Industrial Strategy: views from the PM's Council for Science and Technology

The UK industrial strategy is an opportunity to set out a vision for the future shape of a dynamic economy that works for all. CST welcomes the opportunity to contribute its views. We believe there is a compelling case for putting science, including engineering, social sciences, technology and design at the heart of this vision. These are enduring UK strengths and sources of great creativity. The UK competes not just against OECD countries, but other fast emerging and agile actors across the globe. The successful, high-growth, high-productivity economies of the coming decades will be those that embrace these disciplines through the entire economy, including services, retail, healthcare and energy, as well as manufacturing. Innovation based on science, technology and engineering can also address some of the important societal challenges that we face, such as climate change and an ageing population, and can address these in a cost-effective manner. Innovation policy can also have a significant role to play in tackling regional economic disparities in the UK.

We welcome the determination of the Government to take a comprehensive, principles-based approach and to learn from past experience, in particular not to be trapped by incumbency or to defend uncompetitive practice in declining sectors. We encourage government to be ambitious and to think long term. The value of giving policymakers, researchers, businesses, and investors, confidence in government's long-term aims is huge. A comprehensive approach must truly be that. It is always tempting to assemble a portfolio of small initiatives that might all be individually rational but which cumulatively do not match the scale of the issues they seek to address. The strategy will need to be flexible to adapt to emerging opportunities and challenges, and to accept that ambition inevitably entails some risk.

Critical for success will be clarity about objectives. The aim should be to drive not only output growth but also productivity, dynamism and creativity, fostering economic security and participation for all. The centrality of talent and skills to this vision means it can be at the heart of a new UK relationship with the world. Now is an unprecedented opportunity to project a message of confidence in the UK's world leading science and innovation system, and to send signals to attract global investment and high skilled talent.

While this paper deals primarily with new innovation, there is considerable scope for increasing productivity through greater diffusion of existing innovation, not only of technology but also process – better management, new business models, improved business processes. Open, non-distorting, competitive markets are a key spur both to new innovation and to diffusion.

CST's views on how industrial strategy can drive inclusive productivity and growth can be viewed through four lenses as follows:

1) The foundations - enhancing the innovation ecosystem throughout the UK;
2) Addressing societal challenges;
3) Exploiting the UK's technological comparative advantage;
4) Targeted deployment of Government's levers.

1. The Foundations - enhancing the Innovation Ecosystem (the science base and R&D, innovation institutional architecture, workforce skills, access to finance, infrastructure)

1.1. **Supporting an increase in UK R&D intensity**

Growth and productivity in the UK, as in many advanced economies, is driven to a significant degree by innovation[1]. Innovation is underpinned by research and development, both public and private. However UK productivity growth has stalled. We are well outside the top 10 of OECD countries and below the EU average in terms of our total national investment in R&D as percentage of GDP: at 1.7% in total[1] (0.5% government investment and 1.2% private sector) we lag behind many economies that we would consider much less advanced than our own. The fact that our R&D output, measured in science publication citations, is still strong suggests that this is an area of high potential and high value for money.

A large proportion of current government R&D spending is through tax credits. There is good evidence that this is one effective means of promoting R&D and sends a strong signal about the UK business environment. Nevertheless, a comprehensive strategy would encompass the framework discussed below with the key foundations being the highest priority of all. The service sector may be limited in its current ability to exploit R&D tax credits, both through how R&D is defined, and through limited awareness. Given that the service sector dominates the UK economy and that innovation in this sector can have substantial productivity and competitiveness benefits, we recommend that Government examines the application of R&D tax credits here.

1.2. **Research - leveraging existing excellence**

We are universally recognised as second only to the US in the strength of our scientific research. Yet we spend comparatively little and the proportion of top quality grant proposals that receive funding has fallen steadily as funding has been held or reduced. This strongly suggests that there is considerable untapped potential in the UK science base as a whole. Public investment in research is a proven driver of growth. If we are serious about the place of science and technology in the future UK economy, this is of prime importance. We must feed the roots if we want the branches to grow.

Bringing together the Research Councils and Innovate UK into UK Research and Investment is an important step forward to ensuring we get the most out of our research spending. For the first time we have a way of generating a strategic approach, creating a strong and coherent voice for science and research, and holding the research community and research councils to account for the quality and value of their efforts. It will introduce more genuine dynamism in prioritising not only the best science but also what is most economically and societally useful.

1.3. **Innovation – enhancing the institutional architecture**

The UK's research base is outstanding but innovation performance does not always match this. There are a number of structural issues to tackle. Innovation architecture includes universities, Innovate UK, technology transfer organisations and Catapults. The comparatively limited scale of innovation investment is a key constraint and there is again evidence of very significant unmet demand. This should be a priority area. The Catapults are relatively new; nevertheless it may be useful to examine progress. They need to learn from the best among them and increase international visibility.

[1] http://www.oecd-ilibrary.org/sites/msti-v2016-1-en/table-2.html

1.4. **Innovation - access to finance, capital markets;**
The UK is home to the world's leading financial centre. Nevertheless there is a shortage of capital to take the right risks at the right time, particularly growth capital to develop promising early-stage companies and new infrastructure investment. The perception is also that companies can spin out too soon and sell up too readily. Tackling the associated market failures should be one of the highest priorities. We believe there is a strong case for looking at extending the reach of existing relevant models (e.g. green/innovation investment banks). If new ideas and infrastructure can get through the early and difficult stages then they can become very attractive to institutional investors.

A related issue is that there is a lack of specialist analytical capability available to potential investors in emerging science and technology businesses. UK investor appetite is constrained by lack of incentives to develop analytical expertise in these areas of key UK comparative advantage in science and technology. Government can use its convening power to tackle this issue with the investment community.

