monitoring, congestion management and road charging. The UK has a separate KAA for Transport Systems [5], as well as an Innovation Platform dealing with Intelligent Transport Systems, and these themes are developed further there.

A1.4 Retail and logistics

RFID is becoming an established technology for tracking and item detection, and as this market expands new opportunities continue to open up. These range from increasing the functionality of the RFID tags themselves, for example by introducing sensor technologies, to low cost manufacturing methods such as offered by plastic electronics, to addressing the data handling requirements of national-scale monitoring projects. However, there are also issues to address in terms of privacy and underlying ethics involved, as tracking becomes a pervasive technology.

The world RFID market is projected to grow rapidly from about $5 billion in 2007 (including nearly $3 billion for RFID cards) to over $25 billion in 2017, by which time this will include $6 billion of self-powered 'active' RFID. Several analysts see huge volumes of extremely low cost tags forming a part of the growth – even hundreds of billions in ten years from now [57]. The retail market is one of the High Value Services sectors in which the UK shows particular strength, and which will be examined in the KAA strategy for this area [5].

A1.5 Security and environmental

The requirements of the security sector generate markets for imaging and sensing, which are paralleled in the environmental and industrial monitoring spheres. Remote imaging, scanning and chemical sensing, plus fast turnaround sample analysis technologies are all required, and the UK's strong capability in these technologies leaves it well placed to serve these markets. Individual applications have specific sensing requirements. This strategy seeks to promote the development of these component technologies, but platform technologies are also sought which can combine or configure different functionalities and respond to multiple applications.

Within the UK, EPSRC has a Crime Prevention Programme, whilst the MoD spends a significant proportion of its procurement budget on sensors and sensor systems. Hence, there could be significant benefit to UK-based industries by aligning industrially focused R&D activities to dual-use applications. Global biometric market revenues are expected to increase from $1.5 billion in 2005 to $5.7 billion by 2010. Photonics enables the majority of these products, with fingerprint analysis representing 43.6% of the market utilising laser and image scanning techniques [58]. Electronics and Photonics also have a role to play in Network Security, which is a field where the Technology Strategy Board has an Innovation Platform [5].

Environmental monitoring relies heavily on sensing and imaging technologies, including remote sensing and satellite imaging. The National Environment Research Council (NERC) strategy will concentrate on the development and deployment of these systems. Business opportunities in farming and agriculture range from monitoring of irrigation systems to RFID tagging of cattle herds. This under explored sector offers a very large global market opportunity both for innovations and for new applications of existing technology.

A1.6 Government procurement and the science base

The UK Government currently spends approximately £150 billion per year on procurement [3], or 12% of GDP. This represents a substantial market for all business sectors, not least for technology providers, although much of this procurement is conservative and not encouraging of innovation. However, the government's support of the science base through the UK Research Councils, which amounts to £3.2billion per year, results in highly technology-intensive procurement that represents a significant market opening for technology providers.

For example, the UK hosts a number of world-class large scientific facilities, such as those within the Rutherford Appleton Laboratory and Daresbury Laboratory, and participates in international efforts encompassing many more, largely funded by the government through the Science and Technology Facilities Council (STFC). Such facilities are heavy users of sensor and instrumentation technologies, as well as being centres of excellence for development of the technologies and of expertise and services in the measurement techniques they enable.

There are well demonstrated spillover benefits to industrial and healthcare uses of instrumentation that result from investment in scientific instrumentation [59]. Technology transfer both into and out of these facilities and the scientific demand for instrumentation as a whole is therefore an important commercial channel. The Technology Strategy Board has formed a strategic partnership with STFC, BBSRC, NERC and UKEA, mediated by the Sensors and Instrumentation Knowledge Transfer Network, to strengthen the links between academia and industry that these facilities and science requirements create.

Appendix 2 – Market potential of individual EPES technologies

A2.1 Control systems and power engineering

A2.1.1 Power Electronics and Systems

Global electricity demand was estimated as $1.16 trillion for 2006, of which 36% is for industrial uses. The market is growing at 10.1%CAGR due both to increasing usage (5.6%CAGR) and unit price rises (4.2%CAGR) [15]. This market drives the technology markets for electrical systems.

