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Technology and Innovation Futures: UK Growth Opportunities for the 2020s

Foresight Horizon Scanning Centre, Government Office for Science

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Technology and Innovation Futures:

UK Growth Opportunities for the 2020s

1. Executive Summary

Historically, periods of sustained economic growth are associated with the development of new industries built around clusters of innovations. These developments are dependent on factors such as the availability of complementary technologies and infrastructures, skills and training, and a favourable regulatory environment. In many cases the role of the state as an early purchaser and user has been important.

Many leading nations set out actively to identify promising technology clusters. China, Japan, France and Germany have all identified key future technologies which they see as underpinning the future of their economies, and have built strategies to capitalise on them. In the USA, the Obama administration has committed to producing a comprehensive technology and innovation plan, and has greatly increased funding for biomedical research, the physical sciences and engineering, and boosted support for high-risk/high-payoff research seen as having the potential to produce real breakthroughs.[1]

Technology and Innovation Futures is a forward look at a range of developments which have the potential over the next 20 years to support sustained economic growth in the UK. Based on interviews and workshops with 180 representatives from industry, research, international institutions and social enterprises, the report identifies 53 technologies which are likely to be important to the UK in the 2020s, because of the UK's comparative advantage today, its future needs, or the size of the potential market. As the UK comes out of the economic downturn, it seems likely that future economic prosperity will derive in large part from seizing opportunities offered by technologies such as these.

The 53 individual technologies identified in this report can be readily grouped into 28 clusters, as described in Chapter 4. From these, seven cross-cutting areas have been identified, which are likely to be particularly important to the UK in the 2020s, regardless of how far individual technologies mature in that timescale.

Key Message 1. There are strong opportunities for growth in the UK economy through the 2020s if businesses can harness scientific and industrial capabilities to take advantage of technology-enabled transformations in manufacturing, infrastructure and the internet

- By the 2020s, **manufacturing on demand** – the ability to manufacture a customised product at different sites using hi-tech fabrication devices driven by software-encoded design instructions – may in some sectors overcome the drive towards commoditisation and economies of scale, to meet a growing demand from consumers for personalised products and services. This is already happening in the digital sphere (from iTunes to online gaming) and may move up supply chains in some manufacturing industries, disrupting the 20th century

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1 http://www.ostp.gov/cs/issues/science

'mass market' model, and providing enormous scope for adding value. Adoption of this manufacturing model would offer the UK an opportunity to leapfrog current leading manufacturing countries by implementing cutting-edge manufacturing approaches, providing new opportunities for local, niche manufacturing in the UK. This development would be based on technologies such as rapid prototyping and 3D printing; to benefit, UK companies would need to continue to innovate in the design of products and services.

- National infrastructure will require new technologies to help meet future challenges, such as reducing greenhouse gas emissions, and to enable the widespread deployment of **smart infrastructure**. For example, the electricity distribution network will need new instrumentation to support microgeneration, electric vehicle recharging and smart metering. The challenge of maintaining cyber security for smart water, electricity and transport infrastructures will be paramount, and has been addressed by the recent Strategic Defence and Security Review (SDSR)[2]. Distributed sensor networks will help manage the new infrastructure, and new applications will arise from them, with opportunities created by the UK's strengths in areas such as internet technologies and photonics.
- The **Internet** is set to enter a second transformative phase, with a 'web of data' adding structure, meaning and reusability to online data and documents. New business models and large new businesses would be enabled by such change. Government has a part to play by further opening up public sector data in a way that is compatible with this new 'web of data' model, as it has already with the recently-launched UK legislation online website.

Key Message 2. The energy transition which the UK will undergo during the next 10-20 years, the UK's R&D efforts in new materials, and the burgeoning market for regenerative medicine offer opportunities for UK companies

- The **energy transition** will stimulate technology development in renewable energy generation, batteries and fuel cells, the smart grid, carbon capture and storage, and potentially widespread use of hydrogen as a fuel, along with the resurgence of nuclear. The UK is well positioned to develop technologies and processes in this field and service the new infrastructure.
- The UK is a leader in the research and development of **new materials** which can help achieve carbon emission targets and reduce energy costs.
- **Regenerative medicine,** based on stem cell products, can help grow the UK life sciences sector if research, regulatory and financial challenges can be overcome. The massive purchasing power of the NHS would allow for continued influence on the life sciences industry and provide a platform for public sector R&D in the UK.

Key Message 3. Longer-term thinking, planning and support are all vital for sustainable growth. There is an opportunity for government to put in place frameworks and institutions to support this approach

The importance of taking a longer term perspective is supported by the evidence base for the 53 technologies presented in the Annex. In areas such as biometrics, services for cloud

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2 http://www.cabinetoffice.gov.uk/intelligence-security-resilience/national-security/strategic-defence-security-review.aspx

computing, and nanosensors, markets are already taking off and their size is forecast to increase several times over during the next few years.

For some technologies, the forecasts of market size for the middle of the 2020s are huge: up to $100bn for nanomaterials, over $200bn to build a European smart grid, £150-£350bn global market for industrial biotechnology, and a £100-£150bn market for plastic electronics. In many of these areas the UK holds a strong position, with every opportunity to play a major part in servicing these markets.

The focus of this report is on some areas where a longer-term approach could pay dividends. There is an opportunity for Government to support applied research into areas of significant future potential with funding over several years, directed to a relatively small number of areas where there is significant new industries may develop. This is in line with the recommendations in the recent Hauser Report.

This analysis suggests that for many areas, providing a stable, coherent framework of planning, regulation and support, and continuity of plans and priorities are important for the UK to generate the confidence for the private sector to invest in large-scale, long-term projects. To encourage this, consideration is needed of how best to encourage continuity of plans when governments change.

The treatment of intellectual property is an important part of a long-term strategy. As a leading producer of knowledge and an international centre of IP law practice, the UK has a major stake in the way intellectual property is managed internationally.

Key Message 4. Industry, SMEs and research organisations should be encouraged to work together to develop their own strategies and roadmaps, with Government adopting an observing, listening and facilitating role

Successful innovation in the UK will require business, research and Government to adopt a longer-term perspective and a more collaborative approach. In additional to its important role as a customer for innovative technology, for example through the Small Business Research Initiative (SBRI), Government should consider reinvigorating its role as facilitator and convenor of industry-research collaboration, encouraging large and small businesses to sit together with research and development institutions to identify common goals and strategies for their sector, and benefit from pursuing them together. Industry groupings, representing all levels of the supply chain and dedicated to mapping out an ambitious innovation and growth strategy for their sector, could provide a strong and effective complement to the Technology and Innovation Centres proposed in the Hauser Report earlier this year. Industrial sectors should take the lead, with government taking a facilitative rather than a directive role:

- Current initiatives such as the Technology Strategy Board’s Knowledge Transfer Networks (KTNs), BIS’s Innovation and Growth Teams and Industry Councils are well regarded for their ability to encourage industry and research groups to work together for their mutual benefit. These initiatives provide the inspiration for a more ambitious Government approach to support industry and research in identifying new business opportunities.
- Government should consider focusing its resources on platforms where new technologies and ideas can be propagated within business sectors. Good models for this already exist in the Automotive Council, the Centre for Process Innovation and the National Composites Centre. Industry might be incentivised to develop sector strategies and roadmaps that foster

resilience and growth prospects for all levels of participant, from small SMEs to industry leaders. Such platforms could be linked into centres of research excellence, within universities and at Technology and Innovation Centres.

- The disbursement of a portion of Government funds allocated to support sectors could be made conditional on the sector's development of a plan for the use of such funds to benefit the sector as a whole. This might include the requirement to produce a strategy demonstrating how a sector will harness technology and innovation to promote UK growth and competitiveness.

Chapter 2 of this report explores the seven cross-cutting areas identified as offering particular potential to support sustained economic growth in the UK over the next 20 years; Chapter 3 explains the methodology of the project; and Chapter 4 lists the clusters into which the technologies were grouped during the workshop process. The Technology Annex (separate document) gives information summarising each of the technologies, derived from the workshops, the interviews and desk research.

2. Technology and Innovation Futures: Potential Growth Areas

The 53 technologies identified in this report have been grouped into 28 clusters such as *Bespoke material design and metamaterials*, *Lightweight infrastructure* and *Synthetic biology*.[3]

Looking across the technologies and the way they cluster, several broader areas stand out as sweeping up a number of the clusters, or being particularly cross-cutting. Three of these were identified as potentially transformative, in that they would provide platforms for innovation across a wide range of other technology areas, and their combined impact would be felt in many different areas of UK society and business:

- By the 2020s, the UK could lead a 21st-century manufacturing revolution, fuelled by new technologies, tools and materials, with local, bespoke manufacturing-on-demand based on 3D printing and a move to product *plus* service commercial models – 'servicisation'.
- Smart infrastructure could include a smart electric grid, increased use of sensor networks, and 'cannibalisation' of existing infrastructure.
- The second internet revolution may see the emergence of a 'web of data' adding structure and meaning to the data and text of the web, thereby transforming its value. An alternative might be increased Government regulation and commercial strategies splitting the internet into closed and proprietary 'web zones'.

These three transformative areas are discussed first.

2.1 Manufacturing on Demand

- **Manufacturing transformed by new technologies, tools and materials, IP-based business models, and customisation**
- **Just-in-time manufacturing supersedes just-in-time logistics as energy and shipping costs increase**
- **3D printing finds application in areas as varied as clothing and plastic electronics**
- **Local economies benefit from local manufacturing facilities as customers demand increasing variation and economics favour using local materials – an opportunity for small-scale manufacturing in the UK**
- ***See Technology Clusters on Plastic Electronics; Low impact Materials; Display Technologies; Ambient Intelligence in the Built Environment; Desirable Sustainability and User-centric Design; Organic Solar Cells; Robotics***

[3] See Technology Annex

Context

Manufacturing is currently the subject of heightened policy attention in the UK, much of which can be put down to the goal of 'rebalancing' the economy away from an overdependence on services – notably financial services – and towards the production of 'real' goods. The expectation is that many of the latter will be exported, boosting the UK's current account balance and contributing to GDP growth.