1.5. **Innovation – support through agile adaptive regulation;**
Having the right regulations in place and the right degree of flexibility and responsiveness can give investors and companies confidence in the future operating environment as well as building public confidence that their interests are protected. In some cases entirely new regulations are required for new technologies or use cases e.g. artificial intelligence. In others, regulations that may no longer be fit for purpose or which may have unintended consequences can be revisited. The space to experiment is also important, typified by the FCA's regulatory sandbox for fintech. Building on the Government's Challenger Business Programme, government should seek to make the UK the most innovation-friendly regulatory environment among its peers. For regulation, as for tax regimes, it is of critical importance to investor confidence for the flexibility to have some predictability, for example, in terms of criteria for change.

1.6. **Innovation – scale-up architecture; demonstrators and test beds:**
Test-beds allow innovations to be trialed and refined. These can be large scale facilities and equipment beyond the scope of all but the largest firms, or real-world settings – hospitals, towns, regions – that are willing to provide the right environment. Test beds, like universities, can form the nucleus of an innovation ecosystem. As we have seen with smart cities, internet of things and driverless cars, they offer important opportunities for local leadership as well as attractive destinations for globally mobile R&D investment.

1.7. **Innovation - considering the whole economy; Services 2.0**
All efforts to drive inclusive growth and productivity need to consider the shape of the whole economy and the opportunities that can bring. This includes services. In 2015 the service industries accounted for 74% of businesses, 79% of employment and 71% of turnover in the UK. The picture is similar in other advanced economies with China and the other emerging economies heading in the same direction. We are a global leader in business services, finance, design and law, in which there is potential for sustained growth, particularly with the application of new technologies. This is not an area generally associated with research and development or technological innovation but blockchain, for example, has inspired an array of new financial and other service companies. Uber and AirBnB are based on advanced data science. DeepMind is a world leader in the application of advanced machine learning technologies. Supply chain innovation and data analytics have driven the growth of Amazon. To retain service sector competitiveness UK firms must embrace technology, particularly Big Data and artificial intelligence.

1.8. **Skills**
The economy cannot achieve high levels of productivity and growth without the right talent and capabilities in the workforce. This begins with primary education or earlier, to ensure children are

numerate and literate, right through to having appropriate access to global markets for high-level skills. Skills are also vitally important for the individual and thus for inclusive growth. Now and in the future, economic security will not come from having a job for life but from having the right skills maintained through lifelong learning.

Entrepreneurship education should be an area of focus. We need to encourage greater uptake of entrepreneurship education by undergraduates, by embedding the right incentives for colleges and universities; improving the course quality by establishing educational materials that draw on best practice; developing routes for students to learn directly from entrepreneurial businesses.

1.9. **Infrastructure**

The quality and capacity of infrastructure, at a national and local level, have a significant influence on the attractiveness of a location for research, for business and for people to come to live. Infrastructure makes cities work and ensures rural areas do not get left behind. This includes core infrastructure, primarily transport, energy and water but also the financial infrastructure which plays a key role in the smooth functioning and "livability" of the economy.

Also critically important for the digitisation of the UK economy, is digital infrastructure. 5G (including internet of things), broadband and supercomputing stand out in this respect. This has not traditionally been a focus of public infrastructure investment but government can create the right enabling environment to spur development, testing and implementation, for example via the regulatory and planning regimes or the promotion of test-beds.

1.10. **Innovation and regional policy**

Innovation policy also has a geographical element. The UK economy is overwhelmingly concentrated in the South-East of England. The various elements of the research and innovation framework discussed in this note are, however, among the levers that can help to address this imbalance. As the Government's Science and Innovation Audits have shown, there are many very strong clusters of research and innovation all round the UK; transport medical food and energy in the Midlands; advanced engineering in the South Western England and South Wales; advanced manufacturing in Sheffield; digital economy in the Edinburgh region, health and advanced materials in Greater Manchester to name but a few. There is significant untapped potential in the UK regions that if appropriately exploited could become a powerful driver of regional growth.

UK universities are among our most important assets in this context. They produce ideas and an educated workforce. There is enormous potential when they partner with ambitious city and regional leadership. Test-beds and demonstrators are also a powerful draw for companies. These can be dedicated facilities or they can be simply a willingness on the part of towns or cities to be open to and supportive of innovation – to driverless cars for example. Encouraging cities and regions to compete to win parts of the innovation architecture can be a powerful driver for change. Some of the innovation budget could be allocated by competition between or within regions. The quality of regional infrastructure, both digital and physical, is also an important draw for companies and investors.

2. Addressing Societal Challenges

Innovation is a compelling economic necessity in itself. Focussing innovation efforts in specific areas though creates the additional major benefit of solving pressing societal issues. CST suggests three key priority areas:

2.1 Healthy lives;

2.2 Cities and transport;
2.3 Clean energy;

2.1 Healthy lives

The dramatic increase in life expectancy seen during the 20th century ranks as one of society's greatest achievements. But there is considerable discrepancy between socio-economic groups; healthy life expectancy is not keeping pace with longevity; health systems are oriented towards treating rather than preventing illness; many new treatments are very expensive. A result is that healthcare consumes an ever-increasing percentage of GDP. The Office for Budget Responsibility (OBR) project expenditure on health to grow from 7.3 to 8.3% of GDP, and on long-term care from 1.1 to 2.2% of GDP by the mid-2060s. An ageing population means an increasing dependency ratio. A 2014 survey of over 50s showed that 23% of people had retired because of the onset of ill-health or disability, while 7% retired because they became a carer for a partner, friend or relative. Adding 1 year to working lives would increase GDP by 1% per year after 5 years; adding 3 years would increase GDP by 3.25% per year by the early 2030s. The challenge is to keep more people healthy and productive for longer while keeping funding at sustainable levels. But there are also huge export opportunities. The demand for healthcare is rising globally, creating new markets from which the UK – pharmaceuticals, life science and medical technologies – can benefit.