There is a growing need for reliable and stable power, which will buffer the effects of supply voltage and frequency variations on the supply side. This can be at the level of a few kilowatts in domestic and commercial environments, or it may be at many megawatts or MVAr in Flexible AC Transmission System (FACTS) devices and Dynamic Voltage Restorers (DVRs) for power system operation. The world market for FACTS devices and High Voltage DC (HVDC), which rely on good power semiconductors and materials advances such as the use of silicon carbide, is predicted to be worth over £200 billion by 2015, the UK market being about 5-7% of this total [27]. The low voltage market is also of increasing importance with portable devices such as mobile phones now a consumer phenomenon. In fact worldwide mobile subscribers were estimated at 2.5 billion in 2006, and forecast to grow 42 per cent to 3.6 billion in 2010, which is a huge number of mobile phone chargers [60].

Electrically powered transport, from cars, to planes and ships, are becoming a commercial reality, with different levels of adoption of new technology. These applications require advances in electric motor drives and generator technology with extremely demanding cost targets. According to Frost & Sullivan, "The growth of electronic content in automobiles and the tremendous rise of communication and electronic gadgets have a positive impact on the sales of discrete power semiconductors," to the extent that the world power semiconductor markets are forecast to grow from over $10 billion in 2005 to over $14 billion in 2009 [61]. The forecast for power management ICs is for CAGR of around 10%, whilst Power-over-Ethernet and Power-Factor-Correction technology is around 20%. The worldwide market for integral horsepower industrial AC induction motor, generator and motor drive is estimated to be $30 billion [64]. Electrical engineering in the UK has a manufacturing turnover of about £15 billion, with about £1 billion in net exports; the net export figure has fallen from a much higher figure because of substantial increases in import.

A2.1.2 Microgeneration and portable power

Electricity generation technologies are addressed in detail in the UK strategy for Energy Generation and Supply [4], but should also be considered here, in the context of both electrical systems technology and electronics and photonics.

Given the generation and transmission losses identified above, it may become more economical to generate power or heat close to the point of use, especially if multiple steps of voltage and/or frequency conversion would be needed to supply the electricity from the grid. Although opportunities for truly cost-effective microgeneration in the UK are currently relatively few [63], it is projected that by 2050 microgeneration could provide 30-40% of the UK's electricity needs and help to reduce household carbon emissions by 15% per annum [64]. Technology developments and innovation will be central to this revolution.

Power for use in portable applications is of increasing importance for consumer devices such as mobile phones and laptop computers, for sensor-enabled systems in medical devices and embedded in the environment, and for both drive power and ancillary power in transport applications. Whilst there is a large global market for batteries, the UK is not a major supplier. However the future may not necessarily lie with solutions that can store more energy, and rapid re-charging or power scavenging may provide opportunities for the UK to exploit. The Ministry of Defence is also interested in the various routes to provide portable power to support their ever increasing need to operate in remote areas. Candidate technologies to enter these markets include miniaturised fuel cells, micro-photovoltaics, and devices such as thermoelectrics to scavenge power from waste heat or vibration. Together these constitute portable power generation, and their development is a necessary adjunct to the success of many of the other technologies discussed in this strategy.

A2.1.3 Lighting

The market for lighting is very large – estimated at over $100 billion in 2006. Traditional lighting equipment uses filaments or gas and has made very little innovative progress in efficiency or versatility over time. The semiconductor industry is now offering the alternative optoelectronic solution of solid state lighting (SSL), and light emitting diodes (LEDs) in particular. LEDs have long been used in electronics products for indicators and displays and, due to advances in low cost manufacturing and packaging, have now started to be used for illumination and signage [65]. The market for SSL is predicted to $60.0 billion in 2017 at a CAGR of 57%, as LEDs progressively replace conventional lamps [14]. The first wave of demand will be generated from niche lighting applications including architectural, task lighting, medical and off-grid lighting applications. As an example, automotive applications such as display backlights and headlights are forecast to be worth $1 billion by 2014. Around this time significant implementation in residential and

consumer markets will begin [66]. Other applications include traffic signals, large outdoor single-colour and full-colour signs, indicator lamps in consumer and wireless electronics, automotive exterior and interior lighting, and LCD display backlighting. All of these usage applications will also require advances in driver technology to ensure that the energy savings are not lost in the transformer. For instance, a dedicated low voltage ring mains might be a more efficient solution for some buildings.

A2.2 Plastic and printed electronics

The worldwide market for organic and printed electronics is estimated to rise from $1.18 billion in 2007 to over $48 billion by 2017 [67]. Technology analysts speculate that these new markets could be valued in the hundreds of billions of dollars within 20 years.

One substantial opportunity is in the flat panel display component market, for which a UK capability study has been conducted in the past [68]. Recent data shows the market exceeded $94 billion in 2006 and will grow to nearly $200 billion in the next ten years [14]. Currently this is based on silicon deposited on glass, but plastic substrates and organic semiconductors aim to penetrate or displace parts of this. For example, the e-paper market is predicted to reach $2 billion by 2012 and then double again in the subsequent two years [69].