This is challenging – a recent NESTA[4] report notes that for manufacturing to return by 2020 to the 15% share of the economy it enjoyed in the late 1990s, it would have to grow at a historically high average annual rate of 6.2% per year. While some[5] question policies aimed at boosting exports through manufacturing, below are suggested two ways in which UK industry could participate and even take a lead in a 'new wave' of manufacturing.

'Servicisation'

The first – already well under-way but likely to increase in importance – is to recognise that manufacturing and services will increasingly form part of a joint value proposition, as firms compete on a product + service basis. Companies from the aerospace, chemical and materials industries have already adopted business models based on selling the right to enjoy a service (where the capital costs of the manufactured product are recouped through the operating cost of the service, rather than paid for separately). For example, the engines of some aerospace manufacturers are sold as 'power by the hour': the client pays for the thrust delivered, not separately for the engine and its maintenance. In the same way, some industrial catalysts are paid for according to the service they perform.[6] This trend is important because since 1985, services have contributed 87% of growth in developed economies, and have been the source of all net job creation.[7] Over the next two decades, much of the value added through manufacturing will also be captured in the form of revenues for services. The UK's strong service sector, together with its position in high-value manufacturing areas such as aerospace where service models are gaining ground, make it well placed to capitalise on these developments.

At the same time, service models applied to manufactured goods are crossing over to the consumer market, finding their place alongside computer and mobile phones plans and subscriptions for creative content. Car clubs have become popular in some cities, while subscription services such as Spotify are having an impact on how we 'consume' music. In the future it may be possible to sign a contract to keep a house at 20°C, leaving the means of doing this – selecting energy suppliers, installing heating and insulation systems, etc. – to the contractor.

Distributed Manufacturing: from just-in-time logistics to manufacturing on demand

The second way the UK could participate would be by leading the way in a shift towards distributed manufacturing. A number of trends are expected to collide over the next 20 years with the potential to transform production processes:

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4 *Rebalancing Act*, NESTA, June 2010

5 *How to compete and grow after the recovery: A sector approach to policy making*, McKinsey & Company, March 2010

6 Catalysts enable chemical reactions to take place more quickly and/or at lower temperatures and/or pressures than they otherwise would, and it is, therefore possible to ascribe a "value in use" to any improved catalyst. Accordingly, it is quite common in the industry to find catalysts pricing based on this value to the user.

7 McKinsey & Company, *ibid 5.*

- new manufacturing technologies, including rapid prototyping and 3D printing[8]
- new design tools, including for process design
- more intellectual property (IP)-based business models[9]
- the use of new substrates (such as polymers) in the electronics and semiconductor industries, and the ability to assemble several elements on a single substrate
- 'cradle-to-cradle' recycling and remanufacturing demands leading to more lifecycle approaches to manufacturing[10]
- more leasing and product-as-service business models
- more customised products, with value attached to local production and differentiation
- increased energy costs leading to higher shipping costs.

A distributed manufacturing model would allow products to be designed in one place using software which enables the designs to be transferred for production in several different locations, without the need to build or upgrade facilities for each new product at each production site. The principal drivers of such a change would be higher shipping costs and consumer demand for customised products; while the principal enabler would be improved manufacturing equipment and software. Initially such an approach may simply enable the customisation of products at a local production facility for a local market, but over time they could allow a single facility to produce a range of different products. This facility might resemble a logistics warehouse more than a factory, with equipment and software that could be reconfigured rapidly to meet changing requirements.

It is likely that over the next 20 years there will be increasing demand for personalised *products* in the same way that we already expect tailored *services* (travel itineraries, financial advice). Where high-end bespoke consumer products have led (Savile Row suits, for example), a range of manufactured products, from electronics to household goods, may follow.

An example at one workshop was the application of new technology to the fashion industry, where the UK is a world leader. 3D imaging and scanning technology could be deployed in hi-tech booths – perhaps first replacing one of the fitting rooms at a high-street fashion retailer – where customers would be scanned and provided with a virtual body image, which could be matched with clothing sizes and shapes at the retailers.[11] The customer might later be able to use search technology to identify clothing at online stores that would perfectly fit their body shape.[12] The customer might also share the mannequin online with boutique fashion designers, asking for quotes for a one-off article of clothing.

In the emerging plastic electronics industry, the ability to automate the layering of several elements on a single substrate could enable the automated manufacturing of sophisticated

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[8] See Technology Annex 1.1
[9] See Chapter 2.7
[10] See Chapter 2.1
[11] Selfridges in London has a 'Bodyscan Pod' (used for jean fitting) provided by Bodymetrics using technology originally developed at University College London (see http://www.luxury-insider.com/Regulars/Reviews_and_Commentary/Bodymetrics-Pod/). The UK startup Me_tail (www.metail.co.uk) is preparing to launch an alternative approach to generating a 3D body image, using two full length photos.
[12] Searching for designs could be enhanced using 'visual browsing' interfaces such as FABRIC (http://www.computing.dundee.ac.uk/projects/fabric/) or Google Goggles (http://www.google.com/mobile/goggles/#text)

products using 3D printing and rapid prototyping techniques, for instance improved polyjet or polymatrix printers.[13]

In the construction sector, standard designs, such as house-building elements, could be manufactured using local materials, reducing the costs of shipping bulky or heavy raw materials – costs which will increase with higher energy prices. This could result in more local sources being used for construction materials, although the energy costs of extracting materials in low volumes locally, and foregoing economics of scale, may be prohibitive. Alternatively, raw materials could be transported to the manufacturing site in a non-time-constrained way, using bulk shipping, with materials stored on site until they are needed.[14] To meet increased consumer demand for locally sourced food, supermarkets may set up agricultural and horticultural facilities adjacent to their stores to provide certain perishable foods.

Innovative approaches such as those described above may lead to a renewed sense of local identity: regions and cities may demand different versions or designs of particular products. There may be benefits for the local economy generated by the customising, servicing and recycling of products from local production lines, including skilled employment in a balanced range of activities. Local facilities and skills may encourage the development of product-as-service business models as described above – where the provider of the manufactured product guarantees to keep it in working order, and upgrade it where appropriate.

How the UK can benefit

By the 2020s, the UK could be a leader in a 21st-century manufacturing revolution. The development of small-scale manufacturing capability could be considered whenever investment is made in a new research institution (this may fit the model for the Technology and Innovation Centres proposed in the recent Hauser report). The primary purpose of such facilities may be demonstration of research applications, but institutions could also encourage manufacturing to take place at a small scale, both to provide necessary design and engineering feedback to researchers and product designers, but also to test different methods of small-batch, programmable production. In addition to the domestic market opportunities described earlier, there is potential for a large export market for the intellectual property (IP) behind product and process designs, and the engineering and consultancy services needed to set up facilities.[15]

Later this year, BIS will be launching a Manufacturing Framework that will have a new approach to manufacturing, reflecting its importance for the economic recovery and growth of the UK economy. The Framework will highlight Government's vision and ambitions for manufacturing and identify growth opportunities across all manufacturing, including those provided by new technologies and innovation.

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13 The UK has strong research and commercial experience in 3D printing, both in commercial and personal fabrication, although the technology is still in an early stage of development (see Annex 1.1)

14 See Annex 1.2

15 The Annex identifies electronics and photonics as areas where the UK has done well in developing such 'fabless' manufacture based on IP, e.g. ARM's semiconductor chip technology for low-power, high-performance consumer and industrial products. The Annex also identifies a number of areas where the UK may enjoy a competitive advantage in the 2020s thanks to strengths in research and manufacturing. They include advanced batteries (Annex 2.1), fuel cells (Annex 2.5) and plastic electronics (Annex 1.7). Other possibilities for UK manufacturing include marine and tidal power (Annex 2.13), where the UK has a leading position and active SME developers

2.2 Smart infrastructure

- **Smart electricity grid built on requirements of renewables, microgeneration and smart metering – but the challenges are considerable**
- **Sensor networks play a greater role, with business opportunities for UK firms**
- **Existing infrastructure cannibalised for new uses**
- ***See Technology Clusters on Lightweight infrastructure; Bespoke Material Design and Metamaterials; The plus energy house; Microgeneration; Water***

The apparent permanence of infrastructure disguises the central role it often plays in technological transformations. Information technology, electricity and the steam and internal combustion engines were all ground-breaking inventions, but their impact was in each case dependent on a new and powerful infrastructure: the internet, the electricity grid, and the rail and road networks respectively. Over the past 100 years, some infrastructures have evolved (rail, waste), some have declined in importance (canals) and new ones have been built (electricity, gas). What will the equivalent changes be in the first half of the 21st century?

The **smart electricity grid** might be the first new transformational infrastructure of the 21st century. It has been argued that it will be a prerequisite for an electricity system that meets the carbon reduction requirements of the UK to 2050.[16] But new information and communication technologies will contribute to the improvement of *all* economic infrastructures (including transport, water and waste), by providing data that enables quick and accurate detection of failures, improvements to the efficiency of control systems, and more intensive use of transmission networks.

There are two main components of smart grids. The transmission and distribution components would entail the installation of sensors and digital relays on power lines which enable utilities to operate systems with greater efficiency and reliability. The other component, the 'smart meter', would track electricity use in real-time and transmit that information back to the power company, enabling the introduction of 'smart' tariffs (charging more for electricity consumed when spare supply is scarce and charging less when spare supply is plentiful), and could be configured to control the supply of electricity to homes and businesses. Although complementary, each component could be implemented independently. A number of factors will determine how, and at what pace, the UK implements a smart grid, these include:

- Increasing penetration of intermittent and inflexible generation
- New sources of electricity demand due to increasing electrification of transport and domestic heating
- Consumer engagement and acceptance
- the need to manage energy developed by microgeneration (two-way transmission), and its storage at the point of generation or across the grid
- increase in electricity (rather than gas) demand for car recharging and domestic heating/cooking.