2.2 Cities and transport

Cities are the focus of many of the challenges and opportunities that we face as a society and an economy. They need to work well if we want to realise a vision of high growth, productivity and quality of life. Spillovers and agglomeration benefits make them the most dynamic place to innovate. Attractive cities, including educational and cultural facilities, draw in and retain talent. But they can also be inefficient, congested and polluted, with the impact felt most by the least well-off. Science and engineering, coupled with local leadership and planning, can help solve these problems and allow people to move, breathe and be productive. This creates a global market opportunity. In 1950, 30 percent of the world's population was urban. In 2014 this rose to 54%, and the UN projects that this will rise to 66% by 2050, an urban population increase of 2.5 billion or more. By 2030 the world is projected to have 41 mega-cities of more than 10 million inhabitants compared to 28 today. The global stock of infrastructure is expected to at least double in the next 15-20 years. Design of smart, connected cities as well as the financing, law, design and construction of infrastructure are significant UK strengths.

Drones and autonomous vehicles are radically changing how people and goods can be transported safely and efficiently. 5G will be as important for this as traditional roads and tracks. Multimodal, door to door "transport as a service" bought via a single smartphone app is being trialled in Helsinki. Importantly, new technology also offers ways to improve the efficiency, lifespan and capacity of existing infrastructure. Automation can radically improve utilisation and capacity on existing road and rail, improving productivity in both urban and rural areas.

2.3 Clean energy

Energy underpins all UK economic activity and investment in energy innovation is vital if the UK is to achieve its policy objectives. It will be extremely difficult to deliver secure, affordable and low-carbon energy with current technologies at current costs. Maximising the pace of innovation and its implementation in low carbon will be critical. Innovation will have a transformative effect on the efficiency of our future energy system – holding down energy bills and driving industrial competitiveness and growth across the economy. The market will drive some of this – but private investment will not go far enough, fast enough. We need to open up new technology choices in generation, storage, transmission, and connectivity while de-risking one of the largest infrastructure programmes in government. The pace of innovation will be critical in informing the big infrastructure

investment decisions which will underpin and drive our economy well beyond 2050. Innovation will lower the risk of locking in sub-optimal technologies for the long-term.

As with transport, the use of advanced technology will be crucial to manage existing infrastructure, for example the development of 'smart' electricity grids. Another example is UK domestic heating, which is largely based on piped networks transporting natural gas (methane). One route to decarbonisation of domestic heating would be to switch the existing network of pipes to hydrogen. A collateral benefit of this would be the transport of hydrogen for use by transport. A large scale switch to hydrogen will require the development of new technology and the implementation of carbon capture and storage to deal with carbon emissions from its production.

3. Exploiting the UK's technological comparative advantage

The third lens is technological – what are the key technologies that will underpin industrial strategy? CST suggests criteria that will enable government to make choices about technologies that are ripe for investment by government and the private sector for potentially significant contributions to inclusive growth and productivity. These are:

- That there should be a strong UK research base creating the opportunity for the UK to stay ahead
- That in parallel there is a strong or strongly-emerging business base in the UK;
- That there is a large potential UK and global market for existing and new services and products arising from the technology;
- That analysis of the value chain for these shows strong UK potential to derive economic benefit, including from associated services, and
- That the technology should have broad applicability to a variety of businesses and services.
- A final criterion is what might be termed "divine spark". This aims to capture the element of outstanding creativity or originality that may distinguish certain ideas or innovations.

Below is a preliminary list of technological domains that in our view score well against these criteria and merit further consideration by Government. It is not intended to be exhaustive or exclusive. A brief assessment of each is given in the annex. It is important, however, not to think about these technologies in isolation. Many of the most exciting opportunities will lie at the interface or overlap between the areas of strength.