Similarly, photovoltaic cells achieved global market revenues of $10.6 billion in 2006 (with 55% of the global installed base being in Germany), with growth to between $18.6billion and $31.5billion projected by 2011 [70], by which time a market of $2.3billion is predicted to emerge for thin film and organic semiconductors as they penetrate the market in portable applications and low cost installations in the built environment [71].

Similar rapid market penetration is predicted for plastic RFID tags and other cheap disposable electronics and, combining the organic electronics and lighting themes, the emerging market for organic light emitting diodes (OLED) has been forecast to exceed $400m by 2010, with strong continuing growth to over $6 billion in 2015 [14, 72].

A2.3 Data and image acquisition

A2.3.1 Sensors

The importance of the sensing and instrumentation market is hard to over-state especially since markets for sensor and imaging systems are very broad and diverse, with applications that range from mass-production automotive sensors to astronomical instruments on spacecraft. The 2010 global sensors market is estimated at $61.4 billion [72], whilst the global instrumentation and control market is estimated at £100 billion with the UK having annual sales of around £12 billion [11], with these instruments underpinning £165 billion of manufactured goods in the economy [73]. Within this:

- The combined market for pressure sensors, transmitters and transducers exceeded $4 billion in 2005, and is forecast to approach $5.4 billion in 2010 [74].
- Proximity and displacement sensors exceeded $2.2billion in 2006, and will grow to over $3.0billion by 2013 (4.4%CAGR).
- A new market for sensors based on nanotechnology is expected to reach $2.7bn by 2007 [75].
- Distributed fibre optic sensor revenue is forecast at just under $1 billion by 2010 [14].
- Sensors for homeland security systems are now receiving large investment, particularly in the USA, and the market will exhibit rapid development during forthcoming years.
- Image sensor sales surged to $7.4 billion in 2006, driven by the emergence of camera phones and digital still cameras. Price pressure has cooled revenue growth, but the market will still continue to expand at 10% per year to $12.1 billion in 2011 [76] and perhaps $20 billion by 2017 [14]. 3D/4D visualization in medical imaging is an important subsector, the North American market alone being forecast to rise from $0.5 billion in 2006 to $1.36 billion in 2013.

The worldwide spend on research facilities is more than $20 billion a year, representing a substantial market for instrumentation and sensor technologies. But this is a fragmented market which has made it difficult for companies to view it as a single market for government-funded projects. Nevertheless the scope of the market is revealing a range of opportunities for capability enhancement within the sensor and instrumentation sector. From an end-user perspective, it is essential to recognise that no matter how good the sensor is (and the UK is world class in sensor innovation), there needs to be some level of incorporation into a system, often an instrument, for it to actually fulfil an economically useful role [77].

A2.3.2 Communication and location-based services

The explosive growth of these communications technologies enables new service industries such as telemedicine, which is forecast to grow from $5.8 billion globally in 2007 to over $13.9 billion by 2012, a CAGR of 19%. [43].

The growth of sensor network, embedded systems and AIDC technology markets, combined with increasing active functionality in mobile phone handsets, will also enable a new class of Location Based Service (LBS) industries. The

location sensing market is undergoing a huge change, with sales of Mobile Navigation Devices doubling in 2006 and still growing exponentially [78]. 180 million GNSS-enabled mobile devices were sold in 2007 and 45 different GNSS-enabled phone models were available in Japan in 2006. This wave is about to reach Europe, and the UK is well placed to provide the new downstream services that can be accessed using these devices. Over the next decade, annual revenues of the global Geographic Information System (GIS) market are expected to grow from $4 billion to $150 billion [79]. The European Commission has estimated a potential market for Global Navigation Satellite System products and services (Galileo and GNSS) of €400 billion of which UK industry can expect to capture as much as €24 billion [80]. Location-based services are expected to account for a large amount of this market and as we come to rely on these types of system, the security and resilience of them needs to be addressed.

A2.4 Communications

The optical communications market is now rebounding after the post bubble years (2001-2003), and is forecast to grow from $19 billion in 2006 to nearly $40 billion in 2017 as shown in Figure 23. Photonics is a key enabling technology for broadband communications and, as infrastructure rolls out worldwide, advances in lasers, optical fibres and optical switching present significant opportunities for UK photonics and electronics companies. Photonic components represent 19% of this market, networking equipment 64% and fibre and cable 17% [14]. The largest growth in optical telecommunications products is for fibre to the home/building/node, with 7 million laser based modules sold in 2007. Laser diodes for all telecommunications applications are expected to reach revenues of £1.9 billion in 2008, a 7% growth over 2007.

