Oxfordshire Transformative Technologies Alliance

Science and Innovation Audit

August 2017

Contents

Executive Summary

The Oxfordshire Transformative Technologies Alliance SIA focusses on 4 large scale, disruptive, inevitable, digital technologies, for which the UK has great need and world class strength, particularly in Oxfordshire. There is considerable consensus that business sectors and workforces globally will be significantly disrupted by the development and impact of these technologies. We have sought to think beyond 'business as usual' to identify opportunities and strategies to secure the UK's position in a global context as these technologies increase their market share, and their relevance and influence in policy, society and economies.

The technologies are fast-moving and competitive, and offer opportunities which require strategy and cohesive leadership and prioritisation if the UK is to maintain and develop a global position in the science and innovation and markets.
We consider maximising the value of investments through co-location and connectivity between complementary technologies, and delivery mechanisms and connectivity into the supply chain. The national purpose is to maintain and capitalise on the UK's narrow, and otherwise fragile, early mover advantage.

This SIA demonstrates both the scale and quality of Oxfordshire's science and innovation assets, and their potential to support implementation of the National Industrial Strategy, and have lasting transformational impacts on national competitiveness and productivity through 2030.

Place

The geographic focus for the SIA is on assets within Oxfordshire. There are links with three other areas of the UK: the M3 corridor, greater Cambridge, and the north-east of England, for technology development, manufacture and rollout.

Vision

The core vision of this SIA is for Oxfordshire to be a global leader in the development of transformative technologies that will underpin the future UK economy and provide lasting global competitive advantage.

Convergence of ubiquitous computing power, cloud data storage, and advanced decision making algorithms with mass consumer acceptance of increasingly smart digital devices, will continue to transform society.

The opportunity for the UK is to play a leading role by developing new products and services built on purposeful investment in appropriate skills and strategic support for cross-sector engagement. This will mutually reinforce the growth of these technologies, and their application to a wide range of market sectors. The selected technology areas are:

- Digital Health
- Space-led Data Applications
- Autonomous Vehicles
- Technologies underpinning Quantum Computing

These are not the only themes in which Oxfordshire has highly significant or leading science and innovation capacity in the UK, and internationally[1].

These four technologies were selected because they are specific areas of technology and application development (rather than broad industrial sectors) which, combined, have the potential of driving innovation across many sectors and they share common aspects which make them a cohesive proposition:

1. They are all digital technologies, or are highly dependent on digital technologies. They are all developing rapidly and present long-term opportunities for significant growth and competitive positioning in the global economy.
2. They share co-dependencies, such as cybersecurity and machine learning, which are regional strengths.
3. They will extensively disrupt industry sectors and workforces: integration will require innovative governance. A place-based approach underpins the holistic nature of the opportunities, leading to economies of scale and other potential synergies across the value chain and in new market opportunities.
4. Opportunities for innovation (products and services) exist at the interfaces between these technologies (e.g. vehicle-based health monitors), which are more likely to be identified and exploited quickly if these technologies are co-located and strategized.

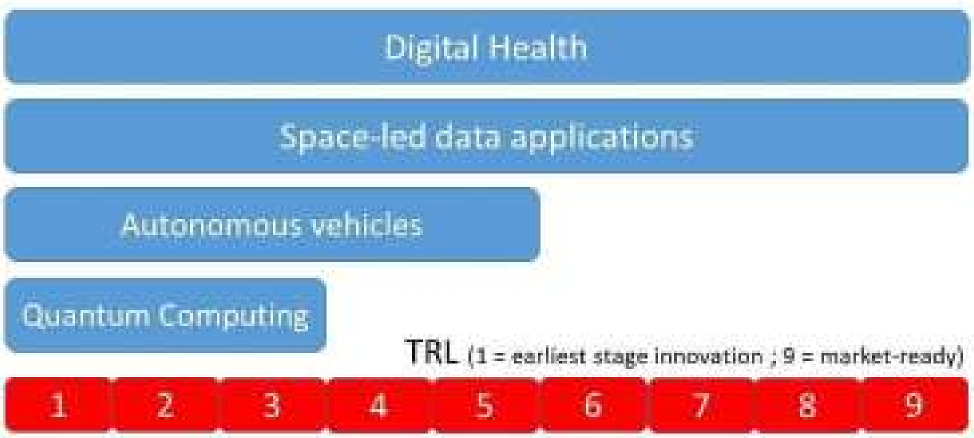
1 Leading strengths in, for example, Sustainability, Biosciences, and High Value Manufacturing, shown in 'Mapping England's Innovation Activity', Smart Specialisation Hub, June 2017. University of Oxford ranks 1st in UK in REF2014 for 12 of the 31 subject Units of Assessment by volume of world-leading research.

5. Their development suits Oxfordshire's highly skilled workforce, with a strategy to deploy the skilled workforce nationally and internationally as new products and services are manufactured and roll out to other regions and countries. A UK growth model would include manufacture at scale in other parts of the UK.
6. Many skills needs are common to all four technologies. A place-based approach creates a value proposition for training and workforce development.
7. The technologies share a development and economic model of having "hardware" (physical components and products), "software" (data and analysis), and data access and consultancy services:

Hardware, software and services are best developed together, to maximise the benefits of test beds, and rollout via Living Laboratories.

These four transformative technologies are at different stages of commercial maturity. Digital health and satellite applications technologies are in the market, and growing. Autonomous vehicles are beginning to be demonstrated. Quantum computers are in early stage research and development, and are part of a larger whole: the ability of the human mind to utilise the brute power of computing.

Human society is on the cusp of a 4th industrial revolution, in which automated systems and data connectivity change possibilities and society. The breadth and depth of research and innovation in Oxfordshire in these 4 transformative technologies should be recognised and supported as a strategic national asset.



Technology readiness levels for Oxfordshire Transformative Technologies

The Transformative Technologies

Connected and autonomous vehicles (CAV)

Oxfordshire is best placed to be a Living Laboratory for real world testing of CAV rollout. By retaining the UK's strong global position in Autonomous Vehicle development, revenue to the economy is expected to be at least £51bn by 2030, with 320,000 new jobs, 5,000 serious accidents avoided and 2,500 lives saved.[2]

Oxfordshire is a near perfect test bed. Vehicles can be tested geographically closely to the design, communications, navigations, and analytics facilities and workforces.

The Oxford Robotics Institute kick-started the UK's autonomous cars programme in 2010. Oxbotica was created in 2014 as a spinout of Oxford University, and now leads the UK consortium to develop and launch a fleet of driverless vehicles on public roads in 2.5 years. The research and development continues in conjunction with RACE (Remote Applications in Challenging Environments) at Culham, which provides testing conditions ready for rollout to public highways. New and expanded settlements across Oxfordshire can be living laboratories for the integration of Autonomous Vehicles, demonstrating transport solutions for further deployment nationally and in other countries.

Digital health

Digital technologies can transform healthcare, from prevention, through diagnosis and intervention, to ongoing monitoring.

The UK market for digital health is expected to grow to £2.9bn by 2018, driven primarily by high growth in apps (38%) and analytics (24%)[3]. The UK can do better than present at capitalising on innovation and bringing beneficial technologies to market more rapidly.

The Oxford Thames Valley region has over 160 digital health companies and 430 stakeholders across industrial, academic, NHS and third sector[4]: this region is a potential major growth cluster for developing and demonstrating high income, technology-based healthcare solutions[5]. Creating a closed loop of data and testing along the entire care pathway will vastly smooth the existing pinch points to market.

Developers with an end-to-end patient pathway and test-bed system can speed innovation, demonstration and rollout, and better evidence health benefits and cost systems. This can create 300,000 new jobs (33,000 in Oxfordshire) by 2030 and yield £1.8bn/year in savings[5] to the NHS.

Space-led data applications

The UK space industry's target is 10% of the global space market by 2030. This should mean £40bn/year and 100,000 jobs for the UK.[6]

---

2 *Connected and Autonomous Vehicles: The UK Economic Opportunity*, KPMG

3 *Digital Health in the UK. An industry study for the Office of Life Sciences*, Deloitte

4 *Digital Health in Oxford and the wider Thames Valley region*, Oxford Academic Health Science Network, Oxford University Innovation and the University of Oxford

5 Existing capacity and excellence makes the region a very strong choice for highly skilled workers and inward investment, and thereby for sector growth for the UK. 1% savings across the NHS through digital health technologies (conservative estimate). NHS budget 2030: £180bn (2017 budget: £123.7bn (source: King's Fund), 3% inflation)

6 *Building our Industrial Strategy: UKspace and Space Growth Partnership Response*, UKspace, and p.68 of *The Space Innovation and Growth Strategy Main Report*

Space data includes earth observation, satellite positioning and communications. To develop products and services space data is applied with other data sources to create real-world solutions.

Oxfordshire has over 75 organisations, Europe's largest Space Cluster, the Satellite Applications Catapult, world-class research, a rich innovation ecosystem, and international pull.

To at least maintain the UK's global position – and add value in conjunction with CAV and Digital Health's use of location data, and communication – the proposed interventions include a data analytics hub to develop applications, and work with Living Labs as demonstrators for data products, and to boost the value proposition for inward investment in UK Space.

Technologies underpinning quantum computing

Quantum technologies will profoundly change the world, and our lives, by 2030. The UK has a strong, but fragile, global position in the race to develop a quantum computing capabilities.

Oxfordshire leads a consortium of 34 organisations to build a quantum computer demonstrator by 2020, and to stimulate quantum industries.

Establishing a 'Quantum Valley' in Oxfordshire, to build a computer, will create 10,000 UK jobs across the supply chain. Oxford University ranks 1st in the UK for mathematics, physics and engineering[7]. Local companies are engaged, e.g. Oxford Instruments which is providing the cooling technology. Oxfordshire leads extensive high-level training programmes in quantum technologies.

Assembling a functional quantum computer will nucleate new companies, and attract inward investment for the UK.

Global USP: opportunities for innovation at the intersections between technologies, for added value and output

Our global USP is to facilitate innovations at the intersections between these four transformative technologies, situated with Living Lab testing and demonstrators. There is added value in combining these transformative technologies in a highly networked science and innovation setting which is excellent at shared features such as machine learning, cyber security, imaging and sensing.

Development of any one of the four technologies will yield economic and social benefits for the UK. There is a strong opportunity for additionality: more applications and products will arise by focussing the development and test sites of these four complementary technologies in a place of world-leading science – opportunities which investment in any of the technologies independently will not achieve.

7 REF2014: the Research Excellence Framework, HEFCE

Key strengths

Oxfordshire has long been a world-leading centre for research and innovation across a wide range of technologies and sectors. It contains Oxford University, ranked number 1 in Europe for both research and commercialisation, large government investments (>£2Bn in internationally leading scientific facilities), especially at Harwell and Culham, leading industry clusters in life sciences, scientific instrumentation and motorsport, and the largest investment fund for university spin-outs globally.

Growth opportunities

This SIA is focussed on four themes where rapidly developing digital capabilities are converging but where the industry is nascent and therefore has the greatest potential for growth, anchoring capabilities in Oxfordshire and securing the UK's global competitive advantage. Within the UK context, Oxfordshire will always be a location where new technologies are invented, developed and tested but most full scale manufacture and assembly will occur elsewhere.

The key to success is for the research, innovation and testing of technologies to be clustered such that national supply chains can be developed from this base and for the skills and services supporting this cluster to be of sufficient quality, scale and flexibility to enable the innovation, integration and translation processes.

Oxfordshire has a history of developing hi-tech clusters of this sort and its proximity to London and Heathrow airport together with its connectivity with the rest of the UK and a global outlook make it ideal for developing and commercialising new technologies. The approach requires building three core capabilities in the county:

- Technology & Instrumentation ("hardware"): linked to targeted sectoral goals in Harwell (satellites and quantum), Culham (autonomous vehicles) and Oxford Hospitals (digital health)
- Data & software: to take data analytics and science from the laboratory into practice, including machine learning, vision and imagery techniques, in the context of cyber security and privacy
- Fabrication & test facilities: Living laboratories where solutions can be deployed and tested together in real-world environments, whether at Culham for autonomous vehicles or smart communities at Bicester and Didcot garden towns

Common features required to underpin development include:

1. Digital skills development and attraction of global talent
2. Investment in supply chains which will grow across the UK
3. Consistent strategic funding for growth
4. National networking to strengthen complementary technical capabilities in other regions

Gap analysis

Through consultation with key players in the county and beyond, gaps have been identified which need to be addressed for innovation and growth to flourish:

1. Oxfordshire's principal challenge is to continue to attract and retain the top talent required for world-leading businesses. This requires significant investment in training of engineers (both software and hardware) and addressing critical issues of the cost of living (associated with the largest house price to salary ratio in the UK) and transport constraints.
2. Whilst the region boasts an enviable track record of start-ups, the ability to grow businesses to medium scale and beyond is challenging through lack of facilities and skilled staff and there is a need to grow "unicorns" and attract inward investment at scale from multi-nationals if the county is to rapidly seed the development of the UK's digital economy.
3. With the wealth of research expertise generating new solutions, the principal challenge with new technologies lies in their translation through integration of capabilities and rapid scale-up by testing and demonstration. Good examples exist with the Satellite Applications Catapult and healthcare translational pathways. These require further integration, and new facilities need to be developed for autonomous vehicles and quantum computing.

Key ambitions/proposals

The critical components of the system that require investment in order to maximise national opportunity in Oxfordshire, can be divided into four areas:

1. Hardware development - e.g.:
    - Space: Disruptive innovation centre to translate technologies from other sectors and platforms to accelerate innovation in the satellite sector
    - Quantum: Facility for the building of the first quantum computer
    - Autonomous vehicles: Accelerate fleet design and national testing
2. Data & software - e.g.:
    - Health: Create a data lake to enable development of new applications
    - Space: Geospatial analytics centre to translate new analytics research into tools to address business requirements with a geospatial context
    - Autonomous vehicles: agreeing frameworks to collate and share data to enable new services whilst addressing cyber-security and privacy concerns within regulatory frameworks
3. Test facilities - e.g.:
    - Health: An end-to-end patient pathway and test-bed system for new digital health technologies
    - Autonomous Vehicles: Development of a test facility to provide comprehensive testing of urban, intra-urban and rural services
4. Technology integration:

    Seamless connectivity between data and communications networks for satellites, autonomous vehicles, and aspects of digital health.

Living Laboratories

Within this SIA, the convergence of sectoral thinking was reflected in the over-arching desire to establish world class 'Living Laboratories' delivered with industry where several technologies can be deployed together to address common challenges (e.g. healthy living, efficient mobility, national productivity).

These Living Laboratories have many layers: strategic planning and local politics; infrastructure and hardware including seamless networks for transport, housing, hospitals and industry; software systems, data management and system of systems control; integrated solutions that use big data to optimise service delivery to improve productivity within environment constraints; sales opportunities, local, nationally and internationally, to generate jobs and growth; and last but not least, deep and wide engagement with the public.

- This model can be built on existing opportunities with Didcot Garden Town and Bicester Healthy New Town, both of which are undergoing rapid development. Also at small scale in the putative Culham Smart Community.

For broader, more effective, national development and demonstration of these (and other) technologies and solutions, we propose involvement in a platform approach to connect development initiatives (such as Healthy New Towns) nationally. This proposal would integrate these transformative technologies further (for example, with environmental management, air monitoring systems, energy, and/or waste solutions being developed and tested in other Healthy New Towns), and accelerate the production of proven solution sets.

Such a national platform could be integrated further, with similar initiatives in other countries, offering more integrative solutions fit for broader application, and would develop more routes to market at international scale.

Networking/collaboration

The progression from hardware to software, and thence to Living Laboratories, suggests a movement from technology towards society. Whilst some would see the inevitable conclusion of digitalisation as being the rise of the machines, with artificial intelligence controlling our lives and robots invading our human spaces, our position is more optimistic. We see these new digital technologies as enhancing our lives - the next generation of smarter tools used by smart humans to improve health, mobility and prosperity.

To achieve this we need thorough and comprehensive conversations that engage all of society. This raises the need to network, collaborate, and communicate - perhaps in unprecedented ways - to ensure that our reliance on digital technologies does purposefully lead to improved quality of life for all.

Connecting across the UK, for global strength

The process of producing this SIA has involved close collaboration between members of the core consortium (OxLEP, Oxford Brookes University, University of Oxford, STFC, UKAEA, the Satellite Applications Catapult, Oxford AHSN and Oxford University Innovation) and the involvement of a wide range of industrial partners. In addition an Advisory Group, chaired by the Pro-Vice-Chancellor Research & Innovation at Oxford University and comprising senior representatives of the business, research and academic communities, has already met twice to advise on the SIA, and this Group will continue to meet in future in order to support and oversee resulting initiatives.

The work on the SIA has also stimulated increased networking between the four themes, and has identified opportunities for Oxfordshire to be *a living lab for the testing and roll out of new technologies*, leading towards a digitally-enabled world where healthcare and transport, as well as numerous other sectors (e.g. agriculture, financial services, energy) are revolutionised through the transformative technologies of satellites and quantum computing. Existing initiatives such as Smart Oxford, Barton Park and Bicester Healthy Towns, and Culham Smart Community provide small scale test beds which can be linked together to form a county-wide network.

To quote one member of the Steering Group: “Part of the process of the SIA for me has been the coming together of elements where I have been working with others and beginning to see how things fit together now and could do in the future”. The diversity, dynamism and tight geographical focus of the Oxfordshire high tech cluster means that interactions between researchers, businesses and residents are made possible by proximity, and the strength of the cluster also means that new ideas are more likely to secure funding and attract the technical and management skills needed to generate economic and social benefits from those ideas locally, nationally and internationally.

The SIA process has emphasised existing links with other SIA technologies, regions, and business sectors. Increased awareness of complementary activities across the UK has identified shared aspirations, and has increased willingness to collaborate for collective benefits and efficiencies. Beyond Oxfordshire, four other LEPs (Thames Valley Berkshire, Greater Cambridge Greater Peterborough, Enterprise M3 and North East) were included in a wider, active grouping because of the strong inter-relationships within the four themes between research and innovation organisations in Oxfordshire and these other areas.

Industrial participants and stakeholders

The production of this report, including its propositions and strategy, has involved intensive collaboration between the 7 members of the core consortium, and the close, dedicated involvement of 33 industrial partners and 18 non-business organisations (listed at Annex A of the full report), most of which have a business representation role and are in regular contact with business regionally, nationally, and internationally.

Examples of links between SIAs, and the importance of the themes to the wider UK economy

1. Agri-tech (East of England SIA) and ‘Space-led data applications’

The East of England has a national leadership role in Agri-tech, resulting from the combination of a strong heritage in crop-based agriculture and horticulture and the depth and calibre of related scientific research in the region.

This SIA region is well-placed to apply, and benefit from, new technologies in precision and smart agriculture, including the application of robotics, sensors and diagnostics, to increase the efficiency, speed and precision of applying fertilizers and pesticides, and of harvesting. Precision and smart agriculture rely on the rapid processing of large amounts of data, much of which is gathered from satellites. There is strong complementarity between the OxTTA SIA proposition in space led data applications to dramatically increase the efficiency and environmental performance of agriculture. For example:

- The Satellite Applications Catapult is working with Cranfield University and the Agri-EPI Centre to exploit EO, weather and field data to support the precision management of grassland agriculture.
- Oxfordshire-based remote sensing consultancy Rezatec have been working with British Sugar to develop decision support tools to help optimise sugar production across the supply chain.

2. Offshore Renewable Energy (ORE Catapult, North East LEP, Midlands Engine SIA) and ‘Autonomous Vehicles’ and ‘Space-led data applications’

The full range of satellite technologies are used to support the offshore renewables sector. In particular:

- Satellite communications and positioning are widely used in the building of offshore facilities; companies developing applications for this market have combined datasets such as weather information and sea conditions for use by offshore energy companies.
- Unmanned Autonomous Vehicles including drones are increasingly deployed; organisations including the Satellite Applications Catapult are using data from drones to complement satellite data, with the drones rely on satellite positioning. Through its Centre of Excellence in the North-East, the Catapult is linked into the drone supply chain in the North East and the Offshore Renewable Energy Catapult.