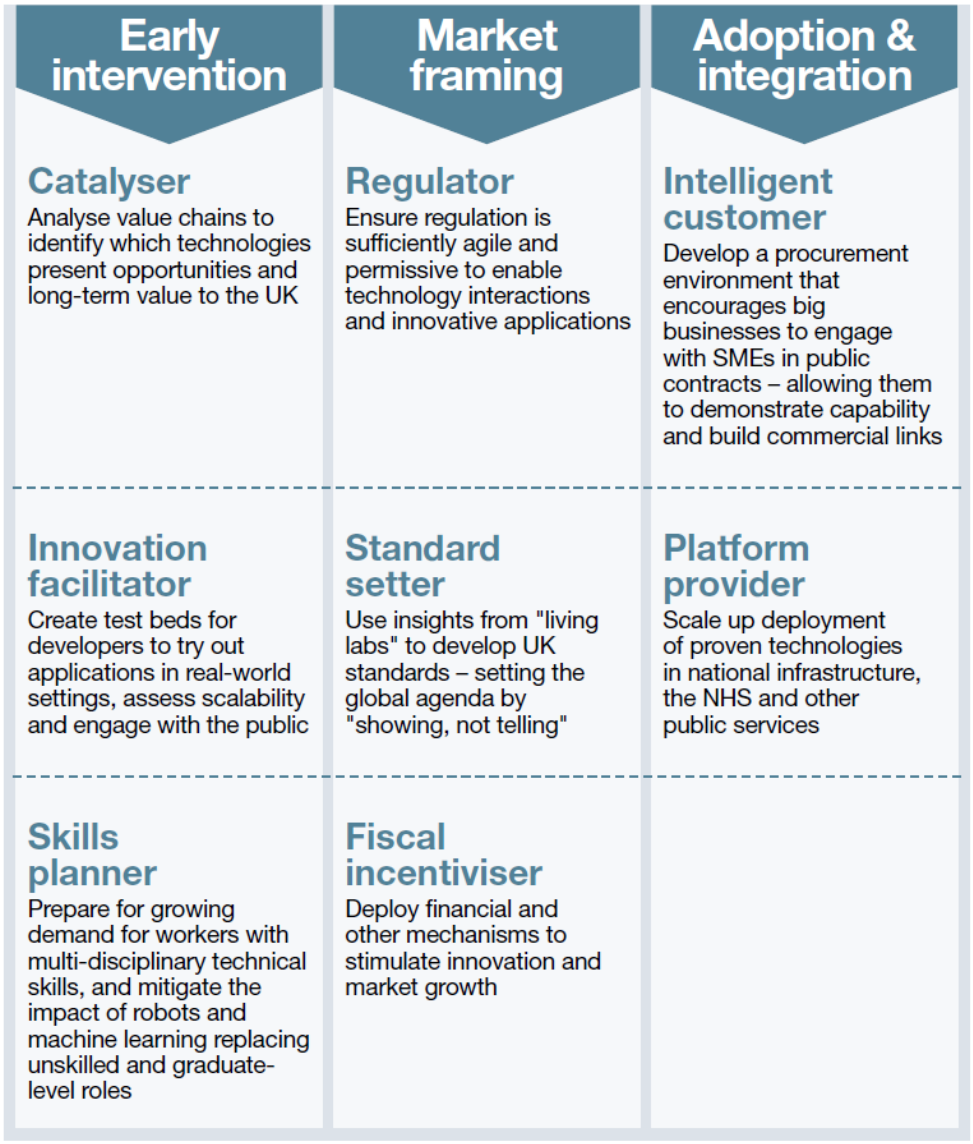
3.1 Robotics and artificial intelligence (including driverless cars and drones)
3.2 Life sciences including medical and agricultural technologies.
3.3 Clean energy technologies
3.4 Advanced materials
3.5 Digital infrastructure including 5G
3.6 Satellites
3.7 Quantum technologies

4. Targeted deployment of Government's levers

The fourth lens for the industrial strategy looks at the levers that government can pull when considering how to support new technologies. These levers were identified as part of the Government Office for Science paper on Technology Innovation Futures. These are summarized in the table at the end of this paper. The specific nature of potential government intervention will vary according to circumstances, depending on the precise nature of the market failure, the state of technological development and the existing innovation architecture in that space.

A strong CST recommendation is that, when it comes to the final choices of which researchers or innovators to support, there is a proper competitive process. This will help to ensure that public funds are provided only for research and innovation to support the most outstanding individuals and teams. This is the essence of the Haldane principle that has served helped the UK to be a globally leading science, engineering and technology nation for more than 100 years.

Government policy levers for supporting emerging technologies



Annex: Information on candidate technology areas for further investigation

This annex contains a preliminary analysis of seven technology domains that the Council of Science and Technology regard as scoring well against the criteria that are set out below for potentially significant contributions to inclusive growth and productivity (and discussed in the main paper). They are:

- That there should be a strong UK research base creating the opportunity for the UK to stay ahead
- That in parallel there is a strong or strongly-emerging business base in the UK;
- That there is a large potential UK and global market for existing and new services and products arising from the technology;
- That analysis of the value chain for these shows strong UK potential to derive economic benefit, including from associated services, and
- That the technology should have broad applicability to a variety of businesses and services.
- A final criterion is what might be termed "divine spark". This aims to capture the element of outstanding creativity or originality that may distinguish certain ideas or innovations.

This is not intended to be a final or exclusive list, nor is the analysis comprehensive. Rather, it is intended to stimulate further investigation by Government. For each technology there is an outline of the potential opportunity, both in the UK and globally; the state of play in the UK focussing on the current research base and business activity; and initial thoughts as to where and how the UK might capture some of the value chain. The technological domains are:

1. Robotics and artificial intelligence (including driverless cars and drones)
2. Life sciences including medical and agricultural technologies.
3. Clean energy technologies
4. Advanced materials
5. Digital infrastructure including 5G
6. Satellites
7. Quantum technologies

Finally and most importantly, when final choices are being made as to which research areas or innovations to support, the view of the CST is that there should be a rigorous competitive process as the best way to ensure the absolute maximum value for money for the UK taxpayer.

Robotics, automation and artificial intelligence (RAAI)

1. How big is the opportunity?

AI technologies are vital for extracting value from big data: in markets such as finance, marketing, healthcare, law, retail, transport and manufacturing. AI will add value to every sector that uses digital technologies and will underpin the internet of things and "Industry 4.0". RAAI systems are an extension of this: interconnected, interactive, cognitive and physical tools, able to perceive their environments and use AI to process the sensor data to reason, make or revise plans and control their actions.

McKinsey estimate the impact of RAAI technologies globally at between $1.7 and 4.5 trillion per annum by 2025 (an extra $0.2-1.9 trillion including autonomous vehicles) with productivity expected to increase due to industry 4.0 by 26% in the future.

Barclay's scenarios suggest £1.2bn additional investment in automation could increase UK value added by £60.5bn over the next decade. CEBR estimated £240 billion in cumulative benefits to the UK between 2015-20 from big data and the internet of things. OECD concluded that firms making better use of customer and consumer data are 8-13% more productive. Robots in manufacturing raised annual labour productivity growth & GDP by 0.36 & 0.37 pp respectively for 14 industries in 17 countries from 1993-2007, though it is clear that these technologies are also transforming services

They will have a major impact on all of the four challenge areas identified. For example in health (surgical robots, exoskeletons, preventative diagnostics; care (monitoring wellbeing, companion robots); cities (building information management systems); transport (autonomous vehicles, traffic management through smart sensors, maintenance through RAAI); energy (smart grids, smart meters, infrastructure maintenance); and business services such as the law (ultrafast data search and processing).