In addition, there are emerging markets for RF electronics technologies in high frequency broadcast communications, as bandwidth requirements force operation further into the microwave frequency range, and towards terahertz. Figure 24 shows how worldwide wireless semiconductor revenue is forecast to double in 5 years from its 2007 level of $40 billion, led by growth rates in excess of 20% in Asian markets. Wireless mobile personal communications are of particular interest, with 3G and Bluetooth now evolving and future developments such as WiMax, Zigbee and 4G/Long Term Evolution (LTE) under way or under consideration. These systems are highly dependent on the ability to design complex silicon-based electronics, which is a notable UK strength. Wireless technologies such as Bluetooth, Near Field Communication, Ultra Wide Band, Wi-Fi, Zigbee and others, are forecast to grow in the very high double digit percentage range over the next five years.

With the advent of sensor networks and embedded devices, there will also be requirements for device technologies to support ad hoc communications networks, with challenges including power management, device miniaturisation and packaging, as well as communications and control protocols that are addressed in the UK's Information and Communication Technology KTA [5].

A2.5 Systems design and integration

A2.5.1 Embedded systems

Whilst it is difficult to separate the values of the integrated circuit, operating system, drivers and application software, and the value added to the final product by embedded software may be substantially higher than the cost of the devices themselves, it is possible to say that the embedded integrated circuit market is estimated to reach $78.7 billion in 2009. It supports a dedicated software market of $3.5 billion with boards accounting for a further $6 billion [43]. Europe is a major player in this market, holding market shares of 30% in the industry/energy and defence/space domains, and 37% in the automotive market. Given that nearly a third of Europe's electronics design companies are located in the UK [6], this places us in a very strong position to extract value from global product markets in large and profitable sectors not traditionally thought of as being part of the electronics market.

Figure 23 – Global Optical Communications Revenue & Forecast, 2000-2017 [14]

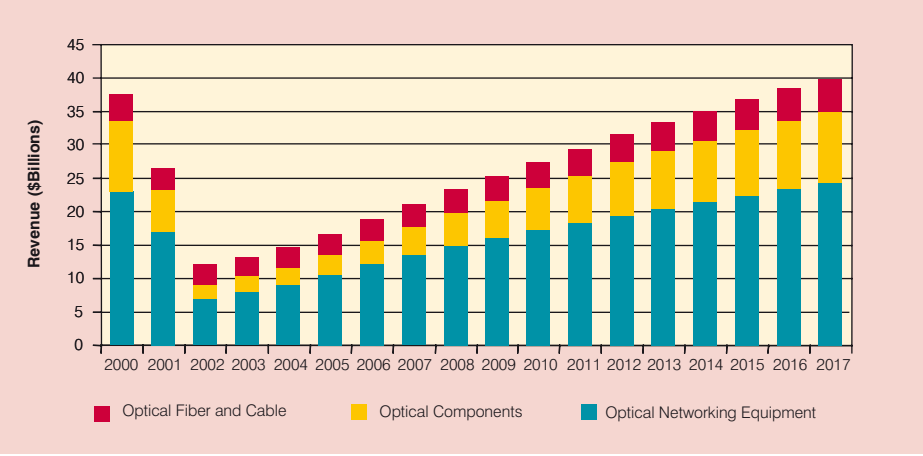
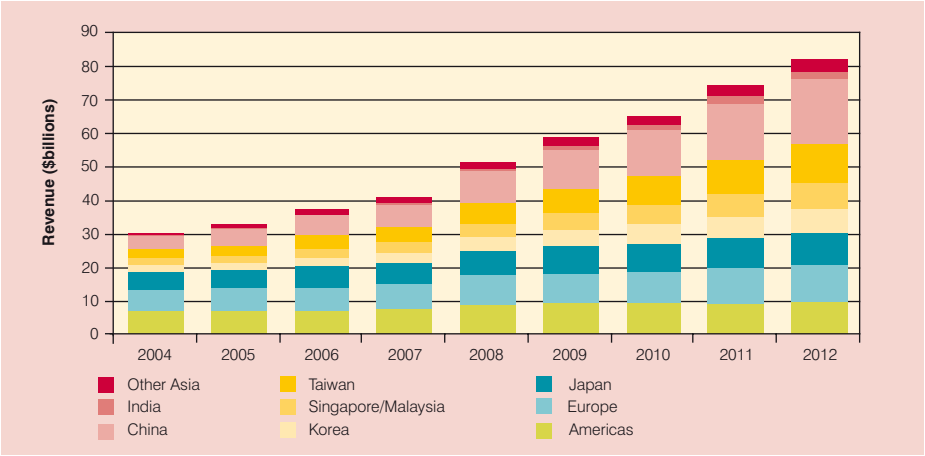