3. Quantum technologies (Innovation South SIA and Glasgow Economic Leadership SIA, in conjunction with Birmingham Hub)

The Quantum Enhanced Imaging (QuantIC) Hub at Glasgow and the Glasgow SIA HEIs are partners in all 4 EPSRC Quantum Technology Hubs. Their Consortium is particularly well-placed to drive productivity from the EPSRC's overall investment.

OxTTA's findings major on the potential in Central Scotland for rapid integration of quantum technologies with photonics, microelectronics, software/ big data interpretation at relatively low TRLs 3-5 into prototype devices that will support major strides in technology adoption (via our demonstrators) in industrial monitoring, process control, asset management, imaging/ visualisation and digital manufacturing at higher TRLs 5-7. The same capacity for integration of quantum technologies into composite devices at low TRLs will particularly complement the OxTTA aspirations in respect of quantum computing and the Innovation South SIA aspirations in quantum supply chain. It will also provide particular opportunity for rapidly increasing links with the Birmingham-based Quantum Hub in Sensors and Metrology.

These SIAs together illustrate the connected, national nature of the investment needed to drive UK-wide success. Investment in each of these regions will lead to spillover benefits in the others (and beyond), and we hope that these three SIAs, taken together will inform a national strategy for developing a UK lead in quantum computing.

4. Satellite technologies and data (Innovation South SIA)

Innovation South's strengths in satellite data are more widely distributed across a larger geography, including a number of excellent Universities, Pirbright and NPL's South Hub and a very large number of major industry partners and many diverse, and innovative SME clusters, including marine and coastal sectors.

The two regions are therefore complementary with Oxfordshire more intensely research-focussed and Innovation South providing more of a balanced and diverse portfolio between corporate R&D, academic and PSRE research and SME innovation across a much larger economic region. In the space sector, Oxfordshire's focus is downstream on satellite data and national testing laboratories whilst Innovation South's key strengths lie in upstream satellite innovation from Airbus, Surrey Satellite Technologies Ltd, NPL and the Universities of Surrey and Southampton with complementary satellite data analytical capability from the University of Portsmouth.

5. Catapults

Oxfordshire is already linked into the whole Catapult network through the Satellite Applications Catapult, which works across the whole network and on projects with High Value Manufacturing, Transport Systems and Offshore Renewable Energy Catapults.

6. Quantum technologies, AV, and compound semiconductors (South Wales)

Compound semiconductors are essential for the development of quantum computers, autonomous vehicles, electronic propulsion and satellite technology requiring advanced data-communications and energy generation. Oxfordshire has considerable expertise from academia to SMEs and larger companies. We anticipate close collaboration with the Compound Semiconductor Applications Catapult in South Wales, together with the other key facilities in the compound semiconductor cluster: the Institute for Compound Semiconductors, the EPSRC Compound Semiconductor Hub and the Compound Semiconductor Centre.

Investing in R&D in these areas will lead to economic growth within the Oxfordshire region, and will also lead to the expansion of the compound semiconductor industry in South Wales, creating economic growth and increased high-value employment in the region, and related industrial benefits elsewhere in the UK.

Diamond Light Source is the UK's national synchrotron science facility and is part of the Harwell Science and Innovation Campus, Oxfordshire

1. Introduction

A Science and Innovation Audit Report sponsored by the Department for Business, Energy & Industrial Strategy

This SIA examines inevitable technologies. There is no question that our lives and our economy will be transformed by autonomous vehicles, quantum computers, digital health solutions and the use of data from satellites. The only question is the role that the UK plays in the science and innovation that shape them and the industries that deliver them.

It is our contention that Oxfordshire's science and innovation assets have such scale and quality that they must be a key part of any national strategy if the UK is to play a key role in these future industries. Decisions we make now will allow Oxfordshire to make a transformational impact on national competitiveness and productivity through the UK Industrial Strategy.

We do not recommend investment solely in Oxfordshire (although we do recommend some investment in Oxfordshire), because each of these industries requires a national strategy to deliver national results. However, we believe that Oxfordshire's role in nucleating clusters of new and growing businesses at this early stage of technology development will be pivotal in the future success of the UK.

If we are successful, we estimate that these four themes will contribute 800,000 jobs to the UK economy by 2030, of which we believe 8% will be in Oxfordshire[8].

Table 1-1: Jobs in 2030, UK revenue, and Global Market [8]

Science and technology area	Jobs in 2030		UK Revenue by 2030 (£Bn)	Global Market by 2030 (£Bn)
	Oxfordshire	UK		
Connected and autonomous vehicles	16,000	320,000	51	900
Digital health	33,000	300,000	50	1,000
Space-led data applications	10,000	100,000	40	400
Technologies underpinning quantum computing	10,000	80,000	40	800
Total	69,000	800,000	181	3,100

8 For derivations of estimates see: CAV: para. 4.38. Digital Health: para. 5.23. Space-led data applications: paras 6.4 and 9.18, and Annex B 'Geospatial Analysis Centre', Economic case. Technologies underpinning quantum computing: section 7.6 and Annex B 'UK Quantum Computing Centre', Economic case

Oxfordshire's approach to the SIA has been the integrated assessment of three factors – Science, Innovation and Place – in the context of four tightly defined science and technology areas in which the county is at the leading edge of research, application and innovation: autonomous vehicles, digital health, the use of data from space, and the technologies underlying quantum computing.

All have the potential for generating major economic benefits for the UK as a whole. Based on a realistic assessment of global markets, Oxfordshire's distinctive strengths in this global context, and its potential market shares, we estimate that ***these four themes will contribute 800,000 jobs to the UK economy by 2030, of which we believe 8% will be in Oxfordshire***.

Quantum computing: an ion trap chip at the University of Oxford

Technology demonstation at Harwell Campus Open Day

Vision

> Our vision is that *Oxfordshire's outstanding scientific assets and its innovation ecosystem will continue to lead the world in developing knowledge and technology that will underpin the UK's industrial future. Oxfordshire can have a pivotal role in a UK strategy which will have national and global impacts on economic, social and environmental well-being.*

Convergence of cheap, ubiquitous computing power, cloud data storage, advanced decision making algorithms with mass consumer acceptance of increasingly smart digital devices will continue to transform society.

The UK can play a leading role in these future industries by developing new products and services built on purposeful investment in appropriate skills and strategic support for cross-sector engagement.

The core vision of this SIA is that Oxfordshire will nucleate transformative digital technologies that will underpin the UK economy and provide lasting global competitive advantage.

We recognise that our selection of Digital Health, Space-led Data Applications, Autonomous Vehicles and Technologies underpinning Quantum Computing are only four of many possible technology areas. Within Oxfordshire we could have chosen 'big science computing', 'nuclear physics', 'advanced materials', 'artificial intelligence', 'robotics' etc… Oxfordshire has world class strength in all of these and in a similar exercise we would expect to find that these strengths too would make a similar contribution to existing and future industries.

The four technologies chosen reflect different stages of commercial maturity with digital health and satellite applications already in the market and growing, autonomous vehicles under development and quantum computers largely in research and development. Our conversations have revealed that they are part of a larger whole: all shaped by the subtlety of the human mind to utilise the brute power of computing.

Human society is on the cusp of a 4th industrial revolution. We are excited by the potential for new ideas and technologies to address societal grand challenges. We also recognise the breadth and depth of activity in Oxfordshire, which should be recognised as a strategic national asset.

The region and the SIA place

1.1 Oxfordshire is globally renowned as a centre of Science and Innovation and one of the top five innovation ecosystems in the world[9]. It includes the best university in the world in 2016-17[10], research organisations with a unique and extraordinarily valuable mix of physical assets and expertise, some of the most exciting and innovative technology based companies with global impact, and a very highly educated workforce[11].

1.2 Oxfordshire has a strong, growing economy, providing 417,000 jobs and accommodating 30,000 businesses. Table 1-1 shows that between 2011 and 2016, employment in Oxfordshire grew at 2.4 times the rate of its population, and that employment in high tech sectors[12] grew at 15.6%. Table 1-1 shows that Oxfordshire grew faster than the country as a whole on all these measures.

Table 1-2: Population and employment growth in Oxfordshire 2011 to 2016

	2011	2016/(2015*) (latest data)	% growth 2011-16	England % growth 2011-16
Population	654,800	683,200	4.3%	4.1%
Total employment	378,000	417,000*[13]	10.3%	9.0%
High Tech employment	44,900	51,900	15.6%	13.7%

Source: Census of Population 2011, ONS Population Estimates (Aug-Oct), BRES data for 2011 & 2016 for employees and self employed

9 'Creating university-based entrepreneurial ecosystems: evidence from emerging world leaders', MIT, 2014

10 2016/17 Times Higher Education World University Rankings

11 Oxfordshire 51.7% educated to NVQ level 4 and above, second to London at 52% (UK average 31.7%). NOMIS Official labour market statistics https://www.nomisweb.co.uk/reports/lmp/lep/1925185557/subreports/quals_compared/report.aspx (see also *The Oxfordshire Innovation Engine* (October 2013), SQW)

12 Based on Eurostat but with additions, consistent with *The Oxfordshire Innovation Engine* (October 2013), SQW. Includes the following SICs: 254, 302-304, 309, 325, 741, 749, 20, 21, 26-29, 58-63, 71, 72.

13 Labour Market profile: Labour demand: jobs density, NOMIS Labour market statistics

Recent employment growth in Oxfordshire has been much faster than was expected in the forecasts used as the basis for the Strategic Housing Market Assessment[14]. Overall the economy created over 39,000 new jobs within the period 2011 - 2015[15]. To put that into context we have created approximately half of the total estimated job creation to 2031 in less than five years. Whilst this is an incredible achievement it does put increasing pressure on an already tight labour market making skills our most valuable commodity.

1.3 Oxfordshire's economy also performs very well on other measures. For example:

- Over the period 2008 to 2014, which takes in the economic downturn and subsequent recovery, Oxfordshire had the highest average growth rate for nominal GVA of all Local Enterprise Partnerships, at 3.2% per annum[16].
- Productivity growth 2011-14 was 15.6%, well above the national average of 12.1% for the UK[17].
- Just 2.8% of Oxfordshire's economically active workforce is unemployed, well below the national average of 4.7%[18].
- Oxfordshire has the highest proportion of high skilled employment among all LEPs, with 51.7% of the workforce in Level 4 (equivalent to first degree level and above)[19].

1.4 On some measures Oxfordshire apparently fares less well. For example, the start up rate is close to the national average (in 2015 there were 42 start ups per 10,000 population, compared with an average of 43 for all English LEPs[20]) and the incidence of high growth companies is below the national average (6.3% of all firms 2012-15, compared to 7.2% for all English LEPs[20]). However, the SIA is concerned with Science and Technology based firms and the strength of the tech based cluster. Since most of the economy is not S&T based firms, those firms dominate the overall statistics. Still, the survival rate of all firms is relatively good (59% of 2012 start ups survived to 2015, compared with 53.5% for all English LEPs[20]) and Oxfordshire has 124 scale-up companies identified employing over 40,000 people with a combined turnover of £5bn and an average annual growth rate of £330k[21]. Science and Technology based firms form the successful backbone of the Oxfordshire economy. This supports our SIA hypothesis of the unfulfilled potential of the commercialization of the research and academic excellence generated locally into scale up and high growth activity in the county and across the UK.

14 Strategic Housing Market Assessment, Oxford City Council, April 2014
15 Creating the Environment for Growth: Strategic Economic Plan for Oxfordshire 2016, Oxfordshire LEP
16 *GVA for Local Enterprise Partnerships: 1997 to 2014*, ONS, 18 February 2016
17 Creating the Environment for Growth: Strategic Economic Plan for Oxfordshire 2016, Oxfordshire LEP
18 NOMIS 'Employment and unemployment (Apr 2016-Mar 2017)': 10,300 unemployed of 366,500 economically active in Oxfordshire.
19 Oxfordshire 51.7% educated to NVQ level 4 and above, second to London at 52% (UK average 31.7%). NOMIS Official labour market statistics https://www.nomisweb.co.uk/reports/lmp/lep/1925185557/subreports/quals_compared/report.aspx
20 Technopolis SIA core data. Source: 2015 ERC growth dashboard data for LEPs within SIA region, selected indicators
21 Scale up Institute, 'Find a ScaleUp business' online directory: Oxfordshire LEP data as at July 2017

The main driver of Oxfordshire's economy[22] is the strong and growing cluster of knowledge-based businesses, spread across a variety of sectors, closely connected to the universities and research institutions, and supported by a range of specialist financial, professional and business services.

1.5 This SIA demonstrates both the scale and quality of Oxfordshire-focused science and innovation assets, and their potential to lead the UK's competitiveness and productivity in four highly disruptive, transformative technologies, and to support regional economic rebalancing. We have chosen to focus this audit on four tightly defined areas of science, technology and innovation with potential for huge economic impact: autonomous vehicles, digital health, the use of data from space, and the technologies underlying quantum computing.

1.6 These efforts will reinforce the UK Industrial Strategy and contribute to the UK's international competitiveness and national productivity. Oxfordshire has great strength in science and innovation, the economy is already growing strongly and the County can be part of an integrated, national investment strategy. The challenge is to invest such that Oxfordshire's strengths deliver growth across the country and such that Science and industry in Oxfordshire underpins the UK's drive for world-leading technology and innovation businesses.

1.7 Secondly, targeted investment along business supply chains will increase the likelihood that potential unicorns in places like Oxfordshire have room to expand and achieve their global potential, but also to make sure that preparations are made for manufacturing and delivery operations to be sited in areas where the costs of capital and labour are competitive and where the improvement in productivity and jobs will be most beneficial to the local communities.

1.8 Finally, government must be flexible and responsive to the way these technologies and sectors evolve. There must be support for disruptive innovation as new companies emerge and begin to compete with incumbents (often using older technology). A balance must be struck between ensuring established companies remain in the UK, adopting new and disruptive technologies and sustaining employment, whilst making sure that disruptive newcomers can compete on a level playing field so that as the industrial landscape evolves, the UK establishes a clear lead in these new industries.

1.9 This will require a carefully integrated approach to funding for discovery science, grants for collaborative R&D between universities and industries and other accelerator mechanisms for bringing innovation rapidly to market, and evolution of the regulatory landscape with an eye on the UK's future.

22 *The Oxfordshire Innovation Engine* (October 2013), SQW, and *Realising the Growth Potential. The Oxfordshire Innovation Engine Update* (May 2016), SQW

The consortium

1.10 The core consortium for this SIA comprises the main science and innovation organisations in Oxfordshire: the Oxfordshire Local Enterprise Partnership (OxLEP), Oxford Brookes University, the University of Oxford, the Science and Technology Facilities Council (STFC), the United Kingdom Atomic Energy Authority (UKAEA), the Satellite Applications Catapult (SAC), Oxford Academic Health Science Network (AHSN) and Oxford University Innovation (OUI).

1.11 Our SIA includes extensive industrial participation. The Strategic Advisory Board of 9 members (listed at Annex A) includes 4 individuals based in companies, and 4 from organisations with specific roles around representing and/or engaging with companies for innovation and growth. The production of this report has also included, through theme-specific workshops, the dedicated involvement of 33 industrial partners and 18 non-business organisations (listed at Annex A), most of which have a business representation role and are in regular contact with business regionally, nationally, and internationally.

1.12 During the writing of the SIA we have held discussions and exchanged data with other groups including the Thames Valley Berkshire LEP, the Greater Cambridge Greater Peterborough LEP, the Enterprise M3 LEP, and the North East LEP.

These organisations are included because of the strong inter-relationships within the four themes between research and innovation organisations in Oxfordshire and each of these other areas, with the potential for spill-over benefits.

2. Excellence in science, innovation, and conversion into business

2.1 Significant and transformative strategic prioritisation of science and innovation requires many place-based strengths in order to deliver value and return, nationally and regionally, with minimal risk, in increasingly global innovation and markets. Science and innovation, and their application, require leading research capability, facilities, skilled people, experienced management, access to capital, appropriate innovation spaces, and effective networks. This SIA region has all of these at very high level.

2.2 The proposition is that, for the focal transformative technologies, science and innovation at the beginning of the value chain should remain focussed through Oxfordshire's existing high-tech industry, universities, and research and technology organisations. This region is at the forefront of academic research in the UK and globally. This applies to all relevant scientific disciplines, and also to most other disciplines including humanities and social sciences which are important for socially engaged and responsible interventions, their ethical and cultural contexts, and for entrepreneurship and business development.

2.3 Our breadth, with depth, along the innovation chain also gives extensive potential for spillover benefits into other technologies and business sectors. Tables 2-1 and 2-2 provide a brief overview of Oxfordshire's main assets for science and innovation and some key data on scale and quality.

Table 2-1: Oxfordshire's assets for Science and Innovation

Asset	Statistics	Strengths *(most relevant transformative technologies)*	Reputation
University of Oxford *(see 2.19 to 2.22, 2.56, and Annex D Figure D-1)*	23,000 students 6,376 research staff Top UK annual research income (£523m)	REF: first in UK for volume of world-leading research. *(All 4)* 170 KE and commercialisation staff *(All 4)*	No. 1 globally. REF Top UK power ranking.
Oxford Brookes University *(see 2.19 to 2.22, 2.56, and Annex D Figure D-1)*	17,000 students	A third of graduates work in Oxfordshire *(All 4)* Top 10 UK University for commercialisation income *(All 4)*	REF: 94% of research internationally recognised

Harwell Science & Innovation Campus (incl. Rutherford Appleton Labor-atory) *(See 2.39 and Fig. D-2)*	200 organisations 5,500 staff £2Bn government investment in facilities	Space, life sciences, big data, physics, advanced engineering, materials *(All 4)* Satellite Applications Catapult *(Space-led data applications; CAV)*	Largest co-located UK space cluster. World-leading facilities (e.g. Diamond, ISIS, RAL Space)
UKAEA's Culham Science Centre *(See 2.17, 2.40, 4.15 4.30-4.32, 9.8)*	50 research-based organisations 2000 staff £2B international investment in unique facilities	Culham Centre for Fusion Energy *(CAV, Technologies underpinning quantum computing)* RACE robotics centre *(CAV, Digital Health)* Material Research Facility *(CAV, Digital Health, Technologies underpinning quantum computing)* Oxford Advanced Skills *(All 4)*	World centre for fusion power research Leader in autonomous vehicles testing
Wallingford (NERC Centre for Ecology & Hydrology (CEH), HR Wall-ingford (HRW)) *(See 6.14 and Fig. D-7)*	Skilled capacity at CEH: 325 researchers and 125 students. HRW: 280 staff	Hydrological and ecological data, monitoring, modelling and simulation *(Space-led data applications)*	World-leading meteorological, water and ecological research and data
Investment and Technology Transfer *(see 2.61)*	World's largest university-focused venturing fund (UVF): OSI (£580m)	Highest level of University spinout generation in Europe: 21 companies in 2016 *(All 4)*	A world-leader for entrepreneurship (ranked 5th in world by MIT)

Table 2-2: Delivering innovation and its outcomes: satisfying the dependencies

Science and Research excellence
Scientific excellence: University of Oxford ranked 1st in the World 2016-17[23] and 1st in UK in 6 of the 15 science subjects in REF 2014[24]
Research and technology organisations: 14 national institutes and organisations, including the Satellite Applications Catapult
Companies**:** 5 high tech companies worth >US$1bn. 30,000 enterprises. Oxford is the UK's 5th highest density city for digital technology businesses by turnover, and has the 6th highest proportion of high-growth companies[25]

23 Times Higher Education World Rankings https://www.timeshighereducation.com/world-university-rankings/2017/world-ranking#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/scores

24 1st out of more than 150 Universities and research institutions in the THE REF 2014 subject rankings: https://www.timeshighereducation.com/news/ref-2014-results-table-of-excellence/2017590.article