2. How good is the UK?

The UK is a world leader in AI technologies with a rich ecosystem of developers, research institutes (including the Alan Turing Institute), investors, businesses large and small including Global firms such as Google and Facebook. InnovateUK and EPSRC have portfolios of worth £27m and £106m respectively in robotics and autonomy. NERC has invested £10m in marine systems. Intelligent Mobility Fund provides £100m for R&D, including trials of driverless cars. The top 12 universities with EPSRC funding for RAS have 140 project partners from industry, making a total value contribution of £43 million. The 4 Centres for Doctoral Training have 70+ industrial partners providing match funding. The BEIS/DfT Centre for Connected and Autonomous Vehicles is overseeing driverless car projects in Bristol, Greenwich, Milton Keynes and Coventry.

3. What part of the value chain can the UK capture and how?

This is a vast and fast-moving sector. South Korea, Japan, China, US and Germany are investing heavily and have a head start in many areas. Investment in the application of AI by the UK business services sector will be essential for this to remain a UK competitive strength. Work by the Council of Science and Technology has identified hazardous environments, health and care as UK opportunities in RAAI, in addition to autonomous vehicles and drones, and has recommended a challenge-led competitive Government/industry co-funding approach to research funding to achieve better co-ordination between key players and industry, and to enable testing of these innovations in real-world settings. This will maximise the prospect of a significant share of the global market. We also need to address the fact that AI start-ups see being purchased by overseas data companies as the most likely viable route to growth. Sustained UK investment would enable these companies to remain in the UK, exporting their services globally. As a funding model, innovation competitions that invite industry/HEI collaboration and co-investment in the area of convergence between robotics and AI would exploit the UK's strengths here, as well as landing globally mobile R&D investments in diverse areas of strength around the country.

Life Sciences and medical technology

1. How large and enduring is the opportunity?

The life sciences, including not only medical sciences and pharmaceutical but also animal and plant technologies, have transformed our lives in diverse ways: improved healthcare, better agricultural productivity, new foods and fuels. These are large and growing markets: In 2014, the pharmaceutical sector generated revenue of $1.2 trillion globally, an all-time high. OECD countries spend on average over 9% of GDP on health with demand increasing rapidly globally driven by higher expectations and because healthy life expectancy is not keeping pace with longevity. Among the big prizes for governments are: finding ways to keep the cost of healthcare at a manageable level while keeping people healthier for longer, and to increase environmentally sustainable production of food and biofuels.

2. How good is the UK?

The UK has two of the top 10 firms in GSK and AstraZeneca, four medical schools in the top twenty of most league tables, and exciting unique projects in health data, including UK Biobank and the 100,000 Genomes project. The UK Life Science sector employs 220,000 people across approximately 4,500 companies, and turns over £67 billion a year, and accounts for 5.6% of trade. The UK biotech cluster in the South East is the largest in the world outside Boston and San Francisco.

The UK is an attractive place for inward investment by life science companies due our world leading discovery science and, in healthcare, our clinical development environment. On the flip-side, it is often felt that UK firms sell up too readily, and UK investor appetite is constrained by the lack of incentives to remain for the long-haul.

The UK already has a good reputation for well-balanced regulation (e.g. the Human Fertilisation and Embryology Authority). Outside the EU there may be further opportunities e.g. to deliver rigorous early stage clinical trials quicker and more efficiently, and by reducing constraints in certain areas such as stem cells and genomic data use.

3. How much of the value chain could the UK capture and how?

There are a number of specific opportunities for the UK, in health and Agri-tech, which build on our strengths:

- The **NHS** is a national asset that, through its enormous procurement power, could play a powerful role in developing the life sciences and medical technologies in the UK by directing innovation towards the areas it most needs.
- The NHS in partnership with innovators, can provide the opportunity to test and gain real world data on products, while delivering development through a shared risk model. The NHS Test bed programme is a good example of how industry and the health system can work together to improve health outcomes and also produce intellectual property.
- **Data** analytics has enormous potential to improve the efficiency and accuracy of healthcare. However, this is highly dependent on the NHS delivering a fully connected longitudinal dataset of its patients and making this available to innovators. As a single payer healthcare system, with real-world data from millions of patients, the NHS has enormous potential to be a powerful driver in the application of data.
- The UK is strong in the discovery and development of **vaccines**, but has a gap in their manufacturing. There are opportunities for inward investment and expanding vaccine discovery capabilities into new areas.

- The **interface between Physical and Life Sciences** in the UK is strong, leading to innovations in drugs, diagnostics and devices. It is crucial to sustain this at the highest level in order to create new tools for interrogating disease, and to drive drug discovery and molecular diagnostics.
- **Cell and gene therapies** and synthetic biology are a disruptive technology with an emerging industry involving therapy developers and their supply chains. The UK has the opportunity to consolidate its leading position through development of manufacturing and delivery solutions. An agile NHS and regulatory environment will be necessary.
- The UK has very good companies and research institutes in **Agri-biotech**, such as Syngenta, KWS, Rothamsted Research, and the John Innes Centre. There is potential for new biotechnology applications, such as DNA editing using CRISPR-Cas9, to revolutionise food production. However this is dependent on there being a supportive regulatory environment and efforts to improve public perception. There is also huge scope for such technology in livestock applications.