Figure 24 – Worldwide Wireless Semiconductor Revenue Forecast by Region [65]



A2.5.2 Robotics and autonomous systems

It has been forecast that the world-wide market for robot systems will exceed $51 billion by 2025 [81], Indeed the Japan Robotics Association has even forecast that the market could exceed $90 billion by 2025 (across security and space, personal and service, medical and bio-industrial and Manufacturing). The surgical robotics market in the USA alone is forecast to be worth approximately $2.5bn by 2011, with an expected average annual growth rate of 43% in the period 2006-2011 [43]. In Europe, uptake of Computer Assisted Orthopaedic Surgery (CAOS) has been limited by concerns over accuracy and standards of equipment, as well as the need to verify clinical outcome [82]. Growth is also on the horizon for the personal robotics market, which means revenue opportunities for key enabling components are set to rise, such that by 2015, worldwide revenue for major component categories – such as processor, microcontrollers, sensors and servos – will reach $12 billion. Some 48% of that will be attributable to task robotics, with 51% from entertainment robotics. The educational and security segments will account for the remaining fraction of revenue [83]. It should be noted that the applications for robotics are wide ranging and the simpler task-oriented systems are the more likely entry route, rather than complex humanoid like machines. These applications also mean that robotics is an enabling technology for sectors such as manufacturing where product quality and yield can be improved.

A2.6 Industrial lasers

European companies lead the world in many of these areas, receiving almost half the revenues from laser sales. The growth in the world market for laser sources and integrated systems continues to be healthy, with new high brightness laser sources and applications in micro-processing providing promise for even more rapid growth in the near and medium term. In 2007, the global market of $6.9billion showed sustained growth in all markets and sectors. Fibre laser sales continue their rapid growth with revenues estimated to grow from $131 million in 2005 to $674 million in 2010, a CAGR of 38.8% [84].

Appendix 3 – Electrical power usage data

A breakdown of overall UK annual electricity consumption by end use is shown in Figure 26, and its evolution over time in Figure 25. An examination of this data identifies the areas of large consumption where there may be opportunities for efficiency improvements.

- The generation and transmission of electricity together account for a loss of ~13% of generating capacity before the user is reached [Figure 26].
- Industrial uses account for ~32% of generating capacity (Energy-other, Chemicals, Paper & printing, Food & beverages etc. and other industries) [Figure 26], and EU statistics universally conclude that 65-70% of this is used in electric motors [Figure 27]. The UK's largest manufacturing sectors include the energy, chemicals, paper and food industries [4], and these are heavy users of motors in the form of pumps, conveyor drives, compressors and fans. There is definitely scope for energy saving. Since the average motor has an efficiency of 88%, improving this to 96% to comply with IET standards [86] would make a saving of 5TWh in the UK alone.
- Commercial environments (retail, hotels/catering, education, offices, warehouses, etc) accounts for ~19% of generating capacity [Figure 26], of which the principal components are lighting (32%), heating (20%) and cooling or refrigeration (22%) [Figure 29]. This sector accounts for almost half of the recent increase in demand.
- The domestic sector accounts for ~28% of generating capacity [Figure 26], around half of which is again accounted for by lighting, heating and refrigeration [Figure 28]. Standby power then accounts for ~6% of domestic usage [Figure 28], almost 2% of all generated electricity.

Figure 25 – UK Annual Electricity Consumption by End Use [85]

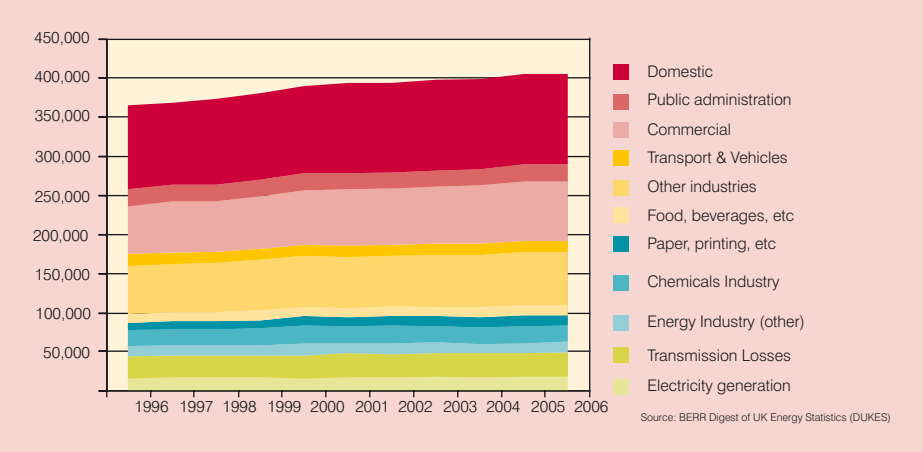


Figure 26 – UK Electricity Consumption by End Use 2006 [85]