25 National Excellence, Tech Nation 2017

Workforce and skills
Workforce: The proportion of Oxfordshire's workforce in science, research, engineering and technology' professions is 10.6% (almost double the 5.4% national average)[26]. 13.5% of Oxfordshire's jobs are in high tech businesses. *(See 2.16)*
Training, students, and consultancy: approximately 14,000 students in courses directly relevant to one, or multiple, transformative technologies *(see 2.21 - 2.22)*
Outputs: publications, technologies, spinout companies, and value generation
Transformative Technologies research: a third of the region's publications in transformative technologies are in the global top 10% *(See Fig. set D-4 and Fig. D-5)*
Spinouts: the highest level of University spinout generation in Europe (21 companies in 2016). £1.4bn raised for spinouts since 2011. *(See 2.31)*
Commercialisation and IP development: the consortium registers 4.2% of UK patents[27]. High rate of conversion by Universities: Oxfordshire registers 21% of UK HEI patents, and grants 25.5% of UK commercial licenses (42% of overseas licenses)[28]
Contribution to the national Exchequer, and GVA: Oxfordshire is a net contributor to the Exchequer. Oxfordshire generates £20.5Bn/year for the UK[29] *(See 2.36-37)*
Science Facilities and Infrastructure
Science parks & Catapults: 5 major zones, including £2Bn of public-funded, world class facilities, and international centres (e.g. Diamond, RAL, and European Space Agency)
Business growth, support, connectivity, and networks
Business incubators & Innovation spaces: 7.5% of UK incubators (highest outside London)[30]. 35 innovation spaces and 13 planned or under development[31]
Networks and connectivity: Oxfordshire includes possibly one of the most extensive active Business alumni network in Europe (10,000 global members)
Income and investment
Research income and InnovateUK funding: 8.4% of UK income[32]. Highest University research income in UK[33]. Funding specialisms align with the Transformative Technologies themes
Business R&D investment: 5% of UK share of public-focussed research investment[34]
Venture capital and specialist innovation finance: Leading region for Patient Capital with two funds based in Oxfordshire with total funds of £1.4 billion *(See 2.31)*

26 Technopolis SIA core data analysis, 'Science and research assets': ONS Annual Population Survey
27 Technopolis SIA core data analysis, 'Science and research assets': PATSTAT, for the period 2004-2014
28 HESA HEBCI data 2015-16
29 Creating the Environment for Growth: Strategic Economic Plan for Oxfordshire 2016, Oxfordshire LEP
30 'Business Incubators and Accelerators: the National Picture' – BEIS research paper number 7 (p.55, Table A1)
31 Defined as "Innovation spaces provide entrepreneurs and businesses with accommodation on flexible terms and access to supporting administrative, business and innovation support services and networks." Source: *Innovation Spaces in Oxfordshire*, December 2016. SQW, on behalf of Oxfordshire Local Enterprise Partnership ('A review of innovation spaces in Oxfordshire' Report to OxLEP, SQW, 2017 (unpublished at Aug2017)
32 Technopolis SIA core data analysis, 'Science and research assets': Gateway to Research (GtR). See Annex D, Figure D-8: Top-20 research themes in the consortium, Technopolis
33 World University Rankings 2016-2017: results announced, THE World University Rankings, Times Higher Education
34 HESA HEBCI data 2015-16. (National BERD data was not used for this analysis. Reasons: national data sources are broken down by broad geographic region covering many LEPs/counties (e.g. BERD), and are affected by the "Head office effect" of reporting being based on where a business is registered rather than where its R&D is conducted. The most recent BERD R&D data by LEP area was 2013, in which Oxfordshire LEP ranked 16th of 39 LEPs, with £411M (2.3% of total for England): a strong representation considering Oxfordshire is among the smallest of LEPs. BERD R&D data also miss R&D of firms registered overseas.)

Science and Research excellence

2.4 Oxfordshire research is world-leading, through Universities, research and technology organisations, and companies.

Science and Research excellence
Scientific excellence: University of Oxford ranks 1st in the World 2016-17[35] and 1st in UK in 6 of the 15 science subjects in REF 2014[36]
Research and technology organisations: 14 national institutes and organisations, including the Satellite Applications Catapult *(See 2.38 – 2.42)*
Companies: 5 high tech companies[37] worth >US$1bn. 30,000 enterprises. Oxford is the UK's 5th highest density city for digital technology businesses by turnover, and has the 6th highest proportion of high-growth companies[38]

Universities

2.5 The University of Oxford has the UK's largest volume of world-leading research[39]. It encompasses 31 subjects ("Units of Assessment"), and ranks 1st in 12 subjects for volume of world-leading research. Oxford Brookes University specialises in 17 REF areas. In REF 2014 94% of Oxford Brookes' research was rated as "internationally recognised". Research includes computing, engineering, mathematics, health and life sciences. Oxfordshire's Universities encompass 32 of the 36 REF-defined subjects. Through the GCGP LEP our SIA is linked with Cambridge University.

2.6 The University of Oxford is ranked 1st in the UK[40] for Mathematical sciences; General engineering; Physics (by research output); Clinical medicine; Public health, Health services & Primary care; Psychology, Psychiatry and Neuroscience; Social work and Social policy; Philosophy; Earth systems and Environmental sciences; and 2nd for Electrical and Electronic engineering, Metallurgy and Materials[41] - all subject areas which underpin our excellence in developing and deploying quantum computing technologies, space-led data applications, autonomous vehicles and robotics, and digital health technologies (see Figure D-1 for attribution of subject areas to each of the four transformative technologies).

2.7 In 2016 Oxford became the first UK University to rank 1st in the Times Higher Education University world rankings, above the California Institute of Technology, Harvard, and MIT[42].

35 THE World University Rankings, Times Higher Education: see https://www.timeshighereducation.com/world-university-rankings/2017/world-ranking#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/scores
36 1st out of more than 150 Universities and research institutions in the THE REF 2014 subject rankings: https://www.timeshighereducation.com/news/ref-2014-results-table-of-excellence/2017590.article
37 Adaptimmune, Circassia, Immunocore, Oxford Nanopore, Sophos.
38 National Excellence, Tech Nation 2017
39 REF 2014 results: table of excellence: Number of FTE staff submitted multiplied by the %age at 4*, s, Times Higher Education
40 REF 2014 rankings, Times Higher Education
41 See Annex D for table of rankings: Figure D-1 'REF output of institutions in the SIA area in selected Units of Assessment'
42 Times Higher Education World University Rankings

Research and technology organisations

2.8 There are approximately 14 national research and technology organisations in Oxfordshire, conducting world-leading research in specific application areas[43]. These include the Satellite Applications Catapult, ISIS Neutron & Muon Spallation Source, the NERC Centre for Ecology & Hydrology, the Medical Research Council Harwell Institute, the Central Laser Facility, and the Rutherford Appleton Laboratory (RAL Space), the European Centre for Space Applications and Telecommunications (ECSAT), and the Networked Quantum Information Technologies (NQIT) Hub.

Companies

2.9 Among UK cities, Oxford has the 5th highest density of digital technology businesses by turnover, and the 6th highest proportion of high-growth companies[44]. There are five high tech companies which were formed in Oxfordshire and are now worth over US$1bn[45].

2.10 The business mix of Oxfordshire is mainly of small and fast-emerging businesses, with a high technology focus. There are approximately 30,000 enterprises in Oxfordshire of which almost 90% have less than 10 employees[46]. Many are science based companies (approx. 1500 (5%) are classified as high tech, which account for 12% of total employment in Oxfordshire). More high tech companies are connected to the region through specialist and unique science facilities in the science parks and universities. 51 businesses registered in the broad consortium area have received public funding to conduct research[47].

2.11 Growth in high tech sectors is well above the national average. E.g. GVA growth in 'information and communication' grew 29.3% in Oxfordshire, 2011-14, compared with the 8.4% UK average[48].

2.12 Oxfordshire has a strong track record in attracting inward investment by innovative companies seeking to interact with the research base. In the past two years Oxfordshire attracted 72 foreign direct investment projects, supporting in excess of 1,200 jobs of which over 40% were higher value, including some very high profile investments such as Kayser Space, which was attracted to the Space Cluster at Harwell.

43 See Annex D, Table D-2 for further information on the assets located at the Harwell Campus, and the transformative technologies to which they are primarily relevant
44 National Excellence, Tech Nation 2017
45 Adaptimmune, Circassia, Immunocore, Oxford Nanopore and Sophos
46 Creating the Environment for Growth: Strategic Economic Plan for Oxfordshire 2016, Oxfordshire LEP
47 Technopolis SIA core data analysis, 'Science and research assets': GRID data
48 Creating the Environment for Growth: Strategic Economic Plan for Oxfordshire 2016, Oxfordshire LEP

Workforce and skills

Workforce and skills
Workforce: The proportion of Oxfordshire's workforce in science, research, engineering and technology' professions is 10.6% (almost double the 5.4% national average)[49]. 13.5% of Oxfordshire's jobs are in high tech businesses. *(See 2.15-2.16)*
Training, students, and consultancy: Approximately 14,000 students in courses directly relevant to one, or multiple, transformative technologies *(see 2.21 - 2.22)*

2.13 Oxfordshire has one of the most highly skilled workforces in the UK, however skills are potentially the scarcest resource in achieving the growth opportunities for the region and for these technologies and their extended benefits. With one of the lowest unemployment rates nationally, and consistently high investment capital where start-ups and scale-ups are flourishing, Oxfordshire's high tech skills pipeline is paramount. Scale ups seeking the best talent may have to attract them from other regions and overseas. Availability of skills is also important for inward investment. The cost of living in Oxfordshire can be a limiting factor.

2.14 Our SIA leadership will rise to our skills challenges, through continued engagement with industry at the cutting edge of our sectors, that will bring forward employer demand for skills and training across the skills infrastructure to support growth in these, and related, technologies.

Workforce

2.15 The high tech business community in Oxfordshire employs 50,400 people[50] in ca. 1,500 firms[51] (about 13.5% of employee jobs in Oxfordshire[52]). Research organisations in the county employ more than 13,000 research staff. Employment grew by 10.3% 2011 to 2015[53].

2.16 10.6% of the broad consortium area's workforce is employed in science, research, engineering and technology' professions (almost double the UK average of 5.4%). **Qualifications** of the workforce to NVQ4+ and NVQ3+ levels are very high (51.7% vs 37.1% UK average, and 66.2% vs 55.8% UK average, respectively). Only 5.6% have no qualifications (UK average: 8.6%).[54]

49 Technopolis SIA core data analysis, 'Science and research assets': ONS Annual Population Survey
50 ONS BRES 2015. All employment (employees and self-employed)
51 Creating the Environment for Growth: Strategic Economic Plan for Oxfordshire 2016, Oxfordshire LEP, p.14
52 *Realising the Growth Potential. The Oxfordshire Innovation Engine Update* (May 2016), SQW, p.11, para. 3.3
53 ONS BRES 2015. All employment (employees and self-employed)
54 Technopolis SIA core data analysis, 'Science and research assets': ONS Annual Population Survey

Table 2-3: Employment in Oxfordshire 2011 and 2014-2015[55]

	2015	% increase since 2011
All in Employment	**417,000**	**10.3%**
'High Tech' Employment	50,400	13.3%
'Autonomous Vehicles' sector employment	**11,400**	**22.6%**
'Digital Health' sector employment	**11,200**	**13.1%**
'Quantum' sector employment	**7,700**	**10.0%**

Source: ONS, Business Register and Employment Survey (NOMIS)

	2014/15
'Space' sector employment	**1,854**[56]

Source: LEP-level data from ONS BRES 2015, in conjunction with UK Space agency

Training and students

2.17 Regional prioritisation to boost the needed skills pipeline, particularly in STEM, has included the recent use of **Local Growth Fund** (LGF) for development of a Technology and Innovation Training Centre in Oxford, and an Advanced Engineering and Technology Skills Centre (Abingdon & Witney College) as well as potential investment in an Advanced digital and science centre from our latest LGF award. OxLEP has also recently supported UKAEA in a £12m bid for a skills facility at Culham Centre for Fusion Energy – an employer-led apprentice training facility for high tech business.

2.18 Supply of skills was highlighted as a challenge in the Space Innovation Growth Strategy Growth Action Plan[57] and has been picked up by the ongoing work of the Space Growth Partnership. Space is an inspirational sector, which can draw students to STEM subjects, as demonstrated by the success of Tim Peake's recent mission to the International Space Station. Oxfordshire is home to the Space Studio School in Banbury, a unique and innovative school that works in partnership with industry for up to 300 14-18 year olds interested in science and maths.

2.19 The leading research organisations in Oxfordshire train more than 45,000 students a year, with more than a third of these at postgraduate level.

2.20 At any one time, for courses of direct relevance to the four SIA themes, there are typically about 13,000 students, being skilled, in Oxford (currently 964 students enrolled in relevant courses at Oxford Brookes University and 12,099 at the

55 See Annex D-3: Employment analyses, Oxfordshire. Source: BRES. Analyses: SQW. Sector-specific analyses employment analyses are based on 2015 ONS data, hence differences between this Table and Table 1-1 (based on more recent, 2016 data, which is not broken down by ONS into the sector categories).

56 'Space' sector data are derived differently from the other sectors in order to increase the reliability and credibility of data for this sector, and because such date were pre-existing for this sector alone. The same NOMIS analysis was run on 'Space' sector employment, using SIC mappings. SIC categories are a particularly problematic fit to the 'Space' sector and space-led data applications. The most intuitively convincing SIC mapping produced figures of 600 employed in Oxfordshire in financial year 2014/15, being an increase of 200% since 2011 using the same SIC categories for 2011 data. Alternative pre-existing surveys and knowledge of employment levels on the Harwell Campus suggested that the method used here is a more accurate depiction of employment in this sector than the NOMIS SIC method.

57 Space Innovation & Growth Strategy - Growth Action Plan 2014-2030, Space IGS

University of Oxford).

2.21 Table 2-4 below shows the student figures for Oxfordshire's Universities, in courses of direct relevance to this SIA proposition. Also shown are figures for Business and Management courses (those of relevance to the themes and SIA objectives) for the skills needed to adapt to transformations and disruptions that the technologies will inevitably bring, and to lead the development of business sectors and models fit for purpose.

2.22 Many courses are of direct relevance to **more than one** of the transformative technologies. This is in keeping with the SIA's hypothesis that there is **added value** to be gained for the UK, and globally, in a regionally focussed strategy for these transformative technologies: efficiencies of scale, as well as **cross-informing** the cutting edge of innovation **between these technologies**, and **into other technologies and sectors**. This approach is also consistent with growing a necessarily flexible and adaptable high-skilled workforce to lead the UK's innovation position.

Table 2-4: Training – Oxford Universities' degree courses underpinning the four Transformative Technologies

University of Oxford Students on degree courses of direct relevance to:	UG (Under-graduate)	PGT (Postgraduate Taught Masters)	PGR (Postgraduate Research Masters)	Doctorate	**Total**
Digital Health	5,149	1,199	120	3,218	**9,686**
Space-Led Data Applications	2,706	764	28	1,409	**4,907**
Autonomous Vehicles	2,646	875	51	1,362	**4,934**
Technologies underpinning Quantum Computing	2,504	552	23	1,388	**4,467**
TOTAL contribution	**13,005**	**3,390**	**222**	**7,377**	**23,994**
TOTAL number of students (courses relevant to more than one technology theme are counted only once)	**5,802**	**2,360**	**124**	**3,813**	**12,099**
Business and Management	261	1,021	0	36	**1,318**

Oxford Brookes University Students on degree courses in:	Foundation	Honours	Masters	**Total by discipline**
Medical & Health Sciences	30	348		378
Computing & Communications Technologies	20	270	36	326
Mechanical & Electrical Engineering	66	123	23	212
Mathematics		48		48
Total by level of study	**116**	**789**	**59**	**964**

Sources: University of Oxford and Oxford Brookes University

2.23 A third of Oxford Brookes graduates and nearly a fifth of University of Oxford graduates remain in Oxfordshire to work. This equates to 26 per cent overall remaining locally and contributing to economic growth, with others skilled in ways of benefit to the evolution of the four technologies elsewhere.

2.24 **Training in partnership with industry:** An intended consequence of the SIA, through the ongoing leadership delivering proposed interventions, is the collaboration with stakeholders in the ongoing enhancement of training fit for purpose. This would include focus on doctoral training centres, and working more closely with partners on placements and course delivery.

2.25 **Consultancy:** In addition to specialist consultancy companies related to the technologies (e.g. Rezatec consultancy firm, on the application of space-led data for international clients), the universities provide over 3,500 days of consultancy expertise a year (consultancy days delivered through Oxford University Innovation: 3,535 (2015-16). Academic consultants utilised: 418 (2015-16)).

Outputs of Oxfordshire science and innovation

Outputs: publications, technologies, spinout companies, and value generation
Transformative Technologies research: a third of the region's publications in transformative technologies are in the global top 10% *(See Fig. set D-4 and Fig. D-5)*
Spinouts: the highest level of University spinout generation in Europe (21 companies in 2016). £1.4bn raised for spinouts since 2011 *(See 2.31)*
Commercialisation and IP: the consortium registers 4.2% of UK patents[58]. High rate of conversion by Universities: Oxfordshire registers 21% of UK HEI patents, and grants 25.5% of UK commercial licenses (42% of overseas licenses)[59]
Contribution to the national Exchequer, and GVA: Oxfordshire is a net contributor to the Exchequer. Oxfordshire generates £20.5Bn/year for the UK[60]

2.26 Oxfordshire's research publications are highly influential nationally and globally in all of the four transformative technology sectors. Figures 2-1 to 2-3 below show the impact of the SIA region's publications in each of the four technologies. There is also an analysis for transformative technologies as a whole, showing the potential for cross-fertilisation and spillover into other technological innovations, business sectors and markets, with further societal benefit.

58 Technopolis SIA core data analysis, 'Science and research assets': PATSTAT, for the period 2004-2014

59 HESA HEBCI data 2015-16

60 Creating the Environment for Growth: Strategic Economic Plan for Oxfordshire 2016, Oxfordshire LEP

2.27 The broad consortium area accounts for 4.9% of the UK's REF-submitted university researchers, who contribute a proportionally higher national share of REF submitted publications (5.1%) and Doctorates (5.4% in the 2008-2012 period).[61]

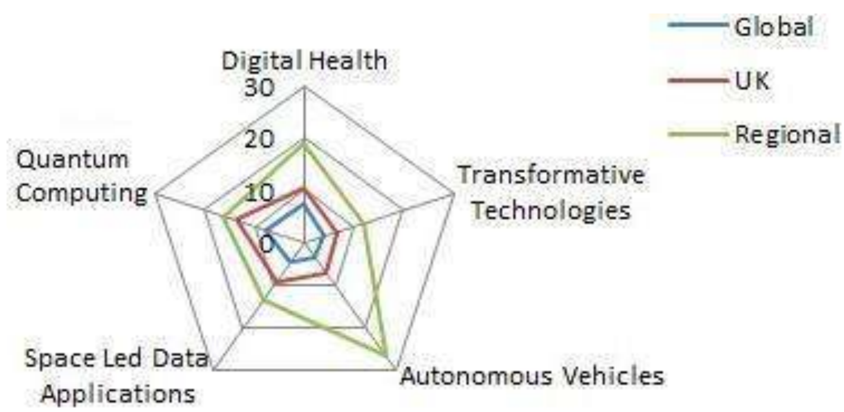
2.28 The diagrams below illustrate the research impact of our SIA region in each of the four technologies. The fifth category, "Transformative Technologies", covers transformative technologies more broadly, with a focus on digital and engineering innovation. This overarching category illustrates the region's high capacity for innovation at the interfaces between the four technologies and with other technologies, and the potential thereby to generate products, services and solutions based upon Oxfordshire being the place to focus these four transformative technologies.

The diagrams compare the SIA region's publications against the UK average, and the global average. The analyses are on citations (the number of times that other researchers and organisations have referred to a publication), this being the primary indicator of the impact of published research.

2.29 Analyses cover (Fig 2-1) the pure number of citations, and (Fig 2-2) the proportion of publications which are among the world's highest 10% in terms of citations. Because some scientific disciplines are more highly cited than other disciplines, those analyses might not accurately reflect relative strengths across the four technologies. For this reason the analyses also include (Fig 2-3) the Field Weighted Citation Impact (FWCI), which is the method for standardising the citation analyses of different fields of science.

2.30 In all cases, the green line's area shows the extent to which the SIA region's research publications are very significantly more impactful than the UK average, and the global average.