Clean Energy

1. How large and enduring is the opportunity?
Global energy markets are entering a new phase of increasingly complex supply-demand dynamics away from fossil fuel production and towards clean energy technologies. UK turnover in the low-carbon sector, including low emission vehicles, stood at around £121.7bn in 2013, employing 460,600 people. The global market is estimated to be worth over £500bn by 2025 and will continue to expand with the pressure to decarbonise under the Paris Agreement. However, IEA data demonstrates the UK underinvests in energy innovation compared to the USA, Japan and Germany. Investing now in innovation would help ensure that UK takes a leading global position.

2. How good is the UK?
The UK is currently the world's largest market for **offshore wind** with 5GW capacity installed and under construction some 19% of the UK's renewable energy generation. BEIS expects potentially a further 6GW by 2025, and up to 31GW by 2050. This industry has the potential to support 22,500 direct jobs in 2025 and contribute £19bn to the UK economy by 2050. However much of the manufacturing is outside the UK. We need to ensure that our investment in clean energy benefits UK companies. For example, using our offshore oil and gas expertise to pioneer wind turbines in deep water locations.

The UK has particular strengths in the low-carbon transport sector. The UK has the EU's only electric vehicle battery cell and pack manufacturing facility, with 1 in 4 electric vehicles bought in Europe during 2014 being manufactured in the UK. There is potential for low carbon tech-diffusion from UK motorsport (sector turnover £9 billion): 7 of 11 Formula 1 companies are based in UK and for the first season of UK based Formula E, all teams were supplied with a battery system created by UK-based Williams Advanced Engineering.

3. How much of the value chain could the UK capture?
Currently natural gas supplies around 70% of all the heat used in UK buildings and industry. To decarbonise heating – one of the biggest remaining clean energy challenges – trials could be done to explore the viability of repurposing the gas grid to carry **hydrogen**. Many countries face the same challenges; the UK would become a world leader in a potentially global market in the use of hydrogen for low-carbon heat and transport (adding the possibility of a low cost hydrogen distribution network to complement Government's existing investments in hydrogen fuelled low carbon transport infrastructure)

Successful innovation in electricity network technologies, including **smart technologies and all forms of energy storage**, could save the energy system around £4.4bn, support the growth of a UK industry and contribute an estimated £5.1bn to GDP by 2050. This is a competitive sector although a UK firm, Moixa Technologies, is developing battery systems for homes and businesses. We have good academic expertise in battery technology and energy storage. We could also leverage the UK's strengths in algorithms and software development which will be essential in a smart energy system.

Extensive research suggests **carbon capture and storage (CCS)** could reduce the costs of decarbonising the UK and the global economy by at least half. CCS could provide cost-competitive low carbon electricity generation, complementing the role of "economically inflexible" (e.g. nuclear) and "intermittent" (e.g. wind). CCS is also essential for large scale low-carbon production of hydrogen from fossil fuels. Globally the demonstration of CCS technology is progressing slowly although the UK, with a strong research base and expertise in offshore oil and gas (needed for CO_2 storage), could seek to enter the sector.

There are also big opportunities in improving the efficiency of our **energy intensive industries** (iron and steel, cement, chemicals, oil refining etc.), together 70% of industrial CO_2 emissions. Technology innovation could focus on demonstration of electrification, use of hydrogen, heat recovery, fuel switching and furnace/kiln design. UK companies that develop such technologies have a significant export opportunity in the future as other countries seek to improve the efficiency of their industry.

As of May 2016, 63 new nuclear plants were under construction in 15 countries. The UK has historically been a world leader in **nuclear power** and has a wide spread of expertise, both in academia and in industry. For example, Urenco is currently developing the U-Battery, an innovative new micro-reactor with multiple applications including providing power in remote locations, for data centres, and combined heat and electricity in industrial sites. It also potentially has a role in the low-carbon production of hydrogen.

Advanced Materials

1. How large and enduring is the opportunity?

We are entering a "golden age" of discovery and application of new materials – ceramics, composites, graphene and 2D materials, nanotubes, amorphous materials – and nearing the point where supercomputers allow the design of materials atom by atom. As much as seventy per cent of all technical innovations have been estimated to be directly or indirectly linked to innovations in materials: higher capacity batteries; stronger, lighter aircraft components; radar absorbent paint for warplanes; crystals that create exceptionally bright LEDs; new substrates for 3D printers; nanomaterials that can treat disease; better photovoltaics; materials embedded with sensors and data handling capability. The global value of advanced materials by 2030 is estimated to be over £250 billion. Advanced materials underpin UK sectors worth a combined £170 billion – including healthcare, energy, aerospace, automotive and Information and Communications Technologies (ICT).

Technological advance and innovation in materials can have a major role in addressing the key challenges: improved battery technology can achieve greater integration of renewables and deliver huge savings in efficiency of electric vehicles: finding the successor to lithium is a huge prize. Carbon nanotubes are highly effective for decontaminating water; anti-fouling paint can save billions in fuel costs for the shipping industry. In healthcare, nanomaterials have the potential to detect diseases, deliver treatments and allow prevention in new ways. Simple things like better non-slip coatings can cut falls.

2. How good is the UK?

Materials science is a longstanding UK strength. Carbon fibre composites were first developed at the Royal Aircraft Establishment in Farnborough. The world rankings for academic departments of materials at UK universities place Imperial College third, Cambridge fifth, and Oxford ninth. Manchester leads on graphene and 2D materials. The Sir Henry Royce Institute for Advanced Materials has Manchester, Sheffield, Leeds and Liverpool as founding partners. Other leading centres include the National Composites Centre, the National Nuclear Laboratory (NNL), the Centre for Process Innovation and other parts of the High Value Manufacturing Catapult The UK has world class materials characterisation capabilities, with cutting-edge facilities such as Diamond and ISIS. Success in materials science already underpins UK success in sectors such as aerospace and automotive.