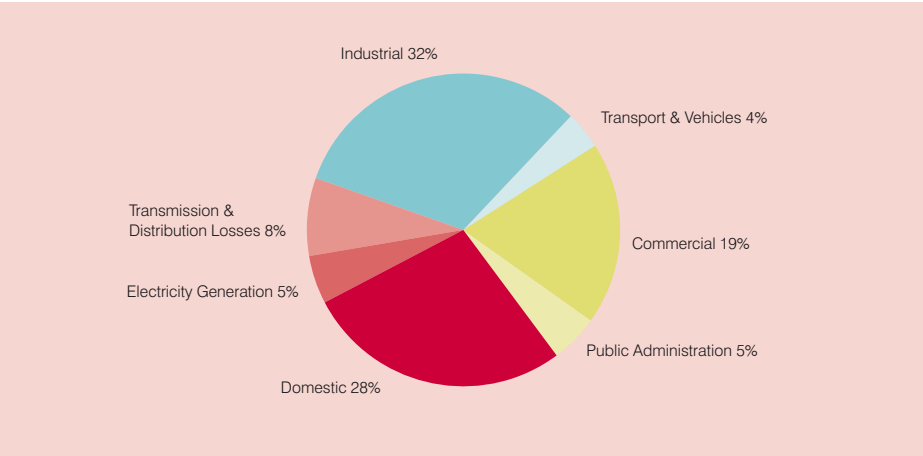


Figure 27 – Industrial Electricity Consumption in EU15 countries [18]

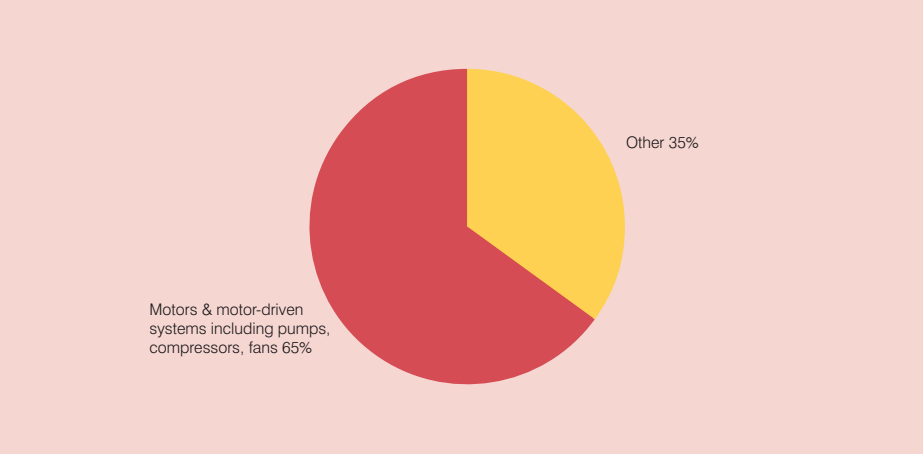


Figure 28 – Residential Electricity Consumption in EU15 countries [18]

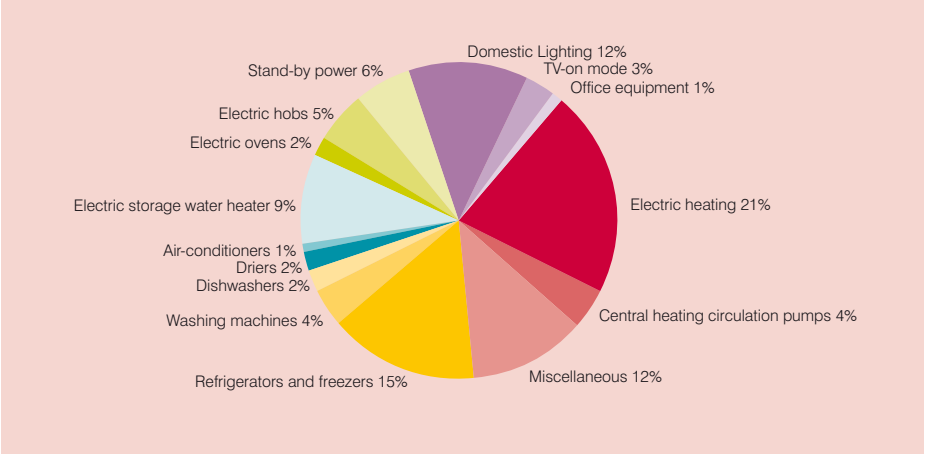


Figure 29 – Tertiary Sector Electricity Consumption in EU15 countries [87]