Fig 2-1: Research publication impact, by average number of citations[62]



61 Technopolis SIA core data analysis, 'Science and research assets': REF 2014
62 For FWCI data and description see Annex D, Figure set D-4

Fig 2-2: Research publication impact, by %age of documents in the top 10% most cited globally[63]

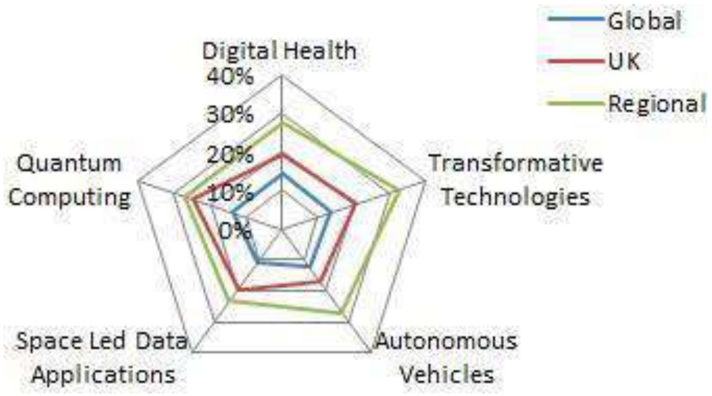
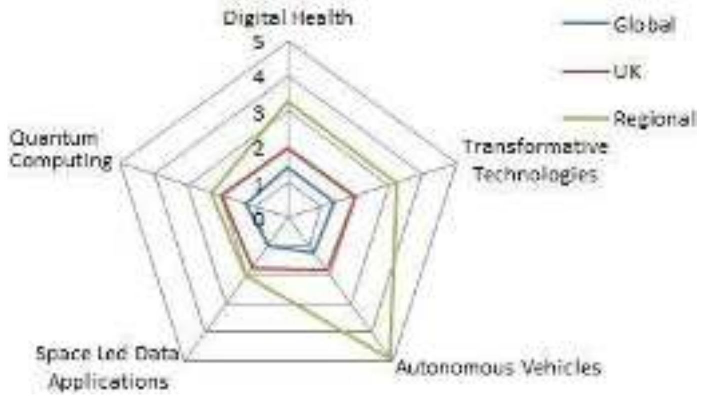


Fig 2-3: Research publication impact, by Field Weighted Citation Impact (FWCI)[63]



Research commercialisation

Spinout company generation

2.31 Oxfordshire has the highest level of University spinout generation in Europe. In 2016 the University of Oxford launched 24 companies, of which 21 are spinout companies (based on Oxford University intellectual property), with a combined £52.6m in early stage funding, setting a new record in spinout generation for the UK and Europe[64]. 140 spinout companies have been launched through Oxford University Innovation since 1987. Since 2011 OUI has generated £1.4bn in external fundraising for spinouts.

IP development

2.32 Oxfordshire is exceptionally successful in generating and commercialising Intellectual Property. Oxford University Innovation (OUI) (formerly 'Isis Innovation Ltd') is among the most successful and prolific University Technology Transfer Offices in the world[65].

63 For FWCI data and description see Annex D, Figure set D-4

64 https://innovation.ox.ac.uk/news/19665/

65 E.g. Technology Transfer Office of the Year winner, Global University Venturing Awards, May 2017: "…the only logical choice after 12 months of headline-grabbing news, from a fivefold increase in seed capital secured by its spinouts to a £100m round for Oxford Nanopore Technologies."

Patents

2.33 Key facts on patents:

- Oxfordshire's two Universities account for **21% of UK higher education patents**[66]
- The SIA has the UK's **highest number of patents for a University**[67]
  - University of Oxford: 244 patents (2nd highest in UK has 111 registered patents)
  - Oxford Brookes 12 patents
- OUI manages approximately **2,900 patents**
- The broad SIA consortium's region accounts for **4.2% of patents** filed by UK inventors, representing a relatively high share[67]

Licenses

2.34 Oxfordshire issued 25.5% of all UK HEI commercial licenses (non-software) in 2015-16, and 42.5% of overseas licenses. The University of Oxford grants the most licenses of UK HEIs (1,652 out of 6,847), and more than the next 4 highest added together.[66]

2.35 Innovative approaches to IP management will be essential in developing income models suited to the next generations of digital-oriented products and services. Oxfordshire's concentration of high-tech SMEs and University-driven spinouts has made the region accustomed to developing and refining IP models. For example, OUI has developed a risk reduction and resource-phasing model for SMEs through a two-phase license: the novel Smart IP Scheme (SSIPS) offsets cost and risk against potential future income, through a reinvestment model which sustains the SSIPS fund, and offers companies the chance to change trajectory of IP licensing as their product develops. The innovative nature of the scheme was recognised through an IPO award in 2014.

Contribution to the national Exchequer, and GVA

2.36 Oxfordshire is one of the few counties to be a net contributor to the national Exchequer. Oxfordshire's workforce generates output to the value of £20.5bn[68]) (data for 2014, in current prices, from ONS) from about 400,000 jobs (including employees and self-employment jobs). In 2014, GVA per hour worked was an estimated £32.70 (UK average: £31.00); GVA per filled job was estimated at £51.2k (2013 data. UK average was £48.8k).

2.37 GVA growth in key high tech sectors is well above the national average (e.g. GVA in 'information and communication' grew by 29.3% in Oxfordshire 2011-14, compared with 8.4% in UK)[68].

66 HESA HEBCI data 2015-16

67 Technopolis SIA core data analysis, 'Science and research assets': PATSTAT, for the period 2004-2014

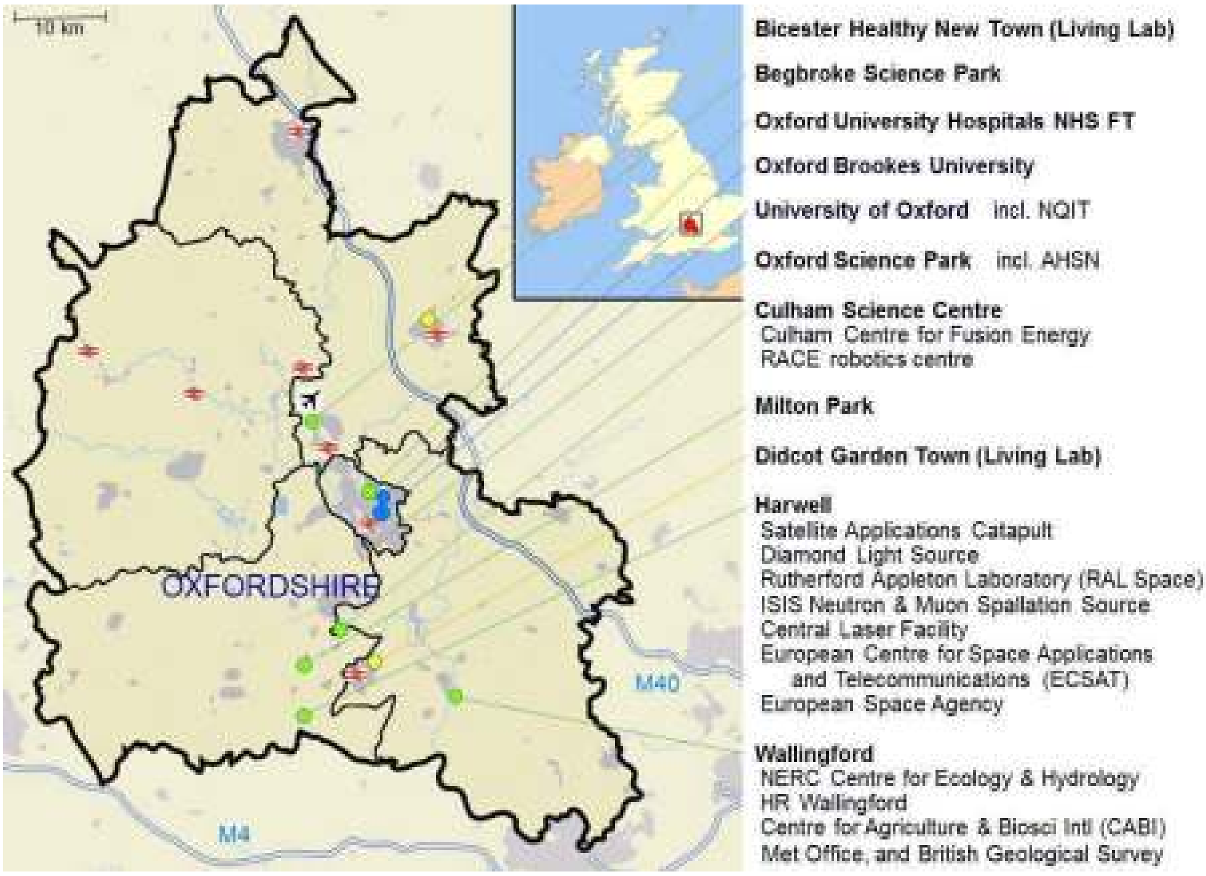
68 Creating the Environment for Growth: Strategic Economic Plan for Oxfordshire 2016, Oxfordshire LEP

Science facilities and infrastructure

Science Facilities and Infrastructure
Science parks & Catapults: 5 major zones, including £2Bn of public-funded, world class facilities, and international centres (e.g. Diamond, RAL, and European Space Agency)

2.38 The key science and innovation facilities in Oxfordshire are shown in Figure 2-4.

Figure 2-4: Oxfordshire's science and innovation facilities



Harwell Science & Innovation Campus

2.39 Harwell Campus comprises 5,500 people working in over 200 organisations and businesses. It is built around the Rutherford Appleton National Laboratory, with over £2bn investment in large scientific facilities. As home of a National Laboratory and several large national and international facilities, it is also home to the Satellite Applications Catapult. Harwell has a global reach that works to the benefit of the whole of the UK. It encompasses life sciences and big data, fundamental physics, advanced engineering, energy, satellite technologies, and materials science.

Table 2-5: Harwell Campus scientific research and innovation centres[69]

Centre	Summary description	Technologies
Diamond Light Source	The UK national synchrotron science facility, producing intense beams of light for a series of `super microscopes' for research from the structure and properties of a wide range of materials, from proteins for designing new and better drugs to and engineering components such as a fan blade from an aero-engine. It serves >5000 scientists a year and supports over 100 companies in proprietorial research.	CAV, Digital health, Technologies underpinning quantum computing
ISIS Neutron & Muon Spallation Source	Using beams of neutrons (and muons) to investigate structures of matter at atomic scale. Serves an international community of >3000 scientists to research clean energy & the environment, pharmaceuticals & health care, nanotechnology, materials engineering, catalysis and polymers, and fundamental studies of materials.	CAV, Digital health, Technologies underpinning quantum computing
PHE Harwell	Public Health England (PHE) is an executive agency, sponsored by the Department of Health. Its Centre for Radiation, Chemical and Environmental Hazards is at Harwell, focusing public health with regards to the environment.	Digital health
Central Laser Facility	The Central Laser Facility (CLF), provides scientists across Europe with specialised laser equipment to experiment in physics, chemistry and biology. Applications include accelerating subatomic particles to high energies, probing chemical reactions and studying biochemical and biophysical processes.	All 4 technologies
RAL Space	200 staff. Research & technology development, space test facilities, instrumentation, and studies of science and technology requirements for space mission design. A Concurrent Design Facility and a robotics test laboratory are operated by RAL Space.	Space-led data applications, CAV, Digital Health
Satellite Applications Catapult	The Satellite Applications Catapult (SAC) fosters innovation and accelerates take up of emerging technologies. Its objective is to promote, develop and facilitate the commercialisation and advancement of the UK's satellite applications industry.	Space-led data applications
STFC	STFC activities include the ESA Business Incubation Centre, designed to bridge the gap between a technology transfer idea and getting the project off the ground, assisting its development into a viable business.	All 4 technologies. Mainly Space-led data applications and Digital Health
ECSAT	ECSAT (European Centre for Space Applications & Telecommunications) has activities related to telecommunications, integrated applications, climate change, technology and science.	Space-led data applications

Source: Consortium members

69 See Annex D, Figure D-2, for further information, including more of the organisations, centres and institutions, and identification of the transformative technologies for which they are most relevant

The UK Atomic Energy Authority (UKAEA) at Culham

2.40 UKAEA operates the Culham Centre for Fusion Energy. The site has ca. 40 tenant companies. The RACE (Remote Applications in Challenging Environments) robotics centre and Materials Research Facility conduct R&D and commercial activities in Autonomous Vehicles, Robotics & Autonomous Systems (RAS), offering test facilities, robotic equipment and expertise for SMEs, multinationals, research laboratories and academia from sectors with 'challenging environments' such as nuclear fission and fusion, petrochemical, space exploration, construction and mining. Through the Culham Centre, UKAEA oversees Britain's fusion research programme, headed by the MAST Upgrade (Mega Amp Spherical Tokamak) experiment, and the world's largest fusion research facility, JET (Joint European Torus), under contract with the EC. These activities are complementary to developing leading science and innovation in the technologies underpinning Quantum Computing.

Milton Park

2.41 Initially developed as an industrial estate, Milton Park is now one of the largest science parks in the country. There are 7,500 employed in 250 organisations on Milton Park, including Adaptimmune, Dow Agrosciences, Evotech, Immunocore, Nexeon, RM Education (digital platforms), Schlumberger (Oilfield services) and Yasa Motors.

Wallingford

2.42 The NERC Centre for Ecology and Hydrology, HR Wallingford firm, CABI, several environmental consultancies and sections of the Environment Agency, the Met Office and British Geological Survey are situated around Wallingford, with critical mass in water science and ecology.

Data Hubs

2.43 The Science Parks and universities have extensive data hubs at different scales, international data connectivities, and analytical capabilities. These are growing all the time. Most recently the University of Oxford opened the Big Data Institute, a new, interdisciplinary research centre that focuses on the analysis of large, complex, heterogeneous data sets. Primarily concerned with health-based data sets, it is superbly placed to integrate with space-led data lakes and services, as well as data lakes and services in autonomous vehicles and robotics. This is an excellent opportunity to develop more sophisticated analytical solutions to complex challenges associated with more effective developments in healthcare and housing, logistics, and remote early-stage interventions. The Centre for Environmental Data Analysis at Harwell houses the largest volume of environmental data in the UK, including international climate change datasets.

2.44 The data components are in the region, as are the skills in analysis, instrument development, and cross-fertilisation of such components as cybersecurity and machine learning. Development of solutions through test-beds and living labs can be phased very effectively with scaleup, to refine and demonstrate solutions for national rollout, and for international export.

Business growth, support, connectivity, and networks

Business growth, support, connectivity, and networks
Business incubators & Innovation spaces: 7.5% of UK incubators (highest outside London)[70]. 35 innovation spaces and 13 planned or under development[71]
Networks and connectivity: Oxfordshire includes possibly one of the most extensive active Business alumni network in Europe (10,000 global members)

2.45 Oxfordshire is in the top 5 places in the world for university-based entrepreneurship[72]. Oxfordshire ranks very highly for starting a small business[73.] Startup business survival rates are high in Oxfordshire. 59% of 2012 start-ups within the Oxfordshire LEP areas survived to 2015 (Average of England LEPs: 55.3%)[74]

Business incubators and innovation spaces

2.46 There 35 existing innovation spaces across Oxfordshire (and 13 planned)[71] - a high concentration for the geography - including co-working spaces and large science parks, with a strong concentration around Oxford. Oxfordshire LEP has 13 business incubators (7.5% of the UK's incubators, and the greatest number outside London, and the highest concentration of incubators in England[75]).

Occupancy rates

2.47 Three quarters of innovation and incubation spaces have occupancy rates of at least 80%. More than half have >90% occupancy. Ten existing innovation spaces and one planned space have a waiting list of firms wanting to take up a space at their facility. Five have waiting lists of five or more firms, and one innovation space has a waiting list of over 20 firms[76].

Planned innovation spaces [76]

2.48 The 13 innovation spaces under construction or planned include four new facilities announced as part of the Oxford & Oxfordshire City Deal in early 2014:

70 Table A1 (p.55) in 'Business Incubators and Accelerators: the National Picture' – BEIS research paper number 7: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/608409/business-incubators-accelerators-uk-report.pdf

71 Defined as "Innovation spaces provide entrepreneurs and businesses with accommodation on flexible terms and access to supporting administrative, business and innovation support services and networks." Source: *Innovation Spaces in Oxfordshire*, December 2016. SQW, on behalf of Oxfordshire Local Enterprise Partnership. Tables on pages 6 & 7 of 'A review of innovation spaces in Oxfordshire' Report to OxLEP, SQW, 2017 (unpublished at Aug2017) comprises a list of the centres.

72 'Creating university-based entrepreneurial ecosystems: evidence from emerging world leaders', Graham, R., MIT, 2014

73 1st in UK: BusinessComparison.com https://www.businesscomparison.com/blog/start-small-business/

74 Business Growth – Technopolis core data: 2015 ERC growth dashboard data for LEPs within SIA region, selected indicators

75 Table A1 (p.55) in 'Business Incubators and Accelerators: the National Picture' – BEIS research paper number 7:

76 'A review of innovation spaces in Oxfordshire' Report to OxLEP, SQW, 2017 (unpublished at Aug2017)

- an Innovation Accelerator for advanced engineering businesses at Begbroke (completed 2017)
- a Bioescalator adjacent to University research facilities and the Churchill Hospital
- the Harwell Innovation Hub, focused on open innovation
- the UKAEA Culham Advanced Manufacturing Hub, focused on remote handling technologies

2.49 In addition, a new business centre, planned to be focused on environmental and green technologies, is planned for the NW Bicester Eco Development; the proposed Oxford Technology Park near London Oxford Airport includes provision for an innovation centre; the Oxford Northern Gateway development is expected to provide around 90,000 sq. m of technology park space; and LGF funding has been awarded to support the development of Osney Mead Innovation Quarter in the heart of Oxford close to the railway station.

Networks and connectivity

2.50 The high tech business community in Oxfordshire is very well networked, including the business angel networks and sector specific networks such as OBN (formerly called Oxfordshire Bioscience Network) and the Cryogenics Cluster. Oxfordshire Venturefest, the national organisation is in its 20th year of highly successful annual events. A significant addition is the Academic Health Science Network for the Oxford region, which has further strengthened the networking opportunities for the bioscience community.

2.51 The LEP runs Oxfordshire Business Support which incorporates a number of Network Navigators, whose job it is to support and link across the various business clusters in Oxfordshire, including the science and innovation groupings. OBS is targeted at start-ups, high growth SMEs, social enterprises and innovative entrepreneurs. In 2015/16, 16,000 businesses and individuals engaged with the OBS helpline and website, and almost 700 of these were supported in more depth.

2.52 In addition, a new business organisation, Advanced Oxford, has recently been established to promote the high tech cluster in the county and secure public and private sector investment to enable growth.

2.53 The Saïd Business School has possibly one of the most extensive active alumni network in Europe, Oxford Entrepreneurs, with 10,000 members and a strong focus on internationally networked business creation and growth. The region attracts top-level, highly experienced CEOs from around the globe.

Income and investment

Income and investment
Research income and InnovateUK funding: 8.4% of UK income[77]. Highest University research income in UK[77]. Funding specialisms align with the Transformative Technologies themes.
Business R&D investment: 5% of UK share of public-focused research & development investment[78]
Venture capital and specialist innovation finance: Leading region for Patient Capital with two funds based in Oxfordshire totalling £1.4 billion *(See 2.63)*

Research income: UK funding

2.54 Oxfordshire organisations account for a total of 3,837 projects, worth £2.7b in funding from the seven UK research councils, according to data from the Gateway to Research (GtR) for the period 2004-2016. This represents 8.4% of the total funding allocated across all institutions in the UK during this period[79].

2.55 Themes receiving the largest share of the total funding within the consortium area during this period were Atomic and molecular physics (£193.2m, being 75% of the UK total), followed by Plasma physics (£104.7m; 64% of UK total) and ICT (£64.5m)[80]. The data highlight research strengths for the consortium area in these technologies.

2.56 The University of Oxford's annual research income is the highest in the UK (£523m, 2014-15)[77].

InnovateUK funding

2.57 The SIA region's largest amounts of InnovateUK income were in the categories of Catapults (£79m), healthcare (£30m) and transport (£10m)[79]. Organisations in Oxfordshire secured £178m of InnovateUK funding between 2011 and 2016[79].