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[16] See Annex 2.10

The connection of significant amounts of renewable generating capacity and microgeneration to the grid is expected to take several years. Beyond ensuring that planned new capacity, such as offshore wind installations, can be connected to the grid, it is important to weigh up whether the UK may benefit more over the next 10 years from investing in research and development of technologies for smart meters and low-carbon energy generation, rather than commencing a costly build-out of sophisticated metering applications while technologies are immature and international standards have not been agreed on. The smart grid will mean new technology, new business models, and new patterns of consumer behaviour. The complex interaction of these three factors is hard to predict: Ofgem and the EU are sponsoring trials to learn about how they interrelate, and successful business propositions may take several years to emerge.

Investment in R&D of grid sensor and metering technology might also be undertaken jointly with the water, waste and transport sectors, as some solutions may be applicable across industries. Following recent publication of the National Infrastructure Plan 2010, the Government has created an Engineering and Interdependency Expert Group to look into how such research efforts can be encouraged. The development of ubiquitous and distributed sensor networks could help manage all kinds of infrastructure in addition to the electricity grid; for example, by providing information about flows and potential system failures in the water supply network.[17] There will be business opportunities for UK firms that find ways to manage data flows, and develop instruments to interpret them and respond, such as smart configurable telemetrics. This might also lead to integrated consumer applications that enable more efficient resource usage. A challenge – but also a business opportunity – will be to maintain cyber security on these critical economic infrastructures as the vulnerability of information systems increases along with their complexity.

One area where some technologies are mature (particularly fibre optics), and where infrastructure has already been shown to have a transformational role, is broadband internet transmission. In countries such as Korea and Japan which have made the delivery of fast broadband connections to the home a priority, many new applications have been developed. With the creative industries representing an above-average proportion of UK GDP, and with the UK's position at the forefront of the development of new internet technologies, the economic benefits of high-speed broadband may be significant. The UK also has research strengths in photonics, which are likely to become more valuable as data transmission speeds and capacities increase, and the energy usage of the internet becomes a more pressing issue.[18]

At the same time as new infrastructures are built out, existing infrastructures may be 'cannibalised', in the sense that fixed-line telephone networks have already been turned into a broadband carriers and the UK's analogue television broadcasting service been adapted to carry first digital and now high-definition television. This trend is likely to gather pace during the 21st century, with the increasing ability of ICT and internet software, combined with sensors and embedded computer power, to reinvent old modes of transport. Within 20 years, 'trains' of driverless GPS-guided goods vehicles may operate on our road network, and railways could allow private vehicles riding on mini-shuttles to run in-between regular passenger services, thanks to a new generation of network management tools inspired by internet 'packet-switching' protocols.

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[17] See Chapter 2.2, and Annex 4.6
[18] See for example, http://www.bbc.co.uk/news/science-environment-11544459

2.3 The second internet revolution

- **The bottom-up development model of the internet may see a move to greater Government direction to enable greater infrastructure investment, provide internet as a right, and regulate content**
- **The internet may develop more incrementally in future, or be split into proprietary ‘web zones’, or a move to a ‘web of data’ may occur which adds structure and meaning to data and text on the web**
- **Such a web of data could transform the value of the internet as new applications and business models arise**
- **By opening up public sector data, UK Government can increase transparency, enable new applications combining data from different government sources, increase data usage and efficiency, and, potentially, generate new leading edge businesses in an emerging market**
- ***See Technology Clusters on New Computer Technologies; Managing and Processing of Real-time Social Data; Multisensory Input and Sensing; Photonics; Sensor Networks and Speckled Computing***

The internet has transformed our lives over the past 20 years. The pace of innovation in web technologies is high, and shows no signs of abating. Given that the industry that has developed around the internet is thriving, with minimal direct public support, and generating remarkable social and economic benefits, it might be considered that this is one area public policy should leave alone. All the more so since the principle of bottom-up, ‘emergent‘ collaboration and innovation, which governments are keen to foster in a wide range of industries and communities, has been hugely boosted by the web. New business models – such as ‘open source‘ software – which have their origins in internet software are now being successfully applied in fields such as pharmaceuticals and ‘green technology‘.

Governments may however seek greater involvement because of:

- **Infrastructure.** The internet has grown to a large extent on the back of existing global infrastructure, notably fixed line telephone networks. To support the growth of the internet, infrastructure will need to be upgraded – not simply data transmission infrastructure such as fibre optic cable, but also data processing, data storage and power supply. In the UK, the question of who should pay for this has not been resolved, and ‘free’ internet at the point of use may not be sustainable as data traffic increases in a tight economic environment.
- **Internet as a right.** The argument about the ‘digital divide‘ has moved on to suggest that governments should provide internet access to all their citizens – Finland recently made such a pledge, and the UK has now set itself the target of the end of the current Parliament to get everyone online. Currently 47% of those living in households with an income of less than £11,500 per year do not use the internet compared to 4% of those earning more than

£30,000; 48% of disabled people remain offline.[19] Although expensive to implement, such as move could achieve significant cost savings if more public services could then be delivered over the internet rather than via offices and call centres – PwC estimates the total economic benefit of getting everyone in the UK online at £22bn.[20]

- **Regulation.** Governments regulate the telecommunications and broadcasting industries in a very different way to the internet. The degree to which the UK and other governments seek to regulate the internet will have implications for how the internet operates.

Is there action the UK Government could take, beyond its traditional regulatory function, to increase the transformatory impact of the internet to benefit UK citizens and companies? Is this an area where Government could act as a smart procurer, an early adopter of a powerful new technology? Could it find a way of both fulfilling its commitment to opening up Government data to the public, and unleashing the potential of data to skip from one application to another across the internet, as easily as a human agent now sends a tweet or places a Skype call?

Incremental improvements rather than fundamental changes to internet standards may be the default way the web will develop. The application of statistical and algorithmic methods to existing web data is likely to lead to the refinement of current search technologies, particularly through the analysis of 'implicit' links – identifying patterns of searching that point to a centre of interest. This could lead to better profiling of web users, and progress towards an understanding of 'intentionality', and the increased relevance of information provided to consumers is likely to overbear concerns regarding privacy and ownership of data.

Users' willingness to tag and share tags is likely to continue to be exploited by internet companies. For example, websites, social networking pages and photo-sharing sites could use applications such as Facebook's Open Graph protocol[21] to tag their content to get specific benefits (e.g. ranking among Facebook's top restaurants in Mayfair), and this tagged content would then be usable by other apps. Many argue that this organic development around user tagging, which brings immediate benefits to users and commercial developers alike, obviates the need for new top-down standards.

Yet – as one workshop participant put it – there is still as sense that 'people can't find what they need to know'. We are still, after all, a long way from what was promised in the early days of the internet. According to forecasts from the late 1990s, software agents should by now be seamlessly pulling together information from the web to make travel bookings on our behalf, based on our budget and preferences. In reality, it is still generally necessary to visit a number of different sites and trawl through a maze of links to book a good deal. Facts or data cannot yet be 'called up'; and the promise of the knowledge society is still some way off. Facebook and Apple are creating web zones that are seen by some as compartmentalising and limiting, in the same way that AOL previously tried to stake out its own closed part of the web.

What is the alternative? The vision of the 'web of data' argues that the web became stuck at the document stage. What was supposed to be a step on the route to the interconnection of all manner of data and even objects over a common internet protocol has turned out to be a sticking point. By adding structure and 'meaning' to the data and text on the web – in other words by indicating what the data in documents or on databases actually are (a city name, an exam result, a delivery address) – it is argued that a raft of new and powerful applications

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[19] UK raceonline2012 manifesto, http://raceonline2012.org
[20] http://www.egovmonitor.com/node/29570
[21] http://developers.facebook.com/docs/opengraph

would be enabled.[22] This process need not be complicated (for example, a film guide might indicate that ‘Casablanca‘ in its listings referred to a film and not a town).

The obvious benefit of adding meaningful or ‘semantic‘ information to web content – making searching more accurate by reducing ambiguity – may not in the end be the greatest. After all, Google manages quite well without a semantic approach[23]. Far more significant – and potentially the big opportunity for Government data – is the way in which the authority of data in the semantic web can be demonstrated using a concept called ‘linked data‘. In the same way that scientific data establishes its authority by referencing approved, peer-reviewed sources, and legal data gains its status by citing previous decisions, data in the semantic web might demonstrate their trustworthiness *in real time* by pointing to the supporting internet reference.

Over time, this could transform business-to-business and business-to-consumer internet transactions.[24] Open, structured data would enable a host of new business models: in the same way that Apple‘s ‘AppStore‘ has provided a platform for a wide range of small, mainly consumer-focused applications, a web of data might stimulate a new set of business applications that generate significant added value and offer a new source of economic value.

A powerful driver for such a transformed commercial future could be government support for structured data. The UK Government is already a world-leader in this area, having benefited from the advocacy of Sir Tim Berners-Lee. For example, Legislation.gov.uk, launched in July 2010, brings together every single piece of UK legislation, from the Magna Carta to the present day, in one place for the first time, and makes it easy for people to use the data to create mobile phone apps or add it to their own websites.[25] The UK is the first country in the world to open up its statute book in this way, allowing anyone from officials to ordinary citizens to scrutinise the laws on which their legal rights and responsibilities are based, and enabling the impact of legislative changes to be calculated in advance of their introduction.

The UK is well positioned on the software development side in this new sector. For the moment, the leading companies in the field are start-ups, but there is the potential for these companies to grow rapidly if the sector takes off. The UK also has strong system integration businesses that could implement corporate systems to take advantage of open data.