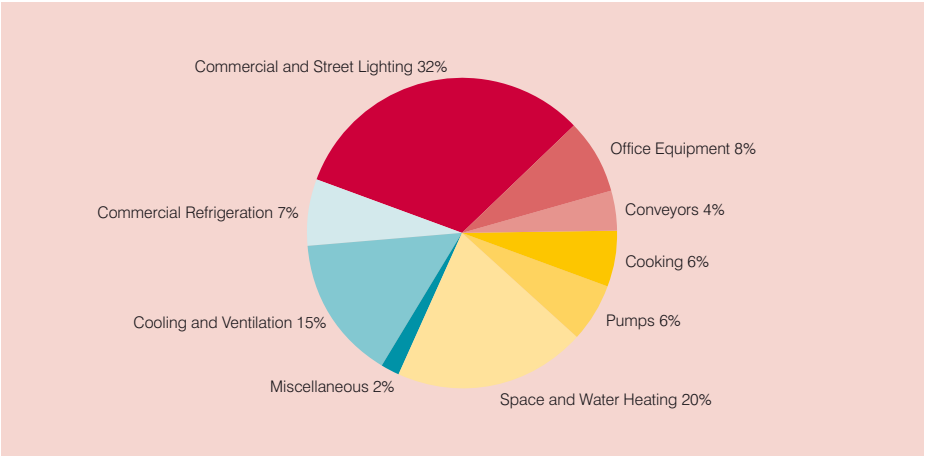
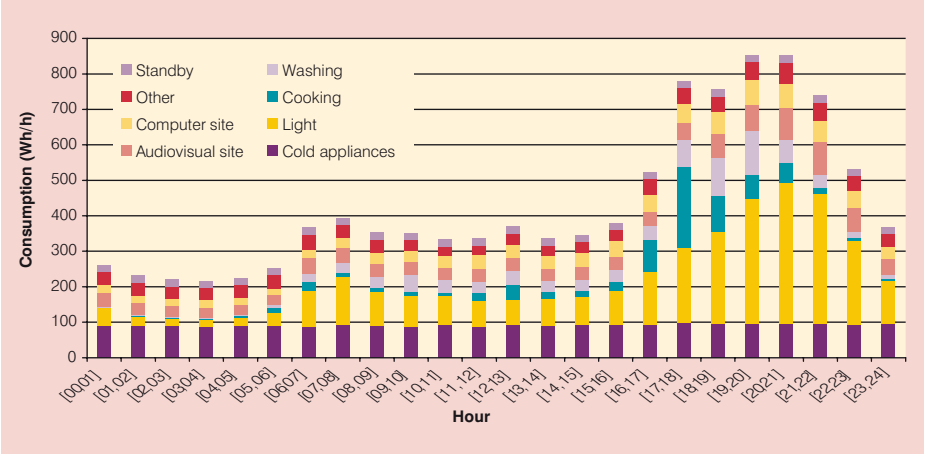


Figure 30 – Diurnal Variation of Domestic Electricity Demand [88]



Electricity demand is also not uniform through the day. In the domestic environment, for example, usage by refrigeration is constant, but consumption in lighting, cooking and washing show strong diurnal variations [Figure 30]. This causes demand to peak in the evening at around double the daily average, to some extent mitigated by commercial sector loads, which peak during the day. Events such as television scheduling can then cause further demand spikes, which require that additional generating capacity must be kept in reserve at all times, at a considerable cost to the producers, both in plant and in system efficiency. Technology that can smooth this usage curve is an attractive proposition from an economic and environmental perspective.

Appendix 4 – Illustrative summary of sensor & imaging applications

The great diversity in sensors and imaging technologies allows their application in many market sectors. A fraction of this potential is illustrated in Table 6.