Research income: international

2.58 Oxfordshire accounts for 12.0% of the UK's REF-submitted international income. A total of £486.47m in research income from international and EU sources was declared through the 2014 REF exercise by the consortium area's institutions (Oxfordshire only)[81]. The SIA themes are well reflected by Oxfordshire's capture of high levels of funding in the Horizon 2020 Programmes: Health, demographic change & wellbeing, Climate action, Secure societies, Nanotechnologies, Advanced Materials, and Innovation in SMEs[82].

77 THE World University Rankings, Times Higher Education THES Rankings
78 HESA HEBCI data 2015-16. (National BERD data was not used for this analysis. Reasons: national data sources are broken down by broad geographic region covering many LEPs/counties (e.g. BERD), and are affected by the "Head office effect" of reporting being based on where a business is registered rather than where its R&D is conducted. The most recent BERD R&D data by LEP area was 2013, in which Oxfordshire LEP ranked 16th of 39 LEPs, with £411M (2.3% of total for England): a strong representation considering Oxfordshire is among the smallest of LEPs. BERD R&D data also miss R&D of firms registered overseas.)
79 Technopolis SIA core data analysis, 'Science and research assets': Gateway to Research (GtR) for the period 2004-2016
80 Technopolis SIA core data analysis, 'Science and research assets': Gateway to Research (GtR). See Annex D, Figure D-8: Top-20 research themes in the consortium, Technopolis
81 Technopolis SIA core data analysis, 'Science and research assets': Horizon 2020 data, CORDIS 2016
82 Technopolis SIA core data analysis, 'Science and research assets': Horizon 2020 data, CORDIS 2016. Annex D, Technopolis Table 6 - Participation in Horizon 2020

Business R&D investment

2.59 **Business R&D investment** is problematic to assess due to the nature of the data sources[83]. HESA HEBCI data (HEBCI Table 1a, 'cash' and 'in kind'), reflect research conducted for public benefit that is not publicly funded, which includes business and NGO funded public research. On this measure the Oxfordshire universities total £16.4m for 2015-16 (5% of UK share[84]. University of Oxford ranks 6th in UK).

Venture capital and Specialist innovation finance

2.60 In the 12 months to July 2015, Oxfordshire's technology firms received a reported £1.4bn in private investments[85] - more than five times the previous year's total of £250m. Not including the University of Oxford, 20 new Oxfordshire technologies and ventures received a record £2.6m in proof-of-concept funding in 2014 alone. This bodes well for future growth.[86]

2.61 The University of Oxford has continued to accelerate the foundation and growth of new science and technology companies. Oxford Sciences Innovation (OSI) is the **largest university-focused venturing fund (UVF) in the world**. Launched in 2015, OSI holds **£580m in capital**. It invests from seed through to pre-IPO, with a long-term investment outlook suited to our SIA's transformative technologies proposition. OSI invested £4.5m in 2015, and £30m in 2016 (alongside similar amounts from other co-investors), from which 25 Oxford-originated spinout companies have arisen.

2.62 Independent investors strongly active in and around Oxford include Oxford Capital, IP Group, Woodford Investment Management, Parkwalk, Mercia, and OSEM.

2.63 Patient Capital is increasingly recognized as key for innovative technology with a development and maturity timescale. Woodford Patient Capital fund, launched in April 2015, provides long term funding for start-ups. The **fund raised £890m at launch**, and is run by one of the country's most successful fund managers, Neil Woodford. It is a global fund based in Oxford, likely to use local networks to identify investment prospects.

2.64 These new funds complement more typical, on-going support for access to finance through, for example, Oxford Innovation's Investment Networks, which over the last three years have held over 60 investment meetings, enabling over 50 companies to raise around £40m in total.

---

83 National data sources are broken down by broad geographic region (e.g. BERD), and are affected by the "Head office effect" of where a business is registered rather than where R&D is conducted. On this measure, Oxfordshire is in the region exhibiting the highest levels of business R&D investment. Those data miss R&D of firms registered overseas.

84 HESA HEBCI data 2015-16

85 http://www.cambridgenetwork.co.uk/news/record-investment-in-oxford-ventures-in-2014/

86 Creating the Environment for Growth: Strategic Economic Plan for Oxfordshire 2016, Oxfordshire LEP

Innovation strengths and growth points

2.65 Based on recent investment the rate of growth of the high tech sector appears likely to increase. In the 12 months to July 2015 Oxford's technology firms received a reported £1.4bn in private investments - more than five times the previous year's total of £250 million[87]. There are five high tech companies in Oxfordshire worth over US$1bn[88], and over 20 new Oxford technologies and ventures received a record £2.6m in proof-of-concept funding in 2014[89].

2.66 There are major growth opportunities in all main areas of the Oxfordshire high tech cluster, which strongly complement the specific Transformative Technologies prioritised in the SIA, and will be developed in conjunction with them:

- The ***bioscience*** cluster has grown strongly in recent years, and is one of the largest in the country. A survey by the Oxford AHSN in 2016 mapped over 650 companies across Oxford Thames Valley region[90]. Since December 2014, ten Oxfordshire bioscience firms have attracted between them over £1bn in investment[91]. The cluster includes 'star performers' such as Adaptimmune and Immunocore, with potential for global impact on cancer therapies over the next 10 years, and committed to continued growth in Oxfordshire.

- In the ***telecoms and computing*** sector major Oxfordshire firms include Sophos, which develops cybersecurity software, and Natural Motion, an Oxford University spin out in 2001 in the highly competitive but also fast growing gaming industry. In January 2014 it was acquired by social network gaming company Zynga for over US$500m.

- In ***physical sciences***, the area has leading firms in cryogenics and magnets (e.g. Oxford Instruments, the first Oxford University spin out, and Siemens Magnet Technologies), battery technology (e.g. Oxis Energy Ltd, a spin out from Oxford University Materials Department), and fusion technologies (e.g. Tokamak Energy, which is developing compact spherical tokamak devices in combination with new magnet technologies).

- ***Engineering and electronics*** –University of Oxford's Engineering Department has generated 26 spin outs since 2001. Leading firms in Oxfordshire include Oxford Photovoltaics, which is developing new solar cell technology; Williams Advanced Engineering, which has diversified into new markets beyond technologies developed in Formula 1; Reaction Engines, developing a new aerospace engine; and Oxbotica, one of the The Wall Street Journal's 'Top 10 Tech Companies to watch in 2015'.

87 http://www.oxfordtimes.co.uk/business/13378021.Tech_firms_reap_the_benefits_of_massive__investment_surge/
88 Adaptimmune, Circassia, Immunocore, Oxford Nanopore and Sophos
89 http://www.cambridgenetwork.co.uk/news/record-investment-in-oxford-ventures-in-2014/
90 Health and Wealth map, OAHSN http://wealthcreationmap.oxfordahsn.org
91 *Realising the Growth Potential. The Oxfordshire Innovation Engine Update* SQW, May 2016

2.67 These opportunities illustrate the strategic priority of the four transformative technologies, and the extent to which co-ordinated prioritisation and strategy yields growth opportunities for the region and for the UK economy.

Regional Commitment to the SIA themes

2.68 Oxfordshire is strongly committed to the ongoing development of the four Transformative Technologies, as evidenced by the five 'Key Sector Profiles' designated in the OxLEP Strategic Economic Plan[92]:

Automotive and Motorsport

Oxfordshire has over 24,000 people employed in manufacturing and 5,500 in engineering activities and technical consultancy. The county is part of the high performance technology and motorsport cluster which stretches into Northamptonshire, Milton Keynes and Bedfordshire. It includes both mainstream vehicle manufacturers (BMW Mini) and specialist motorsport firms (e.g. Williams, Prodrive) and their respective supply chains. Particular research based strengths in Oxfordshire include robotics, electric and autonomous vehicles, advanced engines and propulsion and advanced materials.

Creative and Digital

There are around 22,000 employed in digital employment in Oxfordshire, and 3,000 creative and digital sector businesses generating more than £1.4bn annually. Specialisms include digital gaming, cybersecurity, software development and big data, and digital publishing.

Electronics

Oxfordshire has 3,800 people employed in the manufacture of computer, electronics & optical products - almost a 2.5 times higher proportion of employees than the national average. Specialisms in relation to electronics include sensors, instrumentation, space technologies and medical applications.

Life Sciences

Oxfordshire has around 180 companies in life sciences and more than 150 companies in associated industries. There are over 10,000 employed in scientific R&D and healthcare related manufacturing. And over 24,000 employed in human health activities in Oxfordshire (7.7% of the population). Specialisms include drug discovery and development, diagnostics, medical devices, digital health, precision medicine and genomics.

Space Technologies

Oxfordshire is located at the centre of the UK's space industry. Harwell is the base for 55 space related organisations. The global space market is estimated to reach £400 billion by 2030, with the UK space industry anticipated to increase from its current position of £9 billion a year to £40 billion a year during the same period. UK employment in the industry is expected to increase to 100,000.

92 Creating the Environment for Growth: Strategic Economic Plan for Oxfordshire 2016, Oxfordshire LEP (Figure 7: Oxfordshire's key sector profiles)

3. The themes

3.1 The richness of Oxfordshire's science and innovation ecosystem posed a challenge in framing this audit, as there were many areas of strength to choose from. The four themes we selected are not the only strong ones, nor are they necessarily the strongest[93]. They are areas where Oxfordshire has highly significant or leading science and innovation capacity in the UK, and internationally, where we can be forward looking. These themes, particularly when combined, offer a great prospect for Oxfordshire to make transformative contributions in developing the UK economy.

3.2 Although this science and innovation audit is focused on an assessment of some parts of Oxfordshire's ecosystem, its purpose is much wider. Oxfordshire is but one place that can contribute to a national strategy for the development of each of the four areas examined. We have sought, where possible, to couch our work in the national context, to inform strategic decision making at a national level.

3.3 These four technologies were selected because they are specific areas of technology and application development (rather than broad industrial sectors) which, combined, have the potential of driving innovation across many sectors and they share common aspects which make them a cohesive proposition:

1. They are all digital technologies, or are highly dependent on digital technologies. They are all developing rapidly and present long-term opportunities for significant growth and competitive positioning in the global economy.
2. They share co-dependencies, such as cybersecurity and machine learning, which are regional strengths.
3. They will extensively disrupt industry sectors and workforces: integration will require innovative governance. A place-based approach underpins the holistic nature of the opportunities, leading to economies of scale and other potential synergies across the value chain and in new market opportunities.
4. Opportunities for innovation (products and services) exist at the interfaces between these technologies (e.g. vehicle-based health monitors), which are more likely to be identified and exploited quickly if these technologies are co-located and strategized.
5. Their development suits Oxfordshire's highly skilled workforce, with a strategy to deploy the skilled workforce nationally and internationally as new products and services are manufactured and roll out to other regions and countries. A UK growth model would include manufacture at scale in other parts of the UK.
6. Many skills needs are common to all four technologies. A place-based approach creates a value proposition for training and workforce development.

---

93 Leading strengths in, for example, Sustainability, Biosciences, and High Value Manufacturing, shown in 'Mapping England's Innovation Activity', Smart Specialisation Hub, June 2017. University of Oxford ranks 1st in UK in REF2014 for 12 of the 31 subject Units of Assessment by volume of world-leading research.

7. The technologies share a development and economic model of having "hardware" (physical components and products), "software" (data and analysis), and data access and consultancy services:

Hardware, software and services are best developed together, to maximise the benefits of test beds, and rollout via Living Laboratories.

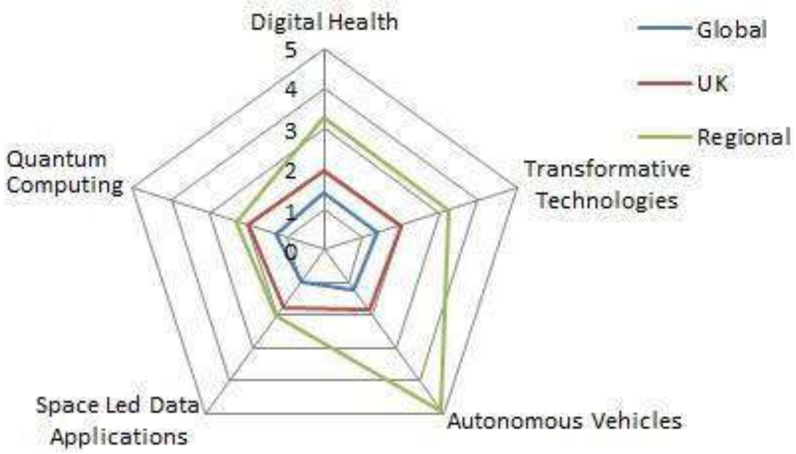
3.4 The multiplicity of deep strength in many areas offers an unusual opportunity as a result of the cross-fertilisation of ideas from one discipline, and one industry sector to another. Innovation is enhanced where opportunities for serendipitous transmission of ideas are high, and the disciplinary and sector breadth in Oxfordshire leads to many such opportunities[94]. We have examined examples of cross-sector activities in relation to our key themes, as this is a distinctive characteristic of the Oxfordshire ecosystem.

The diagrams below illustrate the research impact of our SIA region in each of the four technologies. The fifth category, "Transformative Technologies", covers transformative technologies more broadly, with a focus on digital and engineering innovation. This overarching category illustrates the region's outstanding capacity for innovation at the interfaces between the four technologies and with other technologies, and the potential thereby to generate products, services and solutions based upon Oxfordshire being the place to focus these four transformative technologies.

3.5 Overall, the field weighted citation indices of scientific papers in these fields show that Oxfordshire is a leader in the UK which, as a nation is a world leader itself:

94 *Realising the Growth Potential. The Oxfordshire Innovation Engine Update* SQW, May 2016

Fig 3-1: Research publication impact, by Field Weighted Citation Impact (FWCI)[95]



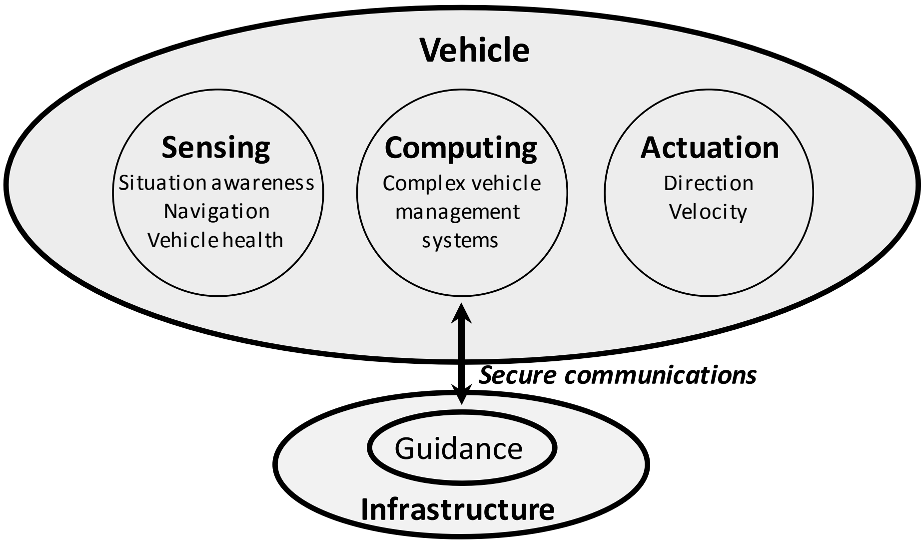
3.6 Between them we expect that these four sectors can contribute 800,000 jobs to the national economy by 2030[96], of which we believe 8%[8] will be in Oxfordshire.

95 For FWCI data and description see Annex D, Figure set D-4
96 See Table 1-1

4. Connected and autonomous vehicles

4.1 The ***core hypothesis*** that has been explored in this Theme is that ***the testing-verification-validation journey is potentially a significant constraint on the emergence of high SAE level CAV and that Oxfordshire is strongly placed to become a hub for CAV development by acting as a living laboratory for 'controlled real world testing'.***

4.2 Connected and autonomous vehicles (CAV) is a vanguard digital technology that is predicted to change mobility of people and goods in all sectors over the next few decades. The initial focus is road transport because of the size and uniformity of the market and the commensurate amounts being invested by multinationals. Benefits of more efficient road transport include: returning time to drivers; decreasing harm by reducing accidents and improving air quality; and, reducing sunk costs by moving away from multiple car ownership per family to mobility as a service.



Source: Automated Vehicles – cross modal learning in autonomy, IET, 2016

Figure 4-1: The Connected and Autonomous Vehicle System

4.3 Oxfordshire has nurtured CAV thought leaders who now have a global reputation that far outweighs their number or funding. Pioneering organisations include: Oxbotica the spin out from Oxford University's Robotics Institute; Charge Auto designing next generation trucks; Preston Racing's 'Streetdrone' initiative; and RACE, the UKAEA's centre for robotics hosting daily CAV testing.

National and international trends and size of global markets

4.4 Local industrial engagement is wide and deep with most of the CAV activity within 70 miles of Oxford. This group has the potential to initiate a globally significant CAV cluster with the full support of local councils that can nucleate a vibrant UK CAV ecosystem.

4.5 There is a wealth of information from national organisations including the Centre for Connected and Autonomous Vehicles, the Transport Systems Catapult, the Automotive Council, the House of Lords enquiry ‘Connected and Autonomous vehicles: The Future?’ and the House of Commons enquiry ‘Robotics and Artificial Intelligence’. Whilst these reports all marvel at the underlying technology they also probe the key market issues that must be resolved: utility, affordability, safety and security and the consequent need for long term testing. Oxfordshire is strongly placed to become a hub for CAV development by acting as a living laboratory for “controlled real world testing”. The ability to test vehicles both in semi-controlled environments and then access the wide range of road types available in the county is leveraged by being able to access a diverse and thriving local innovation ecosystem with relevant capabilities, companies and links to the broader CAV supply chain, with consequent spill-over benefits to the wider UK economy.

4.6 The UK’s automotive industry has been growing strongly in recent years, in part due to sustained investment in innovation. A quick look in the rear view mirror shows that the UK was involved at the start not least with William Morris in Oxford, first in Longwall Street and then from 1912 in Cowley. After considerable commercial success the then ennobled Lord Nuffield became a notable Oxford benefactor with both Nuffield College and the Nuffield Orthopaedic Centre named in his honour. This single history reveals the importance of persistent capital over generations in one place.

4.7 We have come a long way from those early days where people did nearly everything: using a hand crank to start the engine, manual adjustment of the choke, hand signals to indicate intentions, and, assuming the car would break down just before the annual holiday. Cars are now a public necessity, a mature commodity with an exquisite level of engineering refinement in all areas. Unparalleled mechanical reliability is the essential foundation for the next major disruptive move to driverless cars. In fact one could argue that CAV aims to replace the final weak link, namely the human tendency toward distraction, with computer based technology that works “wherever, whenever and whatever the weather”.

4.8 The progression to where cars require no human input is a complex and multi-dimensional one, and to aid understanding of this, the Society of Automotive Engineers published a classification system and supporting definitions that are widely used across the automotive sector. This approach is summarised in Figure 4-2.

4.9 As well as potentially transforming mobility, CAV will have a marked impact on numerous other sectors of the economy including insurance, telecommunications, electronics, sensing, IT, logistics, advertising and retail. Key to maximising spillovers into these sectors is the need for vehicles to become individually secure yet ever more connected. This connectivity requires vehicle-to-vehicle, vehicle-to-infrastructure and vehicle-to-base communication capability.