2.4 The Energy Transition

- **By the mid-2020s, the UK plans to generate a much increased proportion of its electricity from renewables, with wave and tidal power, microgeneration and biofuels joining wind as the main contributors**
- **But this may require profound changes, such as the ability to store electricity in a**

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22 See for example *Pull: The power of the Semantic Web to transform your business* by David Siegel, Portfolio 2009

23 Although interestingly it has recently acquired one of the pioneers of the semantic web, see http://techcrunch.com/2010/07/16/google-acquires-metaweb-to-make-search-smarter/

24 For example, in B2B, applications could run without the need for human intervention. Stock monitoring and ordering applications would no longer require proprietary enterprise software but could be extended to any company publishing its terms and conditions in standardised format

25 www.nationalarchives.gov.uk/news/478.htm

more distributed system relying on intermittent generation. New battery technologies may be needed, and fuel cells, a smart grid, and in the longer term the batteries of millions of electric vehicles could help balance supply and demand

- **Complementing the ‘electrification of everything’ we may see large-scale use of hydrogen as a fuel**
- **Nuclear power is expected to see a resurgence, with more economical and even safer technologies, and developments in CCS could support ‘clean coal’ plants – if the cost can be brought down**
- **While the UK is not a major player in the construction of wind turbines or nuclear power, it is seen as having areas of strength in research and particular opportunities in servicing the new infrastructure**
- ***See Technology Clusters on Hydrogen Economy; Energy Materials and Storage; Closing the Nuclear Cycle; Energy Scavenging; Synthetic Biology; Syngas, and Annex Section 2***

Over the next 20 years, much of the UK’s energy infrastructure will need to be refreshed as existing nuclear power plants are retired, the move from centralised fossil fuel generation towards dispersed generation from renewables compels choices about investment, resilience, and energy networks, and the need to decarbonise the economy pushes Government to put in place new incentives and constraints to change behaviour.

The largest portion of the renewables contribution to UK energy targets to date has been wind power, with a rapid increase in generation in recent years and the potential to meet 30% of the UK renewables targets by 2020. The UK’s well-developed skills in offshore and services mean strong potential for growth in the secondary service centre, but the UK is not currently a major wind turbine manufacturer.

The UK is, however, a world leader in wave and tidal stream technologies for power generation. Coupled with the huge wave resource around UK shores, this represents a considerable opportunity to augment the energy mix. A major change would be to generate electricity from the vast tidal range of the Severn Estuary, though this has been ruled out for the shorter term.

Small-scale generation (microgeneration) offers the potential to heat and light millions of homes and businesses, but those countries such as Germany where microgeneration is beginning to take off have been able to achieve this only through expensive Government subsidy. And while reliable photovoltaic devices are becoming gradually less expensive to manufacture, and new large solar thermal power stations proliferate, so that solar power will become increasingly important globally, the UK’s low sunlight and lower demand for electricity in the summer are likely to limit its use.

There has been increasing concern over crop-based biofuels, which compete with food crops for land and may be detrimental to biodiversity.[26] As an alternative, production of biofuels from ligno-cellulosic biomass is at the pilot scale and at the point of moving to demonstration projects. Third generation biofuels are centred round the use of algae. There are a variety of operational and proposed biomass plants in the UK, and biofuels have the potential to be one of the main contributors to the renewable energy mix by 2020.

To supplement intermittent electricity supply from renewables, nuclear generation – long in decline in the UK – is anticipated to see a resurgence over the next decade as a further low carbon source of electricity. New generation reactors with increased capacity, lower fuel and waste usage and increased safety are now available and current research suggests further improvements. However, the majority of UK nuclear power stations are operated by foreign companies and national manufacturing is not currently geared up to build new nuclear power stations. The challenge for UK industry is to become significantly involved in order to rebuild its market position. Nuclear fusion, as ever, remains on the horizon, and is unlikely to become significant before 2040.

Throughout the 2020s and later decades, fossil fuels will still constitute a large part of the UK's energy mix, and to meet UK emissions' targets, Carbon Capture and Storage (CCS) will be required. A variety of technologies have been developed to capture, transport and store the CO_2 which would otherwise be released to the atmosphere. Issues to be overcome include achieving higher efficiencies of CCS plants, safety concerns over storage and, above all, the high capital costs both of new CCS plants and of retrofitting CCS to existing plants. However, the UK is an early mover in both the technology development and application of CCS, and would be well placed to export elements of it into a market with a global potential of several hundred billion US dollars.[27] It is estimated that this could be worth a potential £1-£2 bn/year to the UK by 2020 and £2-£4 bn/year by 2030.[28]

To accommodate the increasing range of renewable and intermittent energy sources into the national grid, flexible large-scale storage of electricity, demand side management, interconnection and flexible operation of thermal plant will be required to allow short-term supply and demand to be balanced at the local, national and perhaps international level. In the case of electricity storage, the only current tried and tested technology for long-term energy storage on a large scale is pumped hydroelectricity – used extensively on the Continent, but limited in scope in the UK for reasons of geography. There is therefore an intense focus globally on developing battery technology which can work on the largest scale. One promising technology is sodium sulphur (NaS) batteries – long life (15 years) room-size batteries that can act as local reservoirs of electricity, perhaps in combination with renewable generation. A recent project deployed a 1.2 MW capacity battery of this type. Other potential battery technologies include all-liquid batteries which can operate at much greater currents than existing batteries, and low-cost gravel batteries. The UK's strengths in these technologies, together with the greater need because of the limited potential for increased hydroelectric storage, offer opportunities to be at the forefront of developing and demonstrating their practical usage. For smaller scale local power generation, car engines and consumer goods, a low emission alternative to batteries are fuel cells producing electricity from a variety of hydrocarbons and alcohols, or running directly on hydrogen.

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26 Gallagher Review, Renewable Fuels Agency 2008
27 Pike Research estimates up to $221.5 billion by 2030
28 See *Future Value of Coal Carbon Abatement Technologies to UK* Industry, AEA 2009 http://www.aeat.co.uk/cms/assets/MediaRelease/PR_190609.pdf

Complementing the developments in power generation and high capacity electricity storage, smart grids would help overcome the intermittent nature of renewables through intelligently accommodating the supply and demand requirements of all users. A move to electric vehicles would present a further opportunity to utilise their electric batteries for storage and transportation of energy.

While the ‘electrification of everything’ means that smart electric grids occupy a central place in the low carbon roadmap, using hydrogen as a fuel is also a plausible approach. During use as a fuel, hydrogen generates zero or near-zero emissions of air pollutants and CO_2. And, like electricity, it can be produced from fossil fuels as well as from non-carbon-based primary energy sources through processes characterised by near-zero emissions of air pollutants and CO_2. Having near-zero-emission hydrogen as well as electricity would provide society with the capacity to achieve deeper reductions in CO_2 emissions than focusing on electricity alone. The role of hydrogen could become particularly important in fluid fuel sectors – notably transportation – where decarbonisation using battery technology and biofuels is otherwise challenging.[29]

To take this route on a large scale would require construction of a national distribution network with the high level of investment that that entails, but consideration is being given to the practicality of using the existing gas grid, with some modification, to allow the increased use of hydrogen. Hydrogen could be generated from renewable sources, or complement ‘clean coal’ through co-generation from IGCC plants.[30]

2.5 New Materials’ contribution to a low carbon future

- **The UK has a strong position in research and development into new materials which can help achieve carbon emission targets**
- **The materials include strong, light structural materials with application in reducing energy costs of transport and in building, more efficient solar cells, and batteries and fuel cells**
- ***See Technology Clusters on Metamaterials, Display Technologies, Low Impact Materials and Organic Solar Cells, and Annex Section 1***

The developments in new materials over the next 20 years are potentially as fruitful as the increased variety of plastics in the earlier 20th century. One aspect of these materials is their potential importance in helping reduce our use of energy and CO_2 emissions.

Just under a half of total UK emissions are ascribable to building and use of buildings, according to the Low Carbon Industrial Growth Team, and the construction industry represents

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29 See Annex section 2.7
30 *The real drivers of carbon capture and storage in china and implications for climate policy*, Stanford PESD Working paper #88, August 2009

8.5% of UK GDP.[31] New, lower cost and high performance fibrous composite materials are expected to become significant over the next decade; for example, as materials for road and footbridges. Self-healing active surfaces on materials, such as concrete and paint, would increase building durability and longevity, saving energy and reducing emissions. Attention is also being given to minimising emissions from the manufacture of materials such as concrete.

Light, strong materials are important to help the transportation industry reduce emissions. One example is the proposed application of extremely strong, light and low-density carbon nanotubes to commercial aircraft. Their high cost, at least for the time being, suggests that early uses may be in yachts, bicycles and racing cars, where price is secondary to performance.

New materials may also help with the battery development and small-scale power generation highlighted in the Energy Transition area highlighted above. Metamaterials have engineered properties to interact with light and other electromagnetic waves, and offer potential for higher-efficiency solar energy capture, as do thin film nanocrystalline semiconductors using 'quantum dots'. Both areas have considerable UK potential on the basis of levels of research activity. The manipulation of matter at the nanometre scale has applications in batteries, fuel cells and more efficient and hence low-energy processes such as water purification. Again, the UK is in a strong position, in third place in the number of nanotech companies after the US and Germany.

Electrical polymers which conduct ('plastic electronics') offer potential as low energy displays in the form of organic light emitting diodes (OLEDs), which have other desirable properties such as extreme flexibility.