In total, 368 of the 2000 top R&D investing companies are active in materials research and have a UK manufacturing presence. World leading companies include, for metals: Rolls Royce, General Electric and Jaguar Land Rover; for coatings: Pilkington/NSG, International Paints and Akzo Nobel; for functional and structural materials: Morgan Advanced Materials and Victrex; for medical materials: Smith and Nephew and GSK; and for composites: Airbus, Boeing and Williams F1.

3. How much/which part of the value chain could the UK capture and how?

Materials can form up to 60% of the total cost of manufacturing and underpin the high value parts of the UK manufacturing economy. Our strengths in aerospace, automotive, marine, rail, health, renewable energy, oil and gas and ICT rely on materials innovation and the UK is in a strong position to ensure that more of the innovation and the supply chain is based in the UK. In particular, we have an opportunity to become world leaders in carbon fibre composite manufacture for use in automotive and aerospace; new steel and aluminium alloys for use in oil and gas; metamaterials and compound semiconductors for use in the electronics industry; new coatings and joining technologies for use in construction and infrastructure; specialist ceramics for metal processing and medical applications; and specialist energy storage materials for transport and the built environment.

To make this happen, there is scope for additional innovation investment. Innovate UK has successfully helped the development of new aluminium with Jaguar Land Rover and supported a consortium including Bombardier to develop new composites that feature graphene for use in commercial aircraft. Joint industry / government investment in large demonstrators or test-beds to get novel solutions into the hands of the end-user would help the development process. Also important will ensuring that SME can access exiting facilities and fostering collaboration between centres as well as encouraging more academic / business links. Of particular interest are the huge potential productivity gains from shifting from real to virtual discovery and testing, and exploiting the UK's strengths in advanced computational techniques & modelling to accelerate the discovery & market entry of new materials and material properties.

Digital Infrastructure including 5G

1. **How large and enduring is the opportunity?**

Access to a cutting-edge digital infrastructure – particularly High Performance Computing (HPC), Cloud computing, fibre broadband and 5G networks – is essential for research and innovation. It will allow the UK to be at the forefront of Big Data, Internet of Things, new machine learning technologies, advanced modelling and will form the basis of new service development frameworks.

5G is at a critical juncture. It is a developing standard for a far more powerful wireless infrastructure, seamlessly integrated across next generation core networks and delivering massive connectivity, lower and predictable latency, faster data speeds and smarter use of spectrum, energy and network resource. 5G will put the power of big data and machine learning in every pocket and every device. It aims to meet an exponential increase in mobile data demand by business and consumers, improve coverage and allow the realisation of the IoT (internet of things) and other innovations such as robotics and VR. Smaller demonstrators are already developed in mainland Europe and the first large-scale demonstrators will go live over the next two to five years.

It is predicted that 5G revenues could reach **US$250 billion** in 2025. The EU Commission estimates that UK investment in 5G by 2020 could lead to a **€16bn** benefit to the UK across the economy.

In the challenge area 5G, with fibre broadband and new wireless networks at its core and including IoT networks, will be the backbone of the next generation of smart systems: tele-health; smart cities; safe, high-volume, high-efficiency transport networks and driverless vehicles; smart energy grids, meters and management systems. It will spur the development of new business models and digital services. HPC is required for cracking the huge computational problems at the heart of modern R&D such as designing new drugs or modelling aerodynamic drag for cars or the resilience of national infrastructure.

2. **How good is the UK?**

UK is some way behind countries such as South Korea on 5G investment but with strengths in some areas. The £70m 5G Innovation Centre (5GIC) at Surrey University is backed by £12m from UK government and £5m from Huawei. Described as “the world’s largest academic research centre dedicated to next generation mobile and wireless”, it has strong links with public and private sector users. The UK also has leading research and innovation centres in Bristol, Kings London and Lancaster. The UK strengths in underpinning technologies include, satellites, network and radio elements such as antennas, and also in enhanced wireless and IoT testing mechanisms, processors and system on chips, applications and security, and standards (National Physical Laboratory)UK has HPC at Edinburgh, the Met Office and Hartree, although they are modest compared to the largest Chinese and US facilities. We have world class algorithm and data science e.g. Oxford, UCL the Alan Turing Institute.

3. **How much of the value chain can the UK capture and how?**

On 5G, the UK needs to implement 5G as rapidly as possible or risk being left behind. Government needs to use its convening power to bring together the relevant players to make this happen. But there is a choice for the UK over whether we should seek simply to implement or to lead and shape 5G standards and technologies, particularly in our areas of strength. This would allow UK firms to be part of the global rollout of 5G and to ensure the standards work for areas where UK firms can lead 5G applications (security, creative industries, e-commerce). Given the nature of 5G, test beds and demonstrators are critical and an area where UK could take a lead and give the best chance to a broad ecosystem of researchers and businesses. 5G pushes telecoms and ICT much closer together and so may expose some areas of their different regulatory framework that need consideration.
On HPC, rapid advances in technology mean that facilities are soon obsolete. There is a continuing need to revisit UK capability to ensure we retain a level of competitiveness to support UK firms.

Satellites

1. How large and enduring is the opportunity?

Potential: The global space and satellite sector was worth £250bn in 2015. The largest and fastest growing segment is commercial space products and services – in which the UK excels: everything from broadcast to navigation to weather. Over the last year, £1.4bn of venture capital investment alone has gone into commercial space – more than the previous 15 years combined, as prominent entrepreneurs see space delivering the next major technology revolution. No other technology can deliver solutions with instant global impact, or enable commercially viable answers to global challenges like poverty and food security.
The UK space sector has tripled in size since 2000, and currently represents about 6% of the global market. The ambition set out in the Space Innovation and Growth Strategy of 2010, which we remain on track to deliver, is to secure 10% of the estimated £400bn global market by 2030.