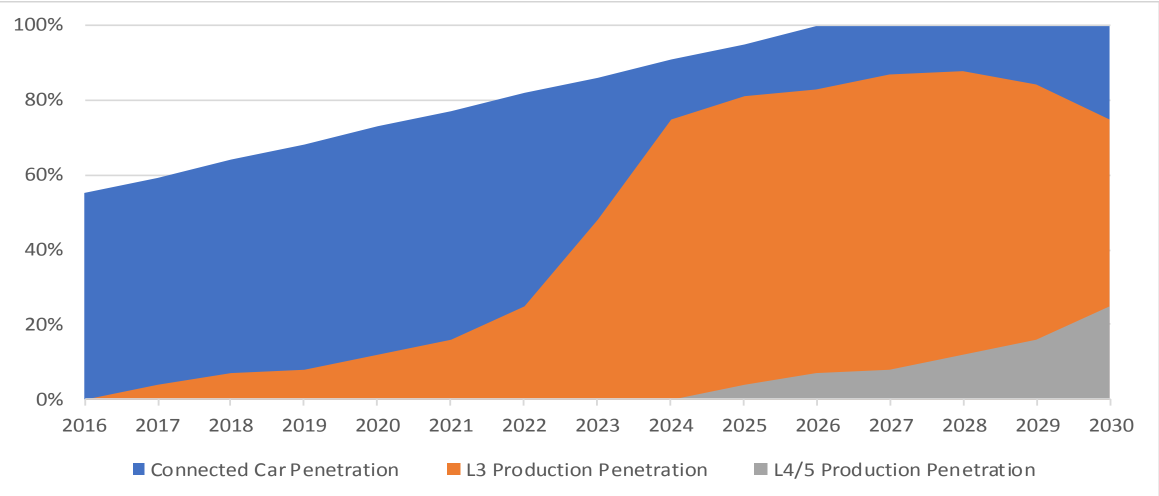
Figure 4-2: SAE Levels for Automated Driving Systems

	L0	L1	L2	L3	L4	L5
	Driver only	Assisted	Partial	Conditional	High	Full
	Driver continuously in control of speed **and** direction.	Driver continuously performs the longitudinal **or** lateral dynamic driving task.	Driver **must** monitor the dynamic driving task and the driving environment **at all times**.	Driver **does not** need to monitor dynamic driving task nor the driving environment at all times: must be in a position to resume	Driver is not required during **defined use case.**	System performs the lateral **and** longitudinal dynamic driving task in all situations encountered during the **entire journey**. No driver required.
	No intervening vehicle system active	The other driving task is performed by the system	System performs longitudinal **and** lateral driving in a defined use case.	System performs longitudinal and lateral driving in a defined use case. Recognises its performance limits and requests driver to resume dynamic driving task with sufficient time margin.	System performs lateral **and** longitudinal driving in all situations in a **defined use case**	
	Conventional car'	Park Assist	Traffic Jam Assist	Highway Patrol	Urban Automated Driving	Full end-to-end journey
Execution of steering and acceleration	Human Driver	Human Driver and System	System	System	System	System
Monitoring of driving environment	Human Driver	Human Driver	Human Driver	System	System	System
Feedback perfomance of	Human Driver	Human Driver	Human Driver	Human Driver	System	System
System capability	N/A	Some Driving Modes	Some Driving Modes	Some Driving Modes	Some Driving Modes	All Driving Modes

Sources: Connected and Autonomous vehicles - the UK opportunity, KPMG, March 2015 and FKA-Berger Automated Vehicles Index, Q1 2016

4.10 The predicted penetration rates for connected and autonomous vehicles in the UK (Figure 4-3) show all vehicles are expected to reach at least SAE Level 3 by 2030.

Figure 4-3: Market penetration projections for connected and autonomous vehicles



Source: Connected and Autonomous vehicles - the UK opportunity, KPMG, March 2015

4.11 First use of autonomous vehicles may well be commercial vehicle platoon truck-trains or cars undertaking lengthy motorway journeys. However, within the UK and many other countries, roads and vehicle movement patterns are much more complex and urban environments predominate and proving CAV capability in such circumstances is highly challenging. Hence, one of the challenges facing companies seeking to access these markets is the need to prove the safety of the vehicles and associated systems.

4.12 In this regard the Department for Transport code of practice for Autonomous Vehicle testing states:

> "*Manufacturers have a responsibility to ensure that highly and fully automated vehicle technologies undergo thorough testing and development before being brought to market. Much of this development can be done in test laboratories or on dedicated test tracks and proving grounds. However, to help ensure that these technologies are capable of safely handling the many varied situations that they may encounter throughout their service life, it is expected that controlled 'real world' testing will also be necessary*".

4.13 This assertion is based on the observation that moving from closed to open road testing will introduce new risks and increased investment. Hence without the ability to access 'real world test conditions' there is a risk that SMEs, innovators and subsystem (typically tier 2 and 3) suppliers will be deterred from engaging with the emerging AV opportunity. Without "controlled real world testing" on a substantive, mixed road network where other vehicles, pedestrians, cyclists etc. have free (and random) access within a suitably monitored and supportive environment, there is a risk that the process of qualifying to become a supplier to the OEMs and public authorities could become problematic. Equally, if the location for the controlled real world testing (a 'living laboratory) is independent of OEM and Tier 1 suppliers, it has the potential to act as a convener for regional, UK and international organisations as they explore CAV options (i.e. act as a nucleating agent for the sector).

Market Size

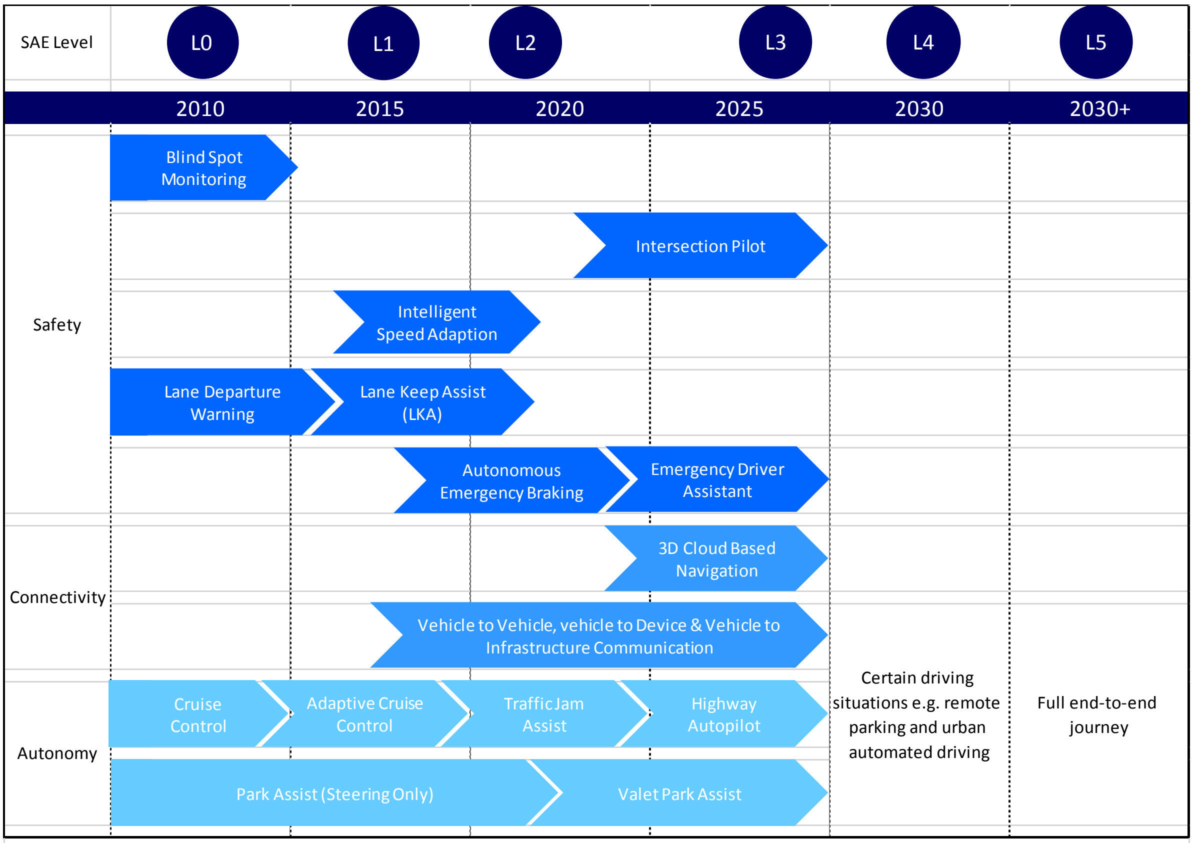
4.14 There is growing consensus between industry commentators, most major OEMs and a number of the global technology giants that over the next 15 years high level CAV will enter, and then increasingly dominate, the global vehicle market. In doing this CAV will transform the way we view and access mobility services, whilst disruptively transforming the current automotive industry and associated sectors ranging from insurance to telecommunications.

Table 4-1: PESTEL analysis

Factors	Key influences
Political	• Good automotive industry-government dialogue on industrial strategy and positive attitude to regulatory reform • Brexit leading to an impact on inward investment in the UK and uncertainty on future regulatory framework • Alignment with digitalisation of UK economy
Economic	• Automotive sector is key to UK economic performance. • Innovation needed to differentiate UK as market to act/invest in. • Emerging markets will be a large driver of growth across all markets
Social	• Congestion and pollution will make individual car ownership less and less attractive • Emergence of mobility as a service options (Uber as early example) – this could be disruptive • Changing attitudes to personal mobility
Technological	• Innovation is rapidly evolving with the advance and convergence of key technologies including increased data volumes, advanced robotics, data science, computational power and connected devices • Unlike most innovative technologies estimates of time to market for high level CAV are reducing (i.e. technology development is ahead of expectations)
Environmental	• Potential of CAV to reduce emissions through increased use of electric vehicles, and closer to optimal vehicle operation will have positive impact on local air quality as well as global scale pollutants.
Legal	• Product and user liability (including impact on insurance) • Data protection and wider information governance • Total restructuring of UK regulatory framework post Brexit with alignment either to EU or US covering approval of digital devices and software, handling and management of personal data, and overall information governance

4.15 There is much less agreement on the timeline that leads up to this, but a number of technology road mapping exercises have been carried out with the result that broadly agreed timelines such as that shown in Figure 4-4 have emerged and are being used by companies as they plan for ‘a CAV future’.

Figure 4-4: Roadmap for Connected and Autonomous Vehicles



Source: Connected and Autonomous vehicles - the UK opportunity, KPMG, March 2015

4.16 Given this backdrop it is not surprising to find numerous announcements regarding CAV being made. Traditional automotive OEMs such as Ford, JLR, Volvo, Nissan and Toyota have made substantial announcements on the development of CAV, alongside investment from 'less traditional players' such as Apple, Google (who have spun its driverless cars project off into a standalone company, Waymo), Intel, Faraday Future and Nvidia. Boston Consulting Group (BCG) estimate that it will cost each OEM upwards of $1bn to develop CAV with high SAE level capability. The context for this being that the Automotive Council estimates the value of CAV will reach £900billion[97] over the next decade. Under such scenarios global CAV sales could be 600,000 units in 2025[98], reaching 3.6 million by 2030[99].

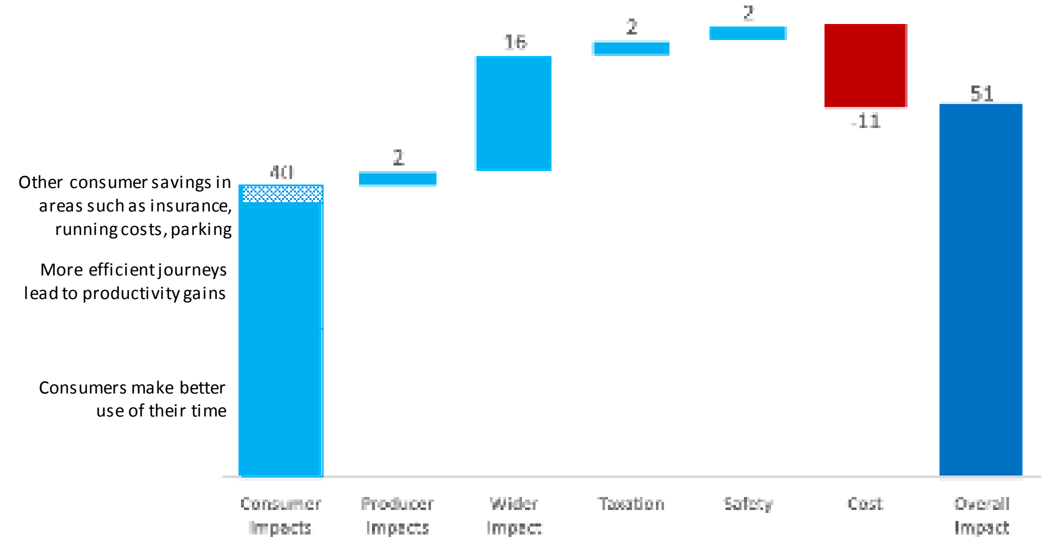
4.17 In its 2015 report 'Revolution in the driver's seat: the road to autonomous vehicles' BCG estimated that by 2025 12-13% of global vehicles sold will have autonomous features. In 2025 sales of all vehicles are predicted to be 111 million, with 12.4% being 'partially autonomous' and 0.5% being 'fully autonomous'. This represents a 2025 CAV market worth some $42 billion. By 2035 BCG predict sales of 122 million vehicles, with 15.0% being 'partially autonomous' and 9.8% being 'fully autonomous' which implies the CAV market will grow to around $77 billion. E&Y cite studies showing 4% of vehicles being autonomous in 2025, rising to 41% in 2030

97 *Driverless vehicles get the green light*, Allianz
98 *Same-Day Analysis: Autonomous vehicle sales forecast to reach 21 mil. Globally*, IHS Markit. See also *Automotive revolution – perspective towards 2030*, McKinsey & Co, January 2016
99 *Revolution in the driver's seat: the road to autonomous vehicles*, The Boston Consulting Group

and 75% in 2035, with this growth being underpinned by an 85% CAGR for sales in the US, Western European and Asian markets. E&Y estimate that the premium paid for such cars will be $7-10,000 in 2025; $5,000 in 2030 and $3,000 in 2035.

4.18 In 2015 the UK built some 1.59 million cars (2.4% of the global market) and given its focus on innovation and higher segment vehicles would expect this market share to grow as CAV and associated technologies enter mainstream markets. At a more quantified level, a KPMG report put the total impact of CAV on the UK economy as £51 billion in 2030, as shown in Figure 4-5. This figure is cited by SMMT as the value added annually (in 2014 prices) of CAV in its 2016 'Motor Industry Facts' publication, which also talks of CAV creating 320,000 additional jobs, avoiding 25,000 serious accidents and saving 2,500 lives between now and 2030.[100]

Figure 4-5: UK Economic Impact of Connected and Autonomous Vehicles in 2030, £bn



Source: Connected and Autonomous vehicles - the UK opportunity, KPMG, March 2015

4.19 In its 2015 report 'Autonomous Cars: Self-Driving the New Auto Industry Paradigm'[101] Morgan Stanley estimated that CAV could produce annual savings of $5.6 trillion globally. This economic benefit is based on a combination of fuel savings, reductions in the cost of accidents, productivity gains, and congestion saving. In the USA, these were estimated to be worth $158bn, $563bn, $422bn and $149bn respectively. Predictions of time to market have fallen over the past 5 years, reflecting the high levels of interest, investment and technical progress that is being made.

100 *Connected and Autonomous Vehicles: The UK Economic Opportunity*, KPMG
101 Morgan Stanley blue paper. See *Morgan Stanley - The Economic Benefits of Driverless Cars*, Robotenomics

Market Drivers

4.20 Technologies that make journeys easier and more productive are perceived to be attractive to many, and contribute to the high levels of (positive) interest in CAV exhibited in the general and technical (automotive) press, with the underlying case being that a "connected network of vehicles will be safer, more sustainable and efficient than the cars of today" (from WSP-Farrells report 'Making better places: Autonomous vehicles and future opportunities, 2016).

4.21 Within the UK there have been a number of studies looking at the potential for wider spillover benefits from the deployment of CAV. These are summarised in Table 4-2.

Table 4-2: Spillover benefits from the deployment of CAV

Up to 90% of all accidents are caused in some way by driver error[102]. In 2014 there were 195,000 casualties at a cost to the UK economy of £10bn. CAV will substantially reduce these figures. Rand Corporation work suggests that if all vehicles were to operate at SAE Level 3 then crashes could be reduced by a third[103]
Vehicle lanes and speeds become fluid to react to demand – some studies suggest that carrying capacity of roads could rise by 40% as a result (and up to 270% on a dedicated motorway)[104]
CAV will transform access to mobility for the disabled and elderly reducing social isolation[105]
On-demand services will connect rural communities and enable seamless interchange with rail and other mass transit systems and in so doing reduce the perceived need for a second car[106]
The ability of CAV to undertake short journeys and self-manage its range will reduce range anxiety in EV owners and hence increase EV penetration and bring forward associated environmental benefits[107]
In a dedicated CAV zone the reduced need for parking could offer between 15 and 20% additional developable area compared to typical current urban layouts. Figures from DCLG give an uplift value of residential land of £1-4 million per hectare[108]
Level 5 CAV can offer door-to-door journeys without needing a parking space at either end. As well as reducing demand for parking space in congested areas, the ability to change locations could improve utilisation of public EV charging infrastructure by ensuring that the associated parking space is not occupied by a fully charged EV[109]
Roadside clutter will be eliminated as road signs, traffic lights etc. will no longer be needed. This reduction in the level of roadside infrastructure required will, and this will deliver reductions in operational and maintenance costs as well as up-front purchase costs[110]

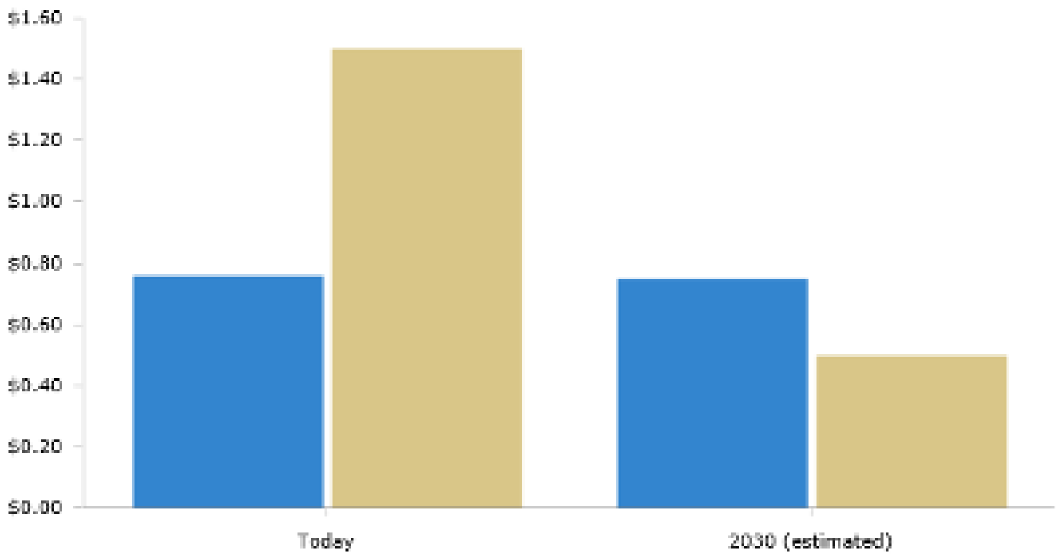
Source: selected studies

102 http://www.wsp-pb.com/Globaln/UK/WSPPB-Farrells-AV-whitepaper.pdf
103 http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-2/RAND_RR443-2.pdf
104 http://www.wsp-pb.com/Globaln/UK/WSPPB-Farrells-AV-whitepaper.pdf
105 http://www.wsp-pb.com/Globaln/UK/WSPPB-Farrells-AV-whitepaper.pdf and https://www.smmt.co.uk/reports/cavs-revolutionising-mobility-in-society/
106 http://www.wsp-pb.com/Globaln/UK/WSPPB-Farrells-AV-whitepaper.pdf
107 http://www.wsp-pb.com/Globaln/UK/WSPPB-Farrells-AV-whitepaper.pdf
108 http://www.wsp-pb.com/Globaln/UK/WSPPB-Farrells-AV-whitepaper.pdf
109 http://www.rand.org/content/dam/rand/pubs/research_reports/RR400/RR443-2/RAND_RR443-2.pdf
110 http://www.wsp-pb.com/Globaln/UK/WSPPB-Farrells-AV-whitepaper.pdf

4.22 Spillover benefits will not be restricted to individuals, with, for example a Rand Corporation study indicating that adoption of connected platoons could improve vehicle efficiency by 4-10%. In the service sector the introduction of CAV could lead to the automation of a range of repetitive - and often dangerous - tasks such as mowing motorway verges and road sweeping (as outlined in the McKinsey Global Institute report 'A future that works: automation, employment and productivity'). The data that such service-CAV vehicles collect on their surroundings can be sent back to a central hub. In such a scenario, the vehicle can be argued to be providing much of the data expected from a 'smart road' at much lower cost than having to install fixed hardware.