2.6 Regenerative medicine

- **Blockbuster drugs have accounted for a large proportion of the pharmaceutical sector's historical growth. The patents on a significant number of these drugs will expire in the next few years.**
- **Regenerative medicine could be a driver of growth for the sector if translational research, regulatory and financial challenges can be overcome**
- **Stem cells have the greatest potential in the field of regenerative medicine, and could see widespread application by the early-mid 2020s.**
- ***See Technology Clusters on Stem Cells; Tailored medicine; and The Cheap Genome***

The UK life sciences sector contributed 6.5% of total UK manufacturing GVA in 2007, an increase of 2.4% over 1997.[32] The UK is currently a net exporter of pharmaceuticals and medical technology. However, patents on a number of 'blockbuster' drugs accounting for a large share of the revenues of pharmaceutical companies based in the UK are set to expire over the next few years. 'Regenerative medicine' – a term used to refer to treatments designed

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[31] *Construction in the UK Economy*, L.E.K. report for CBI, 2009
[32] http://www.bis.gov.uk/assets/biscore/economics-and-statistics/docs/10-541-bis-economics-paper-02

to restore the function of diseased or damaged tissues or organs – could potentially lead to significant improvements in the treatment of chronic diseases, and generate economic benefits for the companies that develop therapies and related infrastructure, such as manufacturing equipment. However, significant translational research, regulatory and financial challenges would need to be overcome[33].

Stem cells – the area of regenerative medicine in which the most significant breakthroughs are expected – are already demonstrating their potential. Already NHS patients are routinely being cured with adult stem cells for damaged corneas and over 250,000 patients (mainly in the USA) have received tissue-engineered skin[34]. While the patient numbers are still low by the standards of large pharmaceutical companies, other more widespread therapies are fast approaching the clinical trial phase or have recently entered Phase 1 (safety studies). These include age-related macular degeneration (commonest form of blindness in the UK) at UCL, diabetes (ViaCyte, USA) and spinal cord injury (Geron, USA). Given the present regulatory framework, it will take 10-15 years before regulatory approval.[35] British stem cell science is well advanced, and among the best in the world. There are concerns though that instead of reaping the rewards of our investment in research, the UK is failing to compete in the all-important translation and commercialisation stages. British funding for such activities is presently an order of magnitude less compared to the USA or even individual states such as California with $3 billion to invest over ten years.[36]

Intensive stem cell research began in the 1980s. Despite successful UK treatments such as skin for burns patients, adult cornea regeneration and tissue-engineered trachea,[37][38] there has been concern about regulation, and the NHS's slow uptake of advanced therapies. But the potential for stem cells to transform medicine is enormous. Many challenges still have to be tackled – including better understanding how stem cells work, overcoming safety and efficacy issues, and scaling-up of manufacturing – but few would dispute that the prize of developing successful treatments is worth competing for. The question is whether the UK can seize the opportunities. A number of past medical breakthroughs that originated within the UK were lost to the US before commercialisation, including the production of penicillin, MRI scanners and monoclonal antibodies.

The major impact of stem cells will not be realised within the decade. This is to be expected, all new therapeutic platforms require a lengthy and resource intensive gestation period. For example, monoclonal antibodies (MAb) were discovered in the UK in 1975 but took 20 years to achieve their full potential, during which time the technology matured and associated infrastructure was put in place. Today the MAb market is worth tens of billions of dollars and growing[39], but the commercial benefits mainly accrued outside the UK. The mass market for stem cell-based products (safe, clinically efficacious, cost effective therapies that can be manufactured at scale and available for routine clinical practice) is expected to start to develop around 2020. However, in the meantime the 'patient-specific cell' service market, based on the patient's own (autologous) stem cells – that is, taken from the patient, bioprocessed and

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33 Mason C. and Manzotti E. The Translation Cycle: round and round in cycles is the only way forward for regenerative medicine. Regenerative Medicine. 2010, 5(2), 153-155.
34 Mason C. and Manzotti E. Regenerative medicine cell therapies: numbers of units manufactured and patients treated between 1988 and 2010. Regenerative Medicine. 2010, 5(3), 307-313.
35 Interview with Chris Mason, UCL
36 California Institute for Regenerative Medicine (CIRM), www.cirm.ca.gov
37 Mason C. and Manzotti E. Regenerative Medicine. 2010, 5(3), 307-313.
38 http://www.bristol.ac.uk/news/2008/6010.html
39 B. Huggett et al, Public biotech 2009—the numbers. Nature Biotechnology 28, 793-799 (August 2010)

reimplanted – is already progressing well. The advantage attributed to this approach is that concerns about rejection or other complications are significantly reduced, along with the time needed for regulatory approval.[40]

The ultimate promise of cell-based therapeutics is widely recognised – the global market is today estimated at around $100-200 million[41], potentially growing to $8.5 billion over the next decade.[42] The discovery of human induced pluripotent stem (iPS) cells in 2007 by independent researchers in the US and Japan has led to renewed media and scientific interest. iPS cells – which are reprogrammed adult cells that behave like embryonic cells, but do not present the ethical issues associated with deriving stem-cell lines from embryos have heralded a new era in stem-cell research. Although their potential for therapies remains uncertain – current methods for reprogramming differentiated cells into iPS cells are both highly inefficient and unpredictable,[43] – further progress is expected in this area.

While of significant potential value in their own right, notably to the NHS and those benefiting from treatments, the development of stem-cell services during the 2010s would also prepare the ground for product applications in the 2020s and beyond, by keeping researchers, cell therapy companies and the associated service sector in the UK.

There could be other benefits of developing expertise in the field. Hospitals might benefit from attracting patients from abroad: encouraging people to come to the UK for state-of-the-art treatments, allowing expertise to develop that would place the UK in a strong position to take advantage of a future industry built around ‘universal donor’ therapies.

Regulation

The UK regulatory system for stem-cell research is recognised as world-leading in its application to human embryonic stem cells. Ten years ago the UK was one of the first countries to regulate the derivation of embryonic stem cells in way which facilitated important research while recognising ethical concerns.[44] With research now being taken forward into products, the UK has worked to ensure that the safety of cells, tissues and cell-based medicinal products is appropriately regulated at the European level. It is in the UK’s interest to seek to preserve the long-term competitiveness of its regulatory environment. This is seen as being ready to adapt to changes in science (such as iPS cell research[45]), and to facilitate regulation of different end products and treatments, while maintaining safety and ethical assurance. UK regulation will need to evolve as stem cell-based technologies progress towards the clinic, otherwise nations that embrace the new technology with bespoke regulation will attract both patients and cell therapy companies.

UK companies

At present, pharmaceutical companies are developing human stem cell lines principally for drug discovery and development (either to identify new drugs or test toxicity before clinical

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[40] The UCL Institute of Ophthalmology has already treated 20 people using an autologous approach
[41] Mason C. and Manzotti E. Regenerative Medicine. 2010, 5(3), 307-313.
[42] PearlDriver Technologies forecast 2008
[43] http://www.nature.com/nature/journal/vnfv/ncurrent/abs/nature09342.html
[44] Embryonic stem cell research has benefited from the UK’s regulatory position, which has allowed publicly funded research on certain human stem-cell lines since 2002 – in the US, embryonic stem-cell research only took place in the private domain until new legislation was enacted in 2009
[45] Japan is widely recognised for its IPS cell work

trials)[46]. A number of small UK companies are developing therapeutic approaches, and there are growing signs that large companies are becoming involved with the sector, including through direct investment in academic regenerative medicine labs and SMEs[47]. The UK could benefit by providing an environment that encourages pharmaceutical companies to set up their regenerative medicine centres in the UK.

2.7 Intellectual property – a strategic national asset

- **The UK is a leading producer of knowledge – the value of this intellectual property is poorly understood**
- **The UK innovation environment may underplay opportunities as opposed to threats associated with IP protection**
- **The UK's strengths as an international centre of IP law practice, combined with its strengths in business and financial services, may be an underexploited source of competitive advantage**
- **This suggests Government taking a more strategic approach to IP**

The nature of key productive assets that ensure competitiveness has changed over the centuries. Since the 18th century there has been a shift from land to industrial plant and machinery to financial reserves and wealth funds. The key productive assets of the 21st century are expected to be knowledge-based. Several countries have responded accordingly, and recent acquisitions by emerging economies such as China and India seem likely to have been at least partly motivated by ownership of intellectual property rights over knowledge assets, rather than the value of the companies' business activity. Last year, for the first time, more patents were filed in China than in the US (even though many of the companies which filed them were not Chinese).

Some countries are making intellectual property (IP) a national strategic priority. For example, Singapore has a national IP office to coordinate the IP aspects of different ministries and its IP system has boosted inward investment in areas such as nanotechnology and biotechnology. In other countries, companies have developed a strong position using a tactical approach: the Indian company Suzlon has carved out a significant stake in the wind energy industry by using the technology made available when valuable patents expire.[48]

As a world leader in the production of many kinds of knowledge, from scientific research to business models and industrial processes, the UK is well positioned to benefit from the rise in status of the knowledge asset. UK companies such as ARM have pioneered the 'fabless'

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[46] For example, Stem Cells for Safer Medicine (SC4SM) is a public-private partnership which has been established to take this work forward

[47] McKernan R. et al, Pharma's Developing Interest in Stem Cells. Cell Stem Cell, 2010 6(6), 517-520.

[48] *Who Owns Our Low Carbon Future? Intellectual Property and Energy Technologies*. Bernice Lee, Ilian Iliev and Felix Preston, Chatham House September 2009

business model[49], where ownership of, and licensing of, intellectual property (IP) is the source of the company's value. The UK's position is further boosted by the value of brands owned by UK companies, which are also protectable as trade marks under intellectual property law and which generate considerable export earnings. Finally, the UK is an international centre of IP law practice: greater awareness of the value of IP, and the creation of an active IP 'marketplace' could have both direct benefits for the legal and accounting professions, and indirect benefits for the UK economy.

But there have so far been few coordinated attempts to take stock of the value of the knowledge assets the UK possesses. A better understanding of the nature and value of UK IP might lead to new ideas of how it could be better exploited, and how to ensure that the value of IP assets is enhanced during the coming decades. Not all assets are necessarily protected by IP rights: the majority of added-value in manufacturing comes from activities where no patent or other registered IP rights are involved, but IP is nevertheless employed to gain or maintain competitive advantage. For example, the UK motorsport industry relies more on keeping key concepts and critical production processes secret than seeking formal protection. Protecting, enhancing and exploiting the UK's knowledge assets is not just about patent filings.