Challenges: Space is an enabler for all four identified challenges – and integral to digital infrastructure. On health, the UK Space Agency, IUK, Satellite Applications Catapult and others have shown how satellites can improve NHS productivity and health outcomes. This includes mobile breast screening units transmitting scans for faster analysis, live monitoring and treatment by doctors of stroke patients in transit, and remote monitoring of patients to avoid unnecessary ambulance journeys. Many citizens and most transport systems rely on satellites to locate themselves and navigate city environments; as more systems integrate, opportunities are only growing. In the new world of non-intermediated services, location, communication and imagery are vital. Much of this is only possible via satellite.

Big Wins: Much of the new investment is going into new large constellations of small satellites for communications and high-frequency imaging. These can require hundreds of satellites, and create big opportunities to scale up the industry. SMEs need help developing appropriate manufacturing techniques to scale up from small production runs and manage risk. The Catapults can help through supporting high TRL level competitive co-funding of manufacturing innovation, to support the productivity gains of manufacturing cost reduction & scale-up.
Disrupted Sectors: Space is ubiquitous, with no limit to its reach. Integration of High Throughput Satellites and new constellations into 5G will only increase their impact. This will create opportunities in agriculture, health, extractive industries, and government service provision.

2. How good is the UK?

World class. Surrey Satellites, now part of Airbus, is often described as a 'New Space' company, making about 40% of the world's small satellites. Clydespace is a leader in nanosatellites. UK research base work on sensors, materials and instruments for domestic industry and the European Space Agency is being exploited by a new wave of businesses. The UK is leading world thinking on Satellite Applications and joining the end market to satellite manufacturing. ESA has chosen the UK for its centre on Satellite Applications, the ECSAT facility in Harwell. The Sat Apps Catapult currently works with 57 UK universities, with particular strengths in satellite engineering, comms, earth observation, navigation and space science. Over 50 companies have set up or relocated in Harwell since 2013, including over 20 inward investors. The UK's focus on applications and space as an economic enabler is unique, but others (eg the US and France) are looking to emulate.

3. How much/which part of the value chain could the UK capture if it moves quickly?

By 2030, an estimated 90% of the economic value of the UK sector will be related to *applications* of space technology on the ground, in retail, health, food production, communications, transport and energy. Around 60% percent of that value will be delivered through exports. Right now, the UK covers the entire value chain from new materials, manufacturing processes, component design, through to satellite manufacture, operations and services. We benefit enormously from this breadth of knowledge: Our detailed understanding of the technology helps us innovate at the services end,

and our knowledge of the markets informs our technology evolution. The UK however has no satellite launch capability. This could enable us to develop new launch operations concepts not available anywhere else and add to the variety and usefulness of services we can offer.

Quantum Technologies

1. What is the opportunity?

Quantum mechanics brought us semiconductors, lasers, digital cameras, solar cells, GPS, mobile communication and supercomputers. A new generation of quantum technology is emerging which will allow accurate navigation without the need for GPS, seeing round corners, detection of buried infrastructure and minerals and non-irradiating methods of imaging the human body. In addition to this, quantum computers have the potential to revolutionise the development of novel materials and drugs and break some types of modern encryption.

These emerging technologies will positively impact on sectors including infrastructure, transport, energy distribution, finance, telecommunications, healthcare and, in the longer term, data analytics – all sectors which contribute to the strategic challenges identified by the CST.

The future global market potential is huge – the UK National Strategy for Quantum Technologies predicts a +£1bn per year industry for the UK within 10 years and a total global market size currently measured in tens of £bn. For example, the global market for MEMS chips alone (a technology in which Quantum Technologies could provide significant enhancement) is $12bn.

This is a global race with international interest in the UK's programme. International businesses like IBM, Toshiba and Google are interested in developing these technologies and we have the opportunity to capitalise on our current comparative advantage in Quantum Technology R&D.

2. What are the UK's strengths?

The UK has a world leading joint research programme between academia and industry. The programme has received c.£350m funding over 5 years which represents the 4th largest absolute investment in Quantum Technologies globally (behind the USA, China and Germany in order).

The programme is focussed on developing commercial applications and networked across the UK with four lead hubs at Birmingham, Glasgow, Oxford and York. As a result, multinational companies such as Airbus, ID Quantique, Toshiba and BT are conducting R&D in the UK. We have also seen other governments and organisations, such as European Commission's flagship for quantum technologies, try to duplicate the UK's model.

3. How much of the value chain can the UK capture and how?

The current global market is predominantly through the sale of component devices to the global research base, a market estimated at £1Bn/year and growing. In this area, the UK has a number companies leading in this market such as Oxford Instruments, M-Squared lasers, Coherent Scotland, Kelvin Nano-technologies and Covesion. Additionally, the UK has a fast growing (8% pa. in 2015) Photonics Industry (£10.5bn in revenue in 2010) which represents a major enabling technology (high quality lasers and optics) for this emerging sector. Due to the complexity of quantum technologies, and the time expected for them to reach maturity, these UK companies and others are in a prime position to grow and sustain a lead in high-value parts of the supply chain as it emerges.

There is a strong case for building on the successes of the UK National Quantum Technologies Programme by extending & growing the existing programme through the mechanism of competitive industry co-funding, and by greater coordination and integration with industry as well as using government levers, such as procurement and regulation (eg. demonstrators and test beds), to create the environment in the UK for Quantum Technologies to flourish. This would ensure the UK leads the world in pulling through these technologies & captures the supplier market. It would also facilitate the dissemination and adoption of these technologies across UK sectors identified above to realise improved capabilities, resilience and productivity.