4.23 As far as the economic case for high SAE level CAV is concerned, this is largely predicated on a move to mobility as a service offering based on vehicle cost being shared across multiple users and removing the need to pay for the driver as part of a 'taxi model'. According to Morgan Stanley research that is summarised in Figure 4-6, whilst the per-mile operating costs of shared vehicles today far outweigh those of privately owned vehicles, autonomous cars unburdened by driver-cost could achieve a shared cost per mile below that of owned vehicles by as early as 2030.

Figure 4-6: Cost per mile: Shared (beige) vs Owned (blue) (US data)



Source: Shared Mobility on the Road of the Future, Morgan Stanley Research, June 2016

CAV test environments in the UK

4.24 In principle, the UK allows driverless car trials to take place on public roads anywhere, without needing permission, so long as they are covered by an insurance bond. Government funded trials in Greenwich, Milton Keynes, Coventry and Bristol have generated huge public interest. The UK government target is to put CAV into challenging road-traffic situations, with the Department of Transport saying that "if you can put a driverless car on the road in Europe's 'megacity' of London … you can put it anywhere".

4.25 However, test environments which simulate real world conditions will continue to be a vital part of the UK's infrastructure for developing CAV. There are various existing test environments, including

- The Horiba-MIRA test track near Coventry has a total of 8 test circuits classified as a 'closed test facility'.
- Millbrook in Bedfordshire is a commercially available test track with the ability to provide a range of driving conditions. Millbrook is also classified as a 'closed test facility'.
- The UK government supported CITE project is creating an advanced, supportive, environment for CAV technologies by creating a connected corridor in the area of Coventry and Warwickshire. Concurrently, the UK Autodrive consortium will see research teams (from the Milton Keynes and Coventry areas) assess public reaction to autonomous vehicles. This is an 'open test site' but appears to (currently) focus on the provision of an infrastructure for connected vehicles.
- AV pod trials have recently been staged in Milton Keynes and Greenwich. In both cases the vehicles operate on public rights of way and operate at low speeds. Both are classified as 'open test facilities' but, place substantial constraints on how/where CAV can be operated.
- Cranfield has announced its intention to develop a Multi-User Environment for Autonomous Vehicle Innovation (MUEAVI) using the main arterial road for the University.
- The Culham site in Oxfordshire, hosts RACE the UKAEA's centre of excellence in robotics and autonomous systems. This is a 200 acre fenced site with 10km of roads.

4.26 As explained below (para 4.30), the Culham site has some distinctive advantages in moving towards testing in real world conditions, as it would plug a gap in the UK CAV testing ecosystem.

Local science and innovation assets and talent

4.27 The RAS 2020 strategy said: "It will not be possible to achieve the vision in this strategy without a strong skill base. It is vitally important that investment is made at an early stage so that innovation is not starved of its primary resource." [Connected and Autonomous vehicles: The Future? House of Lords Science and technology Committee, March 2017].

4.28 Oxford University's Robotics Institute (ORI) has been instrumental in positioning the UK at the centre of CAV. The Institute is part of the Department of Engineering Science. The Times Higher Education World University rankings 2017 ranking Oxford first for all three engineering categories (general, mechanical and aerospace, and electrical and electronic). ORI has established a world leading reputation in mobile autonomy – developing machines and robots which map, navigate through and understand their environments. The world class research and entrepreneurial endeavour led to the founding of Oxbotica in 2014 by the two lead professors in ORI, Prof Paul Newman and Prof Ingmar Posner.

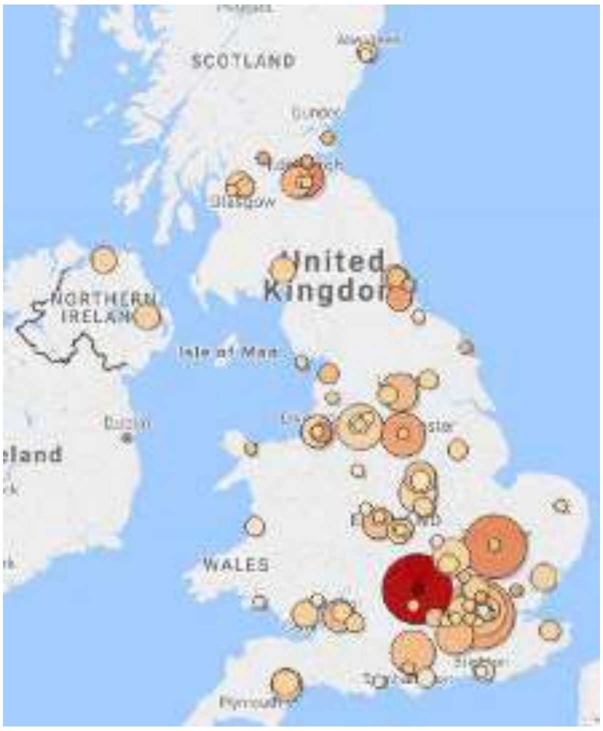
4.29 Table 4-3 and Figure 4-7 show the scale of research in subjects related to CAV in Oxfordshire, compared with the UK and global situation, and demonstrates how strong the research capability is in Oxfordshire.

Table 4-3: Scholarly output and citation count in subjects related to CAV

Area	Scholarly Output	Citation Count
Worldwide	93,878	305,508
Europe	23,384	107,786
United Kingdom	4,726	30,260
University of Oxford	258	8,618

Source: Elsevier SciVal analyses

Figure 4-7: Field Weighted Citation Index Comparison UK, Regional



Source: Elsevier SciVal analyses

4.30 The outstanding innovation capacity in Oxfordshire is demonstrated both by the work of ORI and at Culham, which hosts RACE (Remote Applications in Challenging Environments), the UKAEA's centre of excellence in robotics and autonomous systems. This 200 acre fenced site with 10km of roads and 2000 working adults could become a long-term testing location as Culham becomes a 'living laboratory' for CAV. In such a laboratory, multiple CAV would be monitored as they operated in as close to real world conditions as possible. The evidence generated would have a significant positive impact on the pace at which high SAE level CAV become commonplace on UK roads. The feasibility of this proposition was demonstrated as part of the UK government funded PAVE project, and has already attracted its first users – with the Milton Keynes and Greenwich pods being tested on the site Culham before their deployment 'in the field'. Culham is classified as a 'semi-controlled test site' and in this regard, is a unique facility that if fully developed could plug a gap in the UK CAV testing ecosystem. The combination of the site facilities available and the already good links between Culham, Didcot Garden Town, Oxford/Oxfordshire mean that the pathway from testing at Culham to widespread deployment on the public highway is clear. Indeed, the Oxfordshire County Council Science Transit Strategy makes specific reference to supporting CAV development and testing within the county.

4.31 Given the strong behavioural component inherent in considerations around how CAV will be viewed and utilised it is evident that there is much work to be done in this area and that the ability to study responses to their deployment needs to form part of the testing ecosystem. The fact that the Culham site hosts some 2,000 jobs and has links to Local Authorities delivering local plans makes it a good 'living laboratory' where social and behavioural questions pertinent to CAV can be explored.

4.32 The South Oxfordshire Local Plan published in March 2017 (www.southoxon.gov.uk) sets out plans to develop a 'Smart Community' adjacent to the Culham site. The adjacency of test site and community is not coincidental and the plan to explore 'mobility as a service' (MaaS) options and links between energy and transport (i.e. deeper penetration of electric vehicles) are all covered in discussion of the Culham Smart Community. As these plans are realised the scale of the living laboratory that the local ecosystem encompasses will grow, particularly with regard to the ability to explore social science dimensions of MaaS and smart cities. These local plans sit alongside the fact that the county transport infrastructure includes the M40 and A34 trunk routes and sits at one end of the planned Oxford-Milton Keynes-Cambridge Expressway.

Local industrial strengths and capacities

4.33 Oxbotica, which originated from Oxford University's Oxford Robotics Institute, is the highest profile of the CAV companies in Oxfordshire. It was identified by The Wall Street Journal as one of the 'Top 10 Tech Companies to watch in 2015'. Selenium is Oxbotica's autonomous control system, a vehicle agnostic operating system that can work on anything from forklifts, to cargo pods, to vehicles. The software uses the knowledge of where it is in the world, together with local information about the environment around the vehicle, to determine a safe path and velocity to move the vehicle towards its goal. Oxbotica is providing its Selenium autonomous control system to the GATEway project in Greenwich, London. The software will drive 8 passenger carrying shuttle vehicles, which will be used by members of the public in a two month demonstration starting mid 2017. Oxbotica is also developing an autonomous commercial vehicle for “last mile” delivery, and this will also be demonstrated in Greenwich mid-2017[111].

4.34 StreetDrone is an ambitious Oxford-based start-up with a rich automotive, motorsports and entrepreneurial DNA. The StreetDrone team is passionate about putting the AV revolution into the hands of the many, not just the few. StreetDrone ONE is the first affordable autonomous-ready electric car designed to accelerate the development of autonomous vehicle technology. Based on the Twizy EV, part of the Renault program, StreetDrone ONE is a hardware platform which gives developers the means to test driverless coding on a real-life test vehicle. StreetDrone OS (operating system) allows the car to talk to connected and autonomous software (www.streetdrone.org).

4.35 Charge (https://charge.auto) has been building trucks ranging from 3.5 tonnes to 26 tonnes and is designing all of its vehicles to be in line with electric vehicle legislation in London and the UK. For the first 100 miles the truck travels, it produces 'zero emissions'. For longer journeys, a dual mode can be used to ‘top up’ the battery and extend the range to 500 miles. The trucks will be built at a series of new factories in Oxfordshire over the next few years.

National and international engagement

4.36 The Centre for Connected and Autonomous Vehicles (CCAV) was announced in July 2015. It is a joint team, with members from both the Department for Business, Energy, and Industrial Strategy and the Department for Transport. CCAV is helping to ensure that the UK remains a world leader in the research, development, demonstration, and deployment of connected and autonomous vehicle

111 Oxbotica (partnering with Ocado) first started using the Cargo vehicle in Greenwich at the end of June - see https://www.theguardian.com/business/2017/jun/27/ocados-self-drive-vehicle-makes-deliveries-in-first-uk-trials

technologies. It is working with industry and academia to realise the significant potential benefits of these technologies for UK society and the economy. It will provide a single point of contact for industry and academia in the UK and around the world, as well as ensuring that:

- The UK has a vibrant, world-leading connected and autonomous vehicles industry.
- The UK remains one of the best places in the world to develop and use connected and autonomous vehicles.
- Research on connected and autonomous vehicles is effective, and targeted at delivering value for the UK.
- Connected and autonomous vehicles are safe and secure by design, and handle data appropriately.

The UK has long-standing capabilities across most, if not all, of the sectors supporting connected and autonomous vehicle technologies. Mapping the key players, project sites, and testing/demonstration locations of existing work reveals an existing cluster of expertise and activities clustered within a 70 mile radius of Oxford and enhanced by, the Midlands Engine of the UK's resurgent auto sector, global centres for law, insurance, and finance; four of the world's top 10 universities; motorsport valley (six of the world's 10 Formula One teams); the Malvern cyber-security cluster; the 5G Innovation Centre; four Catapults (Digital, Transport, Energy, and High Value Manufacturing); the Warwick Manufacturing Group; Tech UK; and London (Europe's only mega-city), among many others.

4.37 Within this world class CAV cluster is a core of existing centres of excellence where physical testing and demonstration of these technologies is already taking place (Figure 4-8). This "CAV Core" is loosely defined by London and Birmingham at each end and by the M1 and M40 on each side. This core comprises the public testing environments of most of the UK's substantial existing research, development, and demonstration projects, the end of the London-Dover Connected Corridor, the 5G Innovation Centre, as well as the autonomous vehicle trials of Nissan (Cranfield), Oxbotica (Culham), as well as the separate 100 vehicle trials of Jaguar Land Rover (Coventry) and Volvo (Drive Me London).

Figure 4-8 - CAV Core

4.38 Within this context of regional, national and international science and innovation and capacity, in order for the UK to capture a significant share of the global market, and 320,000 additional UK jobs by 2030, we propose that at least 5% (16,000 additional jobs) of the additional workforce would need to be an expansion of Oxfordshire's leading capacity in science and innovation, and testing, these being key to maintaining or increasing the UK's stake in global CAV. These 16,000 Oxfordshire jobs would include a high proportion of highly skilled jobs, generating high GVA, in keeping with Oxfordshire's employment profile and the continuous prioritisation of science and innovation as robust underpinngs to the region's Skills Strategy and Strategic Economic Plan.

Developments in the wider funding landscape

4.39 Major investments in CAV are being made by the traditional automotive OEMs such as Ford, JLR, Volvo, Nissan and Toyota, as well as by technology companies such as Apple, Google (who have spun its driverless cars project off into a standalone company, Waymo), Intel, Faraday Future and Nvidia. Boston Consulting Group

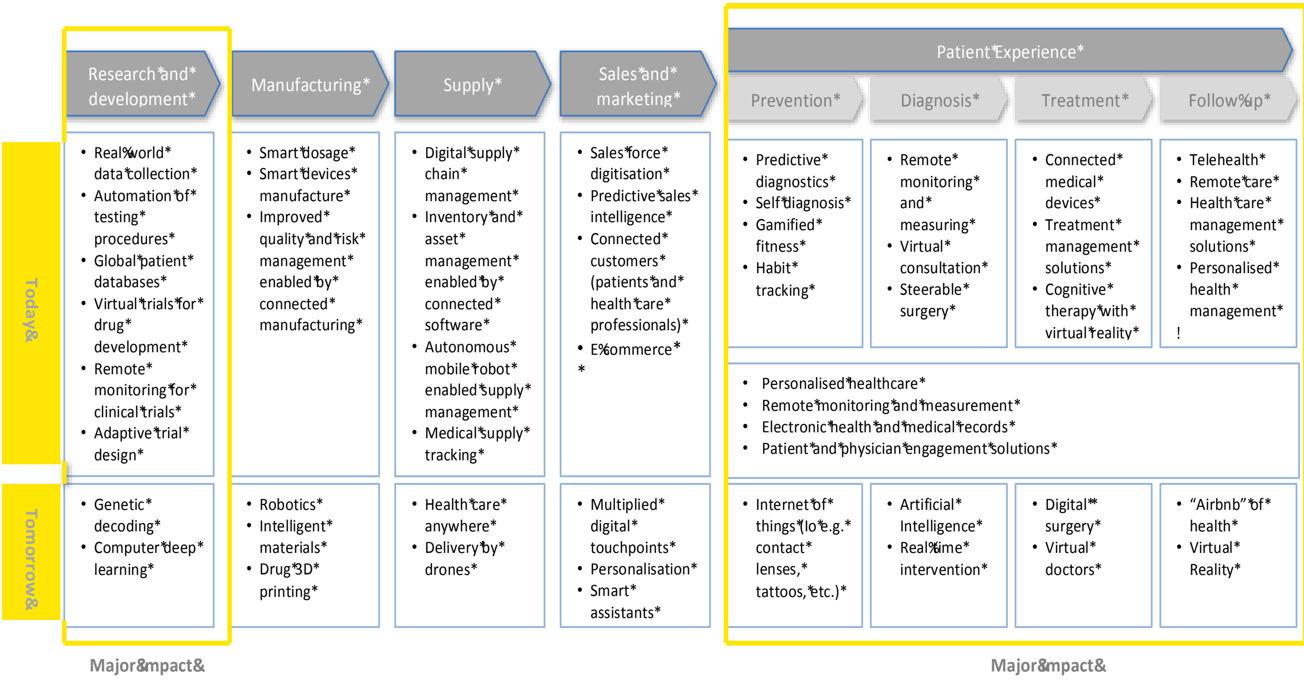
(BCG) estimate that it will cost each OEM upwards of $1bn to develop CAV with high SAE level capability.

4.40 In relation to public sector funding, the House of Lords Science and Technology Committee in its March 2017 report 'Connected and Autonomous vehicles: The Future?' recommended that the UK Government put together a comprehensive testing and research offer to attract manufacturers and academics to the UK immediately. In the same month CCAV announced £100M of funding for an ambitious UK flagship test bed to provide a focus for testing connected and autonomous vehicles at large scale in complex urban environments. The key components of a flagship test bed to support development from initial concept to market deployment included: strong local political support; an active skills and training infrastructure including support on cybersecurity, user behaviour, insurance, law, finance, standards, IP and software; a comprehensive physical infrastructure (roads, signs, signals, intersections, weather conditions, etc.) with a library of general purpose vehicles; cyber and security standards expertise for testing and certifying the resilience and interoperability of technologies against cyber-attack. a comprehensive and flexible mix of connectivity options to reflect current and future connectivity scenarios to support (or interfere with) vehicles and/or infrastructure; a horizon scanning function to keep the test bed at the cutting edge of the latest technological, regulatory, and consumer requirements in this fast-changing sector; a business model accelerator, bringing together different skills and ideas to create the conditions for new CAV products and services from which UK will obtain long-term, sustainable economic value.

5. Digital health

5.1 Digital health can be defined as "the use of digital technologies to improve human health". However, this definition conceals an underlying complexity of applications and solutions that can be applied to all aspects of healthcare commissioning and delivery cross the whole patient pathway, from prevention through diagnosis and intervention to follow up and ongoing monitoring. Figure 5.1 below highlights the current scope of digital health innovations across the value chain in industry through to the patient pathway in healthcare. Digital health is helping to address development pathway timelines, improve manufacturing quality and more effective supply chain management. In healthcare delivery, digital health is impacting the whole patient pathway from prevention through diagnosis and treatment to post-intervention support and follow up. Within the NHS the ambition is to become paperless by 2020,[112] supported by initiatives such as the Global Digital Exemplars[113] and Digital Maturity Assessments.[114]

Figure 5-1. Digital disruption is occurring across the value chain, but is currently most pronounced in R&D and the patient experience segments[115]



112 Wachter, R.M. *Making IT Work: Harnessing the Power of Health Information Technology to Improve Care in England. Report of the National Advisory Group on Health Information Technology in England. Report* (August 2016). See also https://www.england.nhs.uk/digitaltechnology/info-revolution/. Accessed on 25th March 2017

113 https://www.england.nhs.uk/digitaltechnology/info-revolution/exemplars/. Accessed on 25th March 2017

114 https://www.england.nhs.uk/digitaltechnology/info-revolution/maturity-index/. Accessed on 25th March 2017

115 EY. *Digital deals: spotlight on life sciences. Inorganic strategies are driving the digital agenda in life sciences* (February 2017)

5.2 The Digital Health theme has focused on two hypotheses:

- ***Identify critical points when integrating Digital Health inventions within the current healthcare system***[116]
- ***Streamline the process of local, regional, national and international adoption taking into account community settings and end-users to maximise impact.***[117]

5.3 With input from 12 partner companies[118], the theme has sought to identify the critical bottlenecks and barriers to the adoption of digital health products and services into the NHS, and provide examples of how these barriers could be overcome on a regional basis. The business partners were selected on the basis of their expertise in digital health, both from a large company and SME perspective, and in relation to the different types of digital health products and services in their portfolio. The SMEs were a mix of university spin-outs and independent start-ups, thereby providing a broader perspective on the challenges and opportunities.

National and international trends and size of global markets

5.4 The global market for Digital Health was estimated to be over £23 billion in 2014 and is expected to almost double by the year 2018, representing a CAGR of 18%[119]. The Monitor Deloitte Report commissioned by the Office for Life Sciences provides the most comprehensive analysis of the global and UK market, based around four discrete areas:

- Telehealthcare (telecare and telehealth): support and assistance provided at a distance using ICT and the remote exchange of clinical data between a patient and their clinician
- mHealth: mobile phone applications relating to health and/or wellbeing and connected wearable devices
- Health analytics: software solutions and analytical capabilities needed to assimilate big data
- Digitised health systems: digital health information storage and exchange of digitised patient medical records.