The UK could undertake research to understand its IP strengths and weaknesses with regard to global competitors and then use this information to inform sector and technology-specific strategies aimed at playing to its strengths and 'plugging gaps'. The UK Intellectual Property Office (IPO) published an analysis of the Nanotechnology patent landscape in 2009[50], which might serve as a model.

Other, further steps proposed during interviews included investigation of:

- The introduction of 'fair, reasonable and non-discriminatory' ('FRAND') cross-licensing and standards regimes in areas where a technology area is relatively mature, and where technology is being adopted or repurposed from other spaces (e.g. wind energy, where technology components from the aerospace and engineering sectors are in wide use).
- Clearing houses and 'national IP shop windows' in early-stage technology areas where there is a wide diversity of effort, players and technologies to encourage 'critical mass', improve efficiencies and cut through the 'patent thicket' that can arise in such areas (e.g. regenerative medicine).
- The introduction of patent pools in key areas of social need ('clean tech', low-carbon energy).
- Highlighting the intensity of IP activity in particular areas, and explaining the value of, for example, patent pools linked to university research strengths.
- UK Government already owns valuable IP in its datasets. These could be linked with business data, possibly using the 'web of data' model discussed in Section 2.3 above, to develop new business models and propositions.

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[49] firms with no production facilities, but a number of customers for their designs and intellectual property
[50] http://newsweaver.co.uk/mntnetwork/e_article001420348.cfm?x=b11,0,w

3. Background and methodology

The **Technology and Innovation Futures** project has its origins in a short study commissioned by HM Treasury from the Foresight Horizon Scanning Centre ahead of the 2009 Pre-Budget Report. The brief was to identify potentially important technologies for the UK in the next 5-15 years – with particular regard to the economic benefits they could generate. On completion of that work, the Government Chief Scientific Adviser, Professor Sir John Beddington, asked the Horizon Scanning Centre to give breadth and depth to the earlier work, and to focus its investigation on the decade of the 2020s. This is the Technology and Innovation Futures (TIF) project.

No other single Government report covers the scope and timeframe of TIF. Existing work tends either to be sector-based – such as DECC's recent Pathways to 2050 project – or to look to the nearer-term future, rather than a decade or more hence.[51]

Approach

The evidence base used in the TIF project was gathered by deskwork, interviews with 25 eminent figures from research and business, and five workshops involving 150 academics, industrialists, experts from the private sector and Government. The goal was to move beyond the most familiar ideas within sectors and see what different perspectives and ideas emerged. The workshops used a range of futures techniques to provoke and structure discussions. The outputs of the workshops were considered and validated through further deskwork.

The *evidence* gathered in this way is summarised in the Technology Annex as 53 condensed entries on specific future technologies and innovations. For each of these, comparable information is provided (when available) on the size of the potential market in 2025, the disruptive potential of the technology, UK capability, and barriers and enablers.

The seven areas described in Chapter 2 explore possible developments in a few selected areas. Most of the areas were suggested at table discussions during the five workshops, although two (Intellectual Property and Future of the Internet) were mainly prompted by interviews and desk research. The areas were not identified as the result of a prioritisation exercise, but are based on the views and ideas of the experts consulted during the project.

Those attempting to analyse future trends and identify possible developments beyond the near-term use the critical views of a wide range of experts as a guide. These may be collected through a formal written process, such as a Delphi study, but can sometimes more productively be gathered in a workshop setting, where complementary (or contradictory) views can also be taken into account. The combination of disciplines and viewpoints at a workshop can moreover lead to new insights.

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[51] The Technology Strategy Board (TSB) takes a long-term view of market opportunities in all its programmes. In addition, it has recently launched an Emerging Technologies and Industries Strategy that will look at disruptive technologies up to 7-15 years from market. The TSB has participated in all stages of the TIF project and will draw on this report in its work.

Using the report

In reading the clusters, areas and conclusions, their origin in a workshop process should be borne in mind. Attention has only been drawn to the subjective nature of views in the text when they were not agreed by other workshop participants.

The report is directed to those with an interest in the way in which technology and innovation developments can contribute to the UK economy over the next 20 years, those seeking to contribute to future technology transformation, and those interested in how UK industry might position itself to benefit from new sources of economic growth. The work will be used in the Manufacturing Framework, and Infrastructure UK's work on infrastructure technologies.

4. Technology Clusters

Ambient intelligence in the built environment	Annex sections	
In the next ten years, physical objects, places and even human beings will become more and more embedded with computational devices that can sense, understand and act upon their environment. The proliferation of sensor networks and their integration in the built environment during the coming decade will mean the emergence of a sentient world sensitive and responsive to people's needs. Ubiquitous sensors will be the eyes and ears for context-aware systems that can, for instance, control your heating or boil your kettle when you're coming home. The advent of a smart grid for electricity would bring possibilities for two-way control of energy usage through integration of ambient intelligence into a network of devices, or 'internet of things'. Advances in micro-electro-mechanical systems (MEMS) will drive a shift toward integrated sensing and actuation.	3.12 4.1 4.4 4.6 4.10 4.11 4.13	Modelling Human Behaviour Biometrics Intelligent Sensor Networks Next generation Networks Secure Communication Simulation and Modelling Surveillance

Bespoke material design and metamaterials	Annex sections	
Metamaterials, including 'cloaking devices', possess properties not available in nature that arise from their inter-atomic structure. Our understanding of such materials is advancing, but materials often exhibit unpredictable properties. Advances in simulation and modelling will allow design of bespoke materials and metamaterials and lead to advances in many applications including computing, energy generation and storage, superfludity and superconduction.	1.1 1.2 1.4 1.8 1.9 1.10	3D printing and personal fabrication Building and Construction Materials Metamaterials Active Packaging Smart Materials Smart Interactive Textiles

Closing the nuclear cycle		Annex sections
Nuclear power may be vital to meet energy demand and security. New reactors can exploit the full energy potential of uranium, thus greatly extending resource availability – by factors of up to 100 over current technologies. The new reactors are planned to improve safety still further and produce less radioactive waste. They will also reduce the risks of nuclear weapons' proliferation. High-temperature reactors will also have the ability to co-generate electricity and heat for industrial purposes, such as process heat for the oil, chemical and metal industries, for example, and for hydrogen production and seawater desalination. Concerns exist over whether there is a skills gap in the UK nuclear industry with a lack of career progression. UK manufacturing capability is currently limited to niche markets.	2.4 2.6 2.7	Nuclear Fission Nuclear Fusion Hydrogen

Desirable sustainability and user-centric design		Annex sections
We need to make sustainability desirable. User-centric design is critical to the adoption of technologies – identifying how and why people use technologies, and what they actually want. Changing consumer behaviour and reducing use of electricity will be required to meet long-term energy targets. Link to brain-computer interface and user-controlled data.	3.12	Modelling Human Behaviour

Display technologies		Annex sections
There is a huge opportunity to develop industries around foldable, cheap and scaleable low-energy screens, incorporating haptic feedback technologies, and direct projection technologies, e.g. retinal projections. Plastic electronics and OLED/OLEPs are key technologies, although graphics and visualisation software will also be important. UK skills in design will also be valuable in new low-energy lighting industry, e.g. with lighting integrated into wallpaper.	1.7 3.13 4.5 4.11	Intelligent Polymers Brain-Computer Interface New Computing Technologies Simulation and Modelling

Energy materials and storage		Annex sections
Advanced batteries could replace fossil fuels in transport, cutting CO_2 emissions, if electricity from low-carbon sources can be used to charge the batteries. The technology could also create local storage for electricity created by micro-generation, and a way of balancing the contribution to the grid of intermittent generation from renewables, as well as enabling the development of new portable technologies. Opportunity exists to capture and utilise off-peak energy to feed back into the grid at peak times. Likely advances will include large-scale energy storage through advanced battery technology, mechanical devices, or novel solutions such as gravel batteries. The development of efficient methanol fuel cells for CO_2 capture and conversion would be disruptive. Cost-efficient long-distance transmission of high-voltage will also bring new opportunities.	1.3	Carbon Nanotubes and Graphene
	1.5	Nanomaterials
	1.6	Nanotechnologies
	2.1	Advanced Battery Technologies
	2.2	Bioenergy
	2.3	Carbon Capture and Storage
	2.5	Fuel Cells
	2.7	Hydrogen
	2.8	Microgeneration
	2.10	Smart Grids
	2.11	Solar Energy
	2.12	Intelligent Low-Carbon Road Vehicles
	2.14	Wind Energy
	3.3	Industrial Biotechnology
	3.9	Synthetic Biology

Energy scavenging (including self-powered and low-powered devices)		Annex sections
There are always opportunities to capture more energy. A range of technologies exists, from capturing energy from human motion using nano-scale dynamos, to increasing efficiency of photovoltaics through new materials. This represents a huge potential contribution to meeting energy and low-carbon targets with widespread adoption. Improved energy storage is critical.	1.3	Carbon Nanotubes and Graphene
	1.5	Nanomaterials
	1.6	Nanotechnologies
	3.12	Smart Materials
	4.12	Service and Swarm Robotics
	4.4	Intelligent Sensor Networks and Ubiquitous Computing
	4.15	Bio-inspired Sensors

Engineering the computer-brain interface		Annex sections
A neural interface is a direct connection between a human or animal brain and nervous system and a computer or computer network. With the advent of such interfaces, humans and animals would be able to interact directly with computers merely by thinking. They also provide medical opportunities, include the reversal or paralysis or blindness, and treatment of brain disorders.	3.13	Brain-Computer Interface
	3.7	Performance enhancers
	3.11	Tissue engineering
	3.12	Modelling Human Behaviour
	4.10	Secure Communication
	4.8	Service and Swarm Robotics