Table 6: Illustrative Table of Sensor & Imaging Applications

Sensor & Imaging Applications	Healthcare	Environmental	Defence, Security & Safety	Automotive/ Aerospace	Consumer	Industrial & Commercial
Chemical & Biological	Blood sugar	Water quality	Explosives & threat detection	Engine management	Pregnancy testing	Process control
	Breathalyser	Air quality	Fire detection	Vehicle emissions		Industrial emissions
	Sample analysis	Climate monitoring	Gas detection			Chemicals mfr
	Drug development	Soil quality	Biometrics			Oil & Gas
	Animal health	Pathogen detection				Food quality
	Genomics	Sample analysis				Gas detection
	Pathogen detection	Animal health				
	Biomarkers	Genomics				
	Proteomics	Proteomics				
		Gas detection				
		Biological monitoring				
		Biomarkers				
Position & Movement	Fall alerts	Infrastructure monitoring	Triggering	Airbag	Gaming & controllers	Vibration
		Seismology		Suspension	Computer interfaces	Condition monitoring
				Fly/drive by wire		Machine control
				Speed		
Location & Proximity	Patient location	Flooding	Intruder detection	GPS/ GNSS	Handset location	Retail logistics
		Landslides	Ranging & Targeting	Other navigation		
				Traffic monitoring		
				Anticollision / parking sensors		
				Lane Departure		

Sensor & Imaging Applications	Healthcare	Environmental	Defence, Security & Safety	Automotive/ Aerospace	Consumer	Industrial & Commercial
Pressure & Temperature	Microfluidics	Meteorology	Fire detection	Tyre pressure	Thermostats	Process control
	Health diagnostics		Depth monitoring	Altitude		
				Engine management		
Level & Flow	Respirators	Rivers & water treatment		Fuel gauges		Process control
Light & Infrared	Fluorescence & biomarkers	Pollution monitoring	Intruder detection	Keyless entry	Optical data storage	
			Fire Detection		Remote controls	
Imaging	Medical Imaging (multiple types)	Remote sensing	Security cameras	LIDAR	Digital image capture	Machine vision
	Biomarkers		Security scanners		Video capture	Barcode readers
			Biometrics		Document scanning	

Appendix 5 – Glossary

AIDC	Automatic IDentification & Classification
ARTEMIS	Advanced Research & Technology for Embedded Intelligent Systems
ASIC	Application Specific Integrated Circuit
BBSRC	Biotechnology and Biological Sciences Research Council
BERR	Department for Business Enterprise & Regulatory Reform
CAGR	Compound Annual Growth Rate
CAOS	Computer Assisted Orthopaedic Surgery
CFL	Compact Fluorescent Lightbulb
CHP	Combined Heat & Power
CMOS	Complementary Metal Oxide Semiconductor
DIUS	Department for Innovation Universities and Skills
DSL	Digital Subscriber Link
DTI	Department for Trade and Industry (now BERR or DIUS)
EDA	Electronic Design Automation
ELC	Electronics Leadership Council
EMC	ElectroMagnetic Compatibility
ENIAC	European Nanoelectronic Industry Advisory Council
EPES	Electronics, Photonics & Electrical Systems
EPSRC	Engineering & Physical Sciences Research Council
ERG	Electronics Regulatory Group
ETP	European Technology Platform
EuP	Energy using Products
FACTS	Flexible AC Transmission Systems
FPGA	Field Programmable Gate Array
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HF	High Frequency (3MHz-30MHz)
HVDC	High Voltage Direct Current
ICT	Information & Communications Technology
IET	Institution of Engineering and Technology
IGT	Innovation & Growth Team
JTI	Joint Technology Initiative
KTA	Key Technology Area
KTN	Knowledge Transfer Network
LED	Light Emitting Diode
LF	Low Frequency (30kHz-300kHz)
MEMS	Micro Electro-Mechanical Systems
MoD	Ministry of Defence
MONA	Merging Optics and NAnotechnologies

MST	Micro Systems Technologies
NERC	Natural Environment Research Council
NGA	Next Generation Access
NMS	National Measurement System
NPL	National Physical Laboratory
OLED	Organic Light Emitting Diode
PLG	Photonics Leadership Group
PV	PhotoVoltaic
R&D	Research and Development
REACH	Registration, Evaluation, Authorisation and restriction of CHemical substances
RFID	Radio Frequency IDentification
RITE	Regional Information Technology and Electronics group
RoHS	Restriction of Hazardous Substances
SIC	Standard Industrial Classification
SME	Small or Medium-sized Enterprise
SSL	Solid State Lighting
STFC	Science Technology & Facilities Council
TSB	Technology Strategy Board
UHF	Ultra High Frequency (0.3-3GHz)
UKEA	UK Electronics Alliance
UKTI	UK Trade & Investment
WEEE	Waste Electrical and Electronic Equipment

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The Technology Strategy Board
B1 North Star House
North Star Avenue
Swindon
SN2 1JF

Telephone: 01793 442700

www.innovateuk.org