GM food and agriculture – next generation healthier foods		Annex sections
The need for disruptive agricultural technologies is growing. Current technologies promise only incremental increases in yield. The technologies provide opportunities for 3rd generation GM crops, networked and precision farming, and engineered feed-crops to revolutionise industry. There are issues with UK infrastructure, legislation and public acceptance.	1.9 3.1 3.3 3.5 3.6 3.9	Smart and Biomimetic Materials Agricultural Technologies Industrial Biotechnology Nucleic Acid Technologies Omics Synthetic Biology
Hydrogen economy		**Annex sections**
Hydrogen is potentially the most important alternative to hydrocarbon fuels in a low-carbon future. The success of hydrogen will depend on technologies to increase efficiency and reduce the cost of safe production, storage and use of hydrogen. Full life-cycle analysis is critical for ensuring carbon neutrality. A number of possibilities exist for generation of hydrogen, including electrolysis, in the long-term, and co-generation through integrated gasification combined cycle (IGCC) technologies with CCS in the short-term.	2.5 2.7 2.8 2.12	Fuel Cells Hydrogen Microgeneration Intelligent Low-Carbon Road Vehicles
Lightweight infrastructure		**Annex sections**
A confluence of new materials and distributed intelligence is pointing the way to a new kind of infrastructure that will reshape the economics of moving people, goods, energy and information, compared to the capital-intensive networks of the 20th century. Over time, we will see repeated cannibalisation of existing 'heavy' infrastructures by their distributed versions (cf. the internet vs fixed line network).	1.1 1.2 1.3 1.4 1.9 4.6 4.10	3D Printing and Personal Fabrication Building and Construction Materials Carbon Nanotubes and Graphene Metamaterials Smart and Biomimetic Materials Next Generation Networks Secure Communication

Low-impact materials		Annex sections
Production processes use huge amounts of energy and water. Faster, better, cheaper and greener low-impact materials are being developed to move towards low-resource production, to reduce waste and respond to resource scarcity. New low-carbon materials, and manufacturing processes, including low-carbon cement, and rapid prototyping, will allow new models of industrial and personal scale manufacturing. An issue is that many renewables, for instance solar panels, are not necessarily low-carbon at the point of manufacture or disposal, merely at the point of use.	1.1 1.2 1.9	3D Printing and Personal Fabrication Building and Construction Materials Smart and Biomimetic Materials

Managing and processing of real-time social data		Annex sections
The number and complexity of social, economic and political processes that we have been able to model has been limited. In the future the growing availability of computational power will enable individuals, as well as the large organisations, to run simulations and scenarios routinely in the course of their lives, with the possibility that simulation may become a standard for literacy. In addition, organisations, including Government can use data to improve service delivery, and to determine interventions, just as supermarkets have optimised supply chain operations. Developments such as the smart grid would represent both challenges and opportunity to develop algorithms for smart usage (companies and households), and further open standards for interoperability of databases and systems.	3.12 4.2 4.3 4.4 4.5 4.6 4.9 4.11 4.12	Modelling Human Behaviour Cloud computing Complexity Intelligent Sensor Networks and Ubiquitous Computing New Computing Technologies Next Generation Networks Searching and Decision-Making Simulation and Modelling Supercomputing

Synthetic biology		Annex sections
In the past, geneticists have been limited to working with the parts that nature has evolved. A deeper understanding of genomics, coupled with computational biology, is leading to the ability to hack life itself and build organisms that never existed in nature. Synthetic biology points to a future teeming with programmable life-forms built to do our bidding. The idea of synthetic biology is to do for biology what electrical engineers have done for circuit design and what chemists have done for the synthesis of chemicals: to make an engineering field out of it.	2.2 2.7 2.9 2.11 3.3 3.5 3.6 3.9	Bioenergy Hydrogen Recycling Solar energy Industrial Biotechnology Nucleic Acid Technologies Omics Synthetic Biology

Multisensory input and sensing		Annex sections
Holographic projections would allow true 3D displays, but reproducing touch, sound and taste may become possible. This could revolutionise e-commerce, medical imaging and entertainment industries.It requires new developments in cognitive understanding, imaging technology, algorithms for representing sensory information and actuators.	3.2 3.12 3.13 4.6 4.9 4.11	Medical Imaging Modelling Human Behaviour Brain-computer interface Next Generation Networks Searching and Decision-making Simulation and Modelling

New computer technologies		Annex sections
Moore's Law may be broken through disruptive developments in storage, processing and integration technologies including DNA computing, photonics, multiprocessor compiling. Point-to-point technologies could also fundamentally transform the internet architecuture. These technologies would allow cloud computing to reach its potential, though with associated data security and privacy issues. Infrastructure is a key barrier.	4.2 4.4 4.5 4.6 4.7 4.10 4.12	Cloud Computing Intelligent Sensor Networks and Ubiquitous Computing New Computing Technologies Next Generation Networks Photonics Secure Communication Supercomputing

Organic solar cells		Annex sections
Photovoltaic technology has evolved steadily since its appearance in the 1960s to power satellites in space. However, everyday, low cost and efficient technologies remain few. Organic solar cells promise to overcome these barriers in a sustainable manner. Organic solar cells could be printed on a range of materials including clothes. New materials are being developed that overcome band-gap limitations of traditional materials with the promise of large efficiency increases.	1.1 1.3 1.5 1.7 2.11	3D printing and Personal Fabrication Carbon Nanotubes and Graphene Nanomaterials Intelligent Polymers Solar Energy

Tailored medicine		Annex sections
Two different models are proposed around personalised and stratified medicine. Individual and population level-scanning of disease traits will allow tailored diagnosis, treatment and prevention. Advances in fields such as epidemiology, computation, imaging, sensing and pharmacology will lead to cost effective and efficient health management, if the NHS, healthcare and pharmaceutical industry can adapt. This represents value in diagnostics, data and service delivery.	3.2 3.4 3.5 3.6 3.8 3.10 3.12 3.14 4.3 4.4	Medical Imaging Lab-on-a-chip Nucleic Acid Technologies Omics Stem Cells Tailored Medicine Modelling Human Behaviour eHealth Complexity Intelligent Sensor Networks and Ubiquitous Computing

Photonics		Annex sections
The internet currently consumes 4-5% of global energy and is growing fast. Integration of electronic and photonics, or the development of photonic computers using photonic memory, would enable a low-energy internet and communications infrastructure. Other applications include faster communications, quantum detection, imaging and sensing.	3.2 4.4 4.5 4.6 4.7	Medical Imaging Intelligent Sensor Networks New Computing Technologies Next Generation Internet Photonics

Plastic electronics		Annex sections
Plastic electronics technology allows circuits to be printed on many surfaces and over large areas. It is a low-cost alternative to conventional silicon-based electronics. Applications include displays, lighting and photovoltaics, including flat-panel foldable display technologies, and cheap customised and disposable electronic devices. It includes a new generation of hand-held devices, e.g. e-paper, intelligent maps.	1.7 1.9 2.11 4.4	Intelligent Polymers Smart and Biomimetic Materials Solar Energy Intelligent Sensor Networks and Ubiquitous Computing

Robotics		Annex sections
There is an opportunity for developing service robotics, especially where users can collaborate with robots. This represents the potential for a whole new service industry and manfacturing base. Further advances in robot cognition and learning would accelerate this development. Public acceptance may be an issue.	3.12 4.8	Modelling Human Behaviour Service and Swarm Robotics

Sensor networks and speckled computing		Annex sections
Nanoscale energy supply and storage is a key barrier to the development of large-scale ‘invisible‘ networks of sensors. Potential applications are wide-ranging but include detection and prevention of environmental and medical disasters. There are also issues of privacy, ownership and computational processing of data.	1.5 2.1 2.3 3.1 4.4 4.10 4.13	Nanomaterials Advanced Battery Technologies Carbon Nanotubes and Graphene Agricultural Technologies Intelligent Sensor Networks and Ubiquitous Computing Secure Communication Surveillance

Stem cells		**Annex sections**
To realise stem-cell potential, new regulation and business models may be needed. 1) a ‘blood donor’ model using cells from a matching donor (allogeneic); a generation of universal donor cells could enable this model. 2) an ‘IVF’ model, for cells taken from the host, engineered and replaced (autologous), with the delivery of personalised services, potentially by the NHS and a market for ‘health tourism’.	1.9	Smart and Biomimetic Materials
	3.3	Industrial Biotechnology
	3.8	Stem Cells
	3.10	Tailored Medicine
	3.11	Tissue Engineering
Syngas		**Annex sections**
Syngas and other new gas sources, e.g. biomass, would allow ‘orphaned‘ UK gas infrastructure to be utilised sustainably to meet energy demand and carbon emission targets. Syngas requires large-scale infrastructure, but can also be reformed to produce hydrogen, plastics and complex hydrocarbons. Some gas sources work on a small-scale from waste, e.g. biogas. There is the potential for systems integration and carbon capture. Syngas technology can be utilised to generate a range of end-products from plastics to chemicals.	2.2	Bioenergy
	2.3	Carbon Capture and Storage
	2.7	Hydrogen
	3.3	Industrial Biotechnology
The cheap genome		**Annex sections**
High-throughput, low-cost diagnostic techniques, such as individual genome scans for less than £100, will generate huge opportunites and risks for consumers, and may threaten to undermine the current healthcare insurance model. A key enabling technology for personalised medicine, early applications would be to screen high-risk groups for complex disease traits.	1.3	Carbon Nanotubes and Graphene
	3.1	Agricultural Technologies
	3.4	Lab-on-a-chip
	3.5	Nucleic Acid Technologies
	3.6	Omics
	3.8	Stem Cells
	3.9	Synthetic Biology
	3.10	Tailored Medicine
	3.12	Modelling Human Behaviour
	4.1	Biometrics

The plus energy house		Annex sections
Plus energy houses produce more energy than they consume. All the technologies exist to build such houses, but the building industry needs to be galvanised. Modular components that can be mass-produced and easily assembled would drive down cost. The advent of intelligent surfaces, smarter materials and consumer-friendly design would incentivise industry and user demand.	1.2 2.1 2.5 2.8 2.9 2.10 2.11 4.4	Building and Construction Materials Advanced Battery Technologies Fuel Cells Microgeneration Recycling Smart Grids Solar Energy Intelligent Sensor Networks and Ubiquitous Computing
Smart grids - microgeneration		**Annex sections**
Truly smart grids may be required to balance renewable (and often intermittent) energy sources, with both peak and variable energy demand. Intelligent control of local and centralised networks, coupled with real-time sensing and modelling, will be necessary to maintain network resilience. Microgeneration may change the face of the energy services market, with new rental models and dynamic tariffs.	2.8 2.10 4.3 4.3 4.11	Microgeneration Smart Grids Complexity Intelligent Sensor Networks Simulation and Modelling
Water		**Annex sections**
A breakthrough in low-energy desalination would disrupt the global water market, particularly for water-stressed regions. Recycling of grey water, through smart water systems alongside low-, or no-energy devices could dramatically reduce water usage in the UK. UK utilities company investment required seen as a barrier.	1.5 2.9 2.13	Nanomaterials Recycling Marine and Tidal Power

List of Participants

Professor Robin Ali	University College London
Dr Tim Allsopp	Pfizer
Tobias Alpsten	iPlato
Dr Nick Appleyard	Technology Strategy Board
D K Arvind	University of Edinburgh
Carol Atkinson	Building Research Establishment
Professor Abubakar Bahaj	University of Southampton
Henry Baker	HM Treasury
Dr Mark Bale	Department of Health
Dr Peter Bance	Ceres Power
Phil Banks	Home Office
Sir Tim Berners-Lee	W3C
Nic Bilham	The Geological Society
Dr Mark Bodner	GlaxoSmithKline
Sir Leszek Borisiewicz	MRC
Dr Chris Bowen	University of Bath
Dr Stephen Boyd Davis	University of Middlesex
Dr Sam Bradbrook	Health and Safety Executive
Tim Bradshaw	CBI
Professor Nigel Brandon	Imperial College
Peter Brooke	Council for Science and Technology
Professor Guido Bugmann	University of Plymouth
Dr Markys Cain	National Physical Laboratory
Dr Philip Campbell	Nature
Dr Celia Caulcott	BBSRC
Vincent Charlet	Association Nationale de la Recherche et de la Technologie (France)
Professor Brian Collins	BIS
Rich Corken	Intellectual Property Office

Professor Steve Cowley	Culham Centre for Fusion Energy
Kate Craig-Wood	Memset
Jo Dally	Government Office for Science
Martin Dare-Edwards	Infineum UK
Professor Nigel Davies	University of Lancaster
Professor Peter Dobson	University of Oxford
Henry Elliott	Government Office For Science
Dr Peter Ellwood	Health and Safety Executive
Fraser Elms	Herald Investment
Professor Stephen Emmott	Microsoft Research
Rebecca Endean	Ministry of Justice
Darren Fawcett	Pace plc
Dr Liz Fellman	Natural Environment Research Council
Ed Fergus	HSE
Dr Mike Fisher	Nanotech KTN
Rachel Fowler	HFEA
Professor Sir Richard Friend	University of Cambridge
Dr Jack Frost	Johnson Matthey
Emma Fryer	IntellectUK
Vincent Geake	Infrastructure UK
Professor Luke Georghiou	University of Manchester
Robert Ghanea	BT
Michael Gleaves	Science and Technology Facilities Council
Anne Glover	Amadeus Capital Partners
Neil Golborne	The Committee for Climate Change
Dr Dougal Goodman	Foundation for Science and Technology
Dr Nick Green	Royal Society
Ralph Green	EADS Astrium
Dr Mike Gregory	Institute for Manufacturing
Dr Bruce Grieve	Manchester University

John Griffiths	European Marine Energy Centre
John Griffiths	Gasification Matters
Jonathan Hague	Unilever
Andrew Haslett	Energy Technology Institute
Dr Hermann Hauser	Amadeus Capital Partners Ltd
Professor Adam Hedgecoe	Cardiff University
Axel Heitmuller	Cabinet Office
Dr Victor Higgs	Applied Nanodetectors
Dr Graham Hillier	Centre for Process Innovation
Professor Cyril Hilsum	University College London
Professor Anthony Hollander	Bristol
Jackie Hunter	GSK
Mark Husband	Rolls-Royce Group
John Ibbotson	IBM
Dr Hugh Ilyine	Ilyine Ltd
Dr Christian Inglis	The Technology Strategy Board
Martin Jackson	Plastic Logic
Professor Richard Jones	University of Sheffield
Professor Jonathan Jones	The Sainsbury Laboratory
Tim Jones	Future Agenda
Heekwon Jung	Organisation for Economic Co-operation and Development (OECD)
Professor Doug Kell	BBSRC
Alastair Kent	Genetics Interest Group
Pirjo Kylakoski	Tekes - the Finnish Funding Agency for Technology and Innovation
Peter Lockhart	Roke Manor Research
Sir John Loughead	UK Energy Research Council
Dr Sivasegaram Manimaaran	Dept for Business Innovation and Skills
Professor Ben Martin	University of Sussex
Paul Mason	The Technology Strategy Board

Professor Chris Mason	University College London
Professor Gerd Materlik	Diamond Synchrotron
Dan Mathers	National Nuclear Laboratory
Geoff McBride	Science Technologies Facilities Council
Tony McBride	Royal Society
Dr Patrick McDonald	Health and Safety Executive
David McMeekin	London Technology Fund
Dr Richard Miller	Technology Strategy Board
Dr Peter Mills	Human Genetics Commission
Steve Morgan	Dept for Environment, Food and Rural Affairs
Dr John Morlidge	The Technology Strategy Board
John Mundy	Creative North
Sara Murray	Buddi
Dr Andy Nicholson	Defence Science and Technology Laboratory
Luke Nicholson	More Associates
Professor Paul Nightingale	SPRU
Professor Raymond Oliver	Royal College of Arts
Professor Richard Owen	University of Westminster
Dr Kedar Pandya	Engineering and Physical Sciences Research Council
Dr Alex Pang	INSIS, Said Business School
Beverley Parkin	Royal Academy of Engineering
Tom Pasfield	Shell
Professor David Payne	University of Southampton
Ian Pearson	Futurizon.com
Dr Geoff Pegman	Rurobots
Professor Ian Phillips	ARM Ltd
Dr Neil Pratt	Science and Technology Facilities Council
Dr Robert Quarshie	Materials KTN
Alice Raine	Dept for Business Innovation and Skills
Raj Rajagopal	Council for Science and Technology

Dr Rob Reid	Which?
Jan Reid	Scottish Enterprise
Jason Riley	Imperial College
Professor Tom Rodden	University of Nottingham
Professor Steven Rose	Open University
Ant Rowstrom	Microsoft Research
Phil Ruffles	CST
Professor Barbara Sahakian	University of Cambridge
Professor Colin Seabrook	FW Stephens Technology & Innovation
Dr Shantha Shanmugalingan	NESTA
John Sheridan	OPSI
Professor Bernard Silverman	The Home Office
Professor Henning Sirringhaus	University of Cambridge
Professor Morris Sloman	Imperial College
Professor George Smith	University of Oxford
Dr Alexander Sokolov	Higher School of Economics, Moscow
Dr Bob Speel	Government Office For Science
Andy Stanford-Clark	IBM
Alex Stanhope	Technology Strategy Board
Dr Peter Stephenson	Technical Textile Sector, Materials KTN
Professor Michael Sterling	Council for Science and Technology
Professor Fred Steward	University of Westminster
Will Stewart	Royal Academy of Engineering
Nick Stuart	UK Trade and Industry
Quentin Tannock	Cambridge IP
Andy Taylor	Association for British Healthcare Industries
Dr Andrew Taylor	ISIS
Professor Sandy Thomas	Government Office for Science
Kenton Thompson	Dept of Business Innovation and Skills
David Thorpe	Institute for State Effectiveness

Hardin Tibbs	Synthesis Strategic Consulting
Professor Alexander van de Putte	IE Business School, Madrid
Dr Angela Venters	Department of Energy and Climate Change
Professor Sethu Vijayakumar	University of Edinburgh
Mr Ian Viney	Medical Research Council
Sir Mark Walport	Wellcome Trust
John Warrington	NHS
Professor Jeremy Watson	Dept of Communities and Local Government
Dr Robert Watson	Defra
Dr Adam Webb	Research Councils UK
Professor Mark Welland	Ministry of Defence
Dr David Williams	University of Cambridge
Dr Mark Williamson	The Carbon Trust
Dr Penny Wilson	The Technology Strategy Board
Professor Kent Woods	MHRA
Dr Peter Wright	Department for Work and Pensions
Professor Yongbing Xu	University of York
Jamie Young	Royal Society of Arts
Dr Xiao-Ping Zhang	University of Birmingham
Dr Majd Zoorob	PhotonStar LED

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It is inevitable in a project with such a broad scope and large number of contributors as Technology and Innovation Futures, that people on occasion hold different views, for example on how certain technologies will develop. We have tried to reflect the balance of these views in the report, signalling when they were not widely shared; where we have failed to do this we must take responsibility.

Foresight Horizon Scanning Centre

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Any enquiries regarding this publication should be sent to:

Department for Business, Innovation and Skills
1 Victoria Street
London SW1H 0ET
Tel: 020 7215 5000

If you require this publication in an alternative format, email enquiries@bis.gsi.gov.uk, or call 020 7215 5000.

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