116 Full text is: Identify critical points when integrating clinical digital health inventions with current healthcare systems, reflecting the transition from research to commercial products and the re-alignment of care pathways across different settings (e.g. community, primary, secondary and tertiary) to address scale and value

117 Full text is: Streamline the process through which the local to regional and regional to national adoption takes place, taking into account community settings and end-users to maximise impact. We will need to consider internal sub-processes for obtaining regulatory approval as well as funding sources specific for digital health at research and translational stages

118 The partner companies were Brainomix, Drayson Technologies, Johnson & Johnson, Incuna, Intersystems, Isansys Lifecare, Microsoft, OurPath, Oxford Computer Consultants, Oxford Nanopore, and P1Vital. The Knowledge Transfer Network was also a partner organisation

119 Monitor Deloitte. *Digital Health in the UK. An industry study for the Office of Life Sciences* (September 2015)

5.5 The UK market is £2 billion, and is expected to grow to £2.9 billion by 2018, a CAGR of 11%, driven primarily by high growth in mHealth apps (38%) and health analytics (24% CAGR). Table 5-1 gives a breakdown of the global and UK markets.

Table 5-1: Global and UK Digital Health Markets

	2014 UK market size (£m)	2018 UK market size (£m)	2014-2018 UK CAGR	2014 global market size (£m)	2018 global market size (£m)	2014-2018 CAGR
Telecare	246	292	4%	995	1,149	4%
Telehealth	90	148	13%	732	1,236	14%
Applications	75	250	35%	2,200	11,000	49%
Wearables	100	241	25%	1,456	3,095	21%
Health analytics	155	366	24%	3,300	7,200	22%
Digital health systems	1,300	1,640	6%	14,700	19,300	7%

1	2	3	4	5	6	7	8	9	10
Smallest									*Largest*

5.6 In the UK the digital health sector has an estimated turnover of £886 million and approximately 7,400 employees. The digital health sector is the fastest growing life sciences sector for employment with 28% annual growth rate over the last 5 years. Estimates made by the Office of Life Sciences for number of companies, employment and turnover appear low. For example, in the South East, a total of 44 companies are cited. However, a detailed survey undertaken by the Oxford AHSN has identified over 160 companies across the Oxfordshire and Thames Valley region, of which 47 were either start-up or emerging (Table 5-2) [120]. Across the region over 430 stakeholders have been identified with an interest in digital health.

Table 5-2: Stakeholder Categories across the Oxford Thames Valley Region

Type of organisation	Number
Academic Institutions and departments/groups	144[121]
Established companies	114
Start up and emerging companies	47
Networking organisations and consortia	42
Health organisations (providers, CCGs, GP practices)	>200
Incubators and business parks	14
Investment organisations and sources of finance	12
Others – Charities and consultancies	6

Source: Oxford AHSN survey

120 Oxford Academic Health Science Network, Oxford University Innovation and the University of Oxford. *Digital Health in Oxford and the wider Thames Valley region*. (October 2016)

121 Departments either actively involved in research projects or stakeholders in the area

5.7 It is difficult to assess Oxfordshire's position in the current global digital health market. Based on the figures above, Oxfordshire would appear to be well-placed nationally, and combined with the Thames Valley, supports a strong cluster. The figures above show that in 2014 the UK represented 8.4% of the global market, and by 2018 is set to decrease to 6.8%. This implies that the UK will have to do more to remain competitive globally and in preserving market share.

5.8 There are no published estimates for the global market for digital health in 2030, and based on the growth rates cited above, could be worth over £300 billion[122]. However, this estimate is very sensitive to the growth rate, and even a modest increase in the CAGR could lead to a significantly higher figure. For example, an annual CAGR of 25% would generate a global market in excess of £1 trillion. A number of estimates support a higher growth rate and the figure of £1 trillion has been used in this analysis.

5.9 The Tech Nation 2017 Report[123], which focuses on the broader category of digital innovation, places Oxford at the forefront of national digital growth[124]. Oxford has the fifth highest digital business concentration in the country. Oxford was third nationally in terms of digital tech investment (£106 million)), had a digital GVA of £1.1 billion and had 26,367 digital tech jobs. Turnover grew by 43% for the period 2011 – 2015. Average number of start-ups per year was 232 (2011-15).

5.10 A number of powerful shifts are affecting healthcare delivery, which in turn, are reflected in the technological and economic forces shaping the development of the digital health sector. One of the most important factors is the increase in chronic diseases. It is estimated that by 2025, chronic diseases will account for over 80% of DALYs (Disability-Adjusted Life Years), led by cancer, heart disease and unipolar depressive disorders[125]. In the UK there are over 15 million patients with chronic diseases[126] and they affect more than half the US population[127]. A second significant driver of change is the ongoing push for cost-containment, which is leading to a restructuring of the way in which healthcare is delivered through hospitals, and in community care settings. This transformation in the way that healthcare is delivered will be enabled, in part, by the adoption of new digital health products and services.

122 Estimates vary. For example, Global Market Insights estimate that the digital health market will exceed $379 billion by 2024, based on a 25% CAGR (see https://www.gminsights.com/pressrelease/digital-health-market). Projected out to 2030, this would give a global market size of £1.1 trillion. Arthur D. Little estimate that the global market will be over $200 billion by 2020, and based on a CAGR of 21%, this gives a 2030 figure of £1 trillion (http://www.adlittle.com/downloads/tx_adlreports/ADL_2016_Succeeding_With_Digital_Health.pdf). It is likely that the developing markets will see significant growth (see https://www.pwc.com/gx/en/issues/high-growth-markets/assets/the-digital-healthcare-leap.pdf) and the higher figure of £1 trillion has been taken as the 2030 estimate

123 Tech City UK. *Tech Nation 2017. At the Forefront of Global Digital Innovation* (March 2017)

124 Reading, which forms part of a broader Oxfordshire Thames Valley cluster in digital health has the highest concentration of digital health businesses in the country. Reading has 45,269 digital tech economy jobs, with digital GVA of £5.5 billion. It ranks highest in the UK in employee digital productivity. Turnover grew by 57%. The average number of start-ups per year was 605 (2011-15)

125 WHO 2016 (DALYs)

126 Long-term conditions and multi-morbidity, The King's Fund

127 See US Centres for Disease Control. https://www.cdc.gov/chronicdisease/overview/

A broad range of influencers on digital health is described in the PESTEL analysis below.

Table 5-3: PESTEL analysis[128]

Factors	Key influences
Political	• Brexit leading to an impact on inward investment in the UK, restructuring of the regulatory framework and product launch timings • Government industrial policy and investment decisions • Oxfordshire devolution agenda
Economic	• Sustained pressure on healthcare budgets from an ageing population force healthcare systems to refocus on productivity • OECD predicts that global healthcare spend will likely outpace economic growth (3.3% vs 2.0%).[129] • Emerging markets will be a large driver of growth across all markets • Healthcare systems are shifting to integrated care and outcome-based payments from hospital-based care with activity-based payments • Post Brexit economic climate and potential impact on NHS spend
Social	• Population pyramids are inverting, and shifts in the old-age populations are more often more extreme in emerging markets • Chronic diseases will dwarf other needs for healthcare • Patient expectations are rapidly evolving in line with changing consumer habits • Changing attitudes to public health
Technological	• Innovation is rapidly evolving with the advance and convergence of key technologies including increased data volumes, advanced robotics, data science, computational power and connected devices • Explosion of patient-level healthcare data from research, clinical and real-world sources
Environmental	• Environmental legislation unlikely to have a major impact on the sector except where there are cross-overs between pollution monitoring and impact on health
Legal	• Based on existing trends and current legislation • Data protection • Information governance • IVD legislation and CE marking of digital health innovations • Of lesser impact but changes to the EPO framework on digital health innovations and the introduction of a unitary patent • Disruptive changes • Total restructuring of UK regulatory framework post Brexit with alignment either to EU or US covering approval of digital devices and software, handling and management of patient data, and overall information governance • Potential of Scottish independence and the impact on the home market to lead to greater fragmentation across the legal and regulatory landscape

Source: OLS, OECD

128 Office for Life Sciences, OECD
129 OECD GDP long-term forecasts 2009-2060

Local science and innovation assets

5.11 The main science and innovation assets across the region can be divided into academic, industrial and NHS. The regional assets can be categorised under a number of key areas[130]:

- Digital Health Centres of Excellence: The Oxford University Hospitals NHS Foundation Trusts is a Global Digital Exemplar (GDE) along with Oxford Health NHS Foundation Trust.

- Genomics, big data and epidemiology: Oxford is home to the Wellcome Trust Centre for Human Genetics, the Oxford Genomics Centre, the Big Data Institute and the UK Biobank[131].

- World-leading centre for medical research: The University of Oxford is ranked first in the world for medicine, It is also partner to the NIHR Biomedical Research Centre at the University Hospitals NHS Foundation Trust, and was awarded £113.7 million over 5 years under BRC 3.

- Harwell HealthTec Cluster: The Harwell HealthTec Cluster is a world-leading healthcare innovation hub founded on inter-disciplinary collaboration between physical and life sciences. Among its multi-disciplinary community, Harwell hosts approx. 1,000 people working in more than 40 organisations on life-science topics, such as drug discovery and development of bio-compatible materials.

- World-leading centre for mathematics and computer technology: The Oxford Department of Computing is internationally competitive, and is among the top three UK computer science departments.

- Medical publishing centre: Oxford has a strong tradition in both medical publishing and continuing education.

- International reputation in biomedical engineering: The Institute of Biomedical Engineering at Oxford develops novel medical devices, technology and systems.

- New digitally focused hubs and incubators: The Hill[132] is a digital health hub situated at the John Radcliffe Hospital, Oxford, and aims to foster digital innovations within the NHS. Trust.

- A test bed for big city problems: Smart Oxford[133] and two centres under the NHS Healthy New Towns initiative - Bicester and Oxford (Barton) are test beds for the use of smart technologies and the built environment to engender

130 *Digital Health in Oxford and the Wider Thames Valley Region*, Oxford AHSN, October 2016
131 http://www.ukbiobank.ac.uk
132 http://www.thehill.co/home/. Accessed on 25 Mar 2017
133 Smart Oxford - the learning city, Smart Oxford 2017. http://oxfordsmartcity.uk/cgi-bin/index.pl. Accessed on 25 Mar 2017

healthy life-styles[134].

- Global outreach: As a result of its international standing among universities, Oxford has a truly global outreach, attracting thousands of students, researchers and clinicians from around the world.

- An emerging centre for clinical entrepreneurship: The Oxford region has long been associated with turning technological developments into new company formation.

- Regional strength in health science research: There is significant health and social care research in universities and hospitals across the region that complements and extends that taking place in Oxford University[135].

- Developing Networks: the digital health space is supported by a number of networks including Digital Oxford,[136] and specifically Digital Health Oxford (DHOx)[137]. The Oxford AHSN[138] also provides a networking focus, bringing together industry, the NHS and academia. There is also the Harwell HealthTec Cluster which promotes interaction between the private and public sector. TheHill provides an opportunity for clinicians, researchers and industry to engage and there are a wide range of events that focus on digital health that are held across Oxfordshire. Most recently, the Precision Medicine and Digital Health Technology Showcase, hosted by the NIHR Biomedical Research Centre, Oxford University Innovation, the Oxford AHSC and the Oxford AHSN, is a good example of connectivity between industry, academia and clinicians.

5.12 The supply chain across Oxfordshire is well-placed to support the cluster. A range of developers and consultants (for example, Global Initiative, Incuna, Oxford Computing Consultants and White October) support the development of new digital health solutions, while across the adjacent Thames Valley, there is a large concentration of global suppliers and developers such as Microsoft, Hewlett Packard and Oracle. Major players such as GE Healthcare, Cerner and CSC also have a presence. A range of smaller companies provide connectivity, data handling and consultancy.

5.13 While the digital health cluster is growing, there remain a number of obstacles to the full realisation of the growth potential across Oxfordshire. Digital health often requires new approaches to healthcare delivery and in generating value across different delivery partners. Inevitably, there can be a resistance to change, and in particular in the NHS, there are challenges associated with the adoption of new innovations which require changes to service delivery. Knowledge extracted from

134 Healthy New Towns, NHS England, 2017. Accessed 25 Mar 2017: https://www.england.nhs.uk/ourwork/innovation/healthy-new-towns/

135 More detailed information is available in *Digital Health in Oxford and the Wider Region*, pp 20-27

136 See http://www.digitaloxford.com. Accessed on 27 Mar 2017

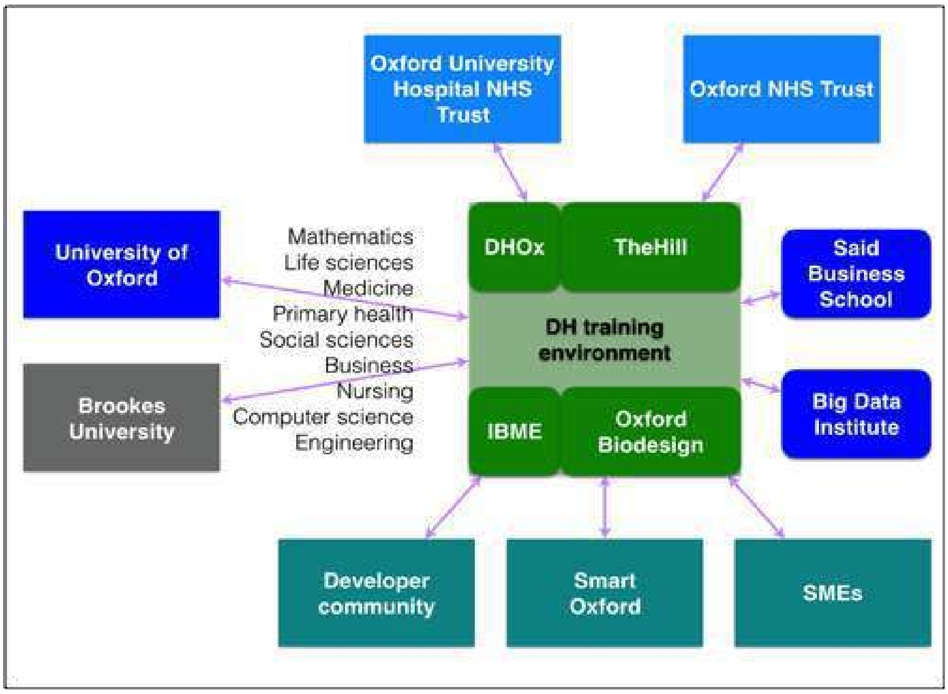
137 See http://www.dhox.org. Accessed on 27 Mar 2017

138 See http://www.healthandwealthoxford.org. Accessed on 27 Mar 2017

research and clinical data will help push this change, but here there is still much more work to be done around data connectivity between secondary, primary and social care systems. Obstacles to data sharing arise at the level of information governance, public perception, security and confidentiality, and the appropriate use of data for research purposes. Other factors include budgetary silos across health and social care systems, as well the lack of flexibility in large proprietary health management systems, and the opportunity for linking new digital health solutions into such systems. The ability to generate evidence and relevant validation for digital health solutions remains an issue and the ability to monetise new innovation presents particular challenges to developers and innovators. Finally, there are concerns of the supply of relevant skills to support the generation, development and adoption of digital health solutions across Oxfordshire. All of these areas will need to be addressed, and many of these challenges are present in other parts of the UK.

Local science and innovation talent

5.14 Digital health is an emerging field, which is highly inter-disciplinary. Not surprisingly, there are as yet, few formal training courses dedicated to training digital health specialists. Instead, there is a different model emerging where training is hands-on based around a specific concept, with loose coalitions of people with appropriate expertise forming to take a project forward. Oxfordshire is a cauldron for this type of innovation, bringing together graduates from the two universities with a thriving developer community, two hospital trusts and an expanding industrial base. Nonetheless, this intense focus on medical and social innovation underpinned by new digital applications has led to the creation of a number of training initiatives that both foster and support these developments.



5.15 Over 9,000 students are enrolled at the University of Oxford in courses that are of most direct relevance to digital health. An increasing array of courses and networking opportunities are available through, for example through the Institute of Biomedical Engineering and the Said Business School.

5.16 The Big Data Institute is a new, interdisciplinary research centre that will focus on the analysis of large, complex, heterogeneous data sets into the causes and consequences, prevention and treatment of disease. At full capacity it will house around 350 researchers.

5.17 Networks such as DHOx engage local communities of developers, clinicians, students and innovators in events and hackathons and in 2016 over 1,000 people attended DHOx events. DHOx is in contact with over 2,000 people that have an interest in digital health. The clinical community is also becoming more involved with digital health and the establishment of TheHill at the John Radcliffe Hospital has provided an additional focus for digital health-related activities.

Local industrial strengths and capacities

5.18 The Oxford Thames Valley digital health cluster is based around two 'spines', which intersect at Harwell. The first, the Oxfordshire 'Knowledge Economy Spine' runs from north to south and takes in three main centres: Bicester, Oxford and Science Vale (the area around Harwell, Culham, Didcot, Wantage and Grove)[139]. The second spine runs along the Thames Valley M4 corridor, encompassing Slough, Reading and Newbury, with an axis point at Harwell.

5.19 The large number of science parks, incubator facilities, co-working spaces and accelerator programmes in Oxfordshire was referenced in Chapter 2. Of particular relevance to the digital health theme are the activities of Oxford University Innovation, with its digital health incubator and TheHill.

5.20 As part of the audit, the 160 companies across the Oxford and Thames Valley region were approached for further supporting data into their digital health activities and company assets. Responses were received from 20 companies, representing a 12.5% response rate. Of these, 18 were privately owned companies and 2 were publicly quoted. The annual turnovers range from £25,000 to £8.4 billion per annum, with the majority in the range from £250,000 - £500,000 per annum, with 55% of the companies surveyed making a profit in the last financial year. In terms of company age, 42% of companies are between 1 – 5 years old, and a further 21% are – 10 years old. All companies surveyed expect to grow in the next year with 70% expecting to grow more than 50%. The companies surveyed ranged from SMEs to

139 See *The Oxfordshire Innovation Engine*, SQW, October 2013, and *Realising the Growth Potential. The Oxfordshire Innovation Engine Update* SQW, May 2016

large businesses, and the number of employees ranged from 2 – 30,000 (global footprint). Most of these companies have between 2 – 105 employees with a median at 23 employees. In terms of barriers to growth, 55% of those surveyed reported marketing opportunities as a barrier and 25% reporting skills.

National and international engagement

5.21 Connectivity across the NHS is based in part, around the recommendations set out in the Wachter report. In collaboration with Arden & GEM Commissioning Support Unit, the Oxford AHSN is working with NHS England to provide

- An overview of the region's connectedness – locally, nationally, internationally
- A description of alliances; coordinating structures; examples of local capacity to work collaboratively across science and innovation
- Discussion of key networking bodies and processes within and beyond Oxfordshire

5.22 Data generated by Elsevier looked at a number of metrics for the period 2011-16 using key word searches as set out in Table 5-4.

Table 5-4: Selected publication metrics

Metric (2011-2016)	Regional	UK	Global
Documents	5,169	72,742	483,889
Field Weighted Citation Impact FWCI	3.3	1.94	1.42
Citations	98,888	763,373	3,625,390
Average Citations per document	19.1	10.5	7.5
% of documents in top 10 most cited	27.5%	19.3%	14.4%
Regional % of UK documents vs Regional % of UK citations	7%	13%	
% international collaboration	58.9%	49.1%	26.0%
Data on number of patents citing documents	128		
Number of documents cited by patents	43	322	2,102

Source: Elsevier

Development in wider funding landscape

5.23 Access to sources of capital has been an essential part in building the digital health sector, irrespective of whether it is through the NHS, academia or commercial companies. Depending on the stage of development, type of innovation and type of organisation, there are different funding options available. The majority of companies involved in the SIA secured external funding from a number of sources: (i) 22% of companies surveyed had angel investors; (ii) 33% secured venture capital finance; (iii) Around 17% of companies received charitable funding; (iv) 22% received EU funding, and 11% of companies were successful in securing grant funding. Of these, 56% who received funding, secured over £100,000.[140]

The pre-existing strengths of digital health provide the opportunity to create an innovation ecosystem that brings investment to enable improvements in health treatments and outcomes in partnership with the NHS. Data enabled ecosystems for innovation in healthcare have the potential to create real, full time interoperable data platforms to support knowledge creation and insight from real world data derived from clinical care processes and key health and patient reported outcomes measures. Such an endeavour would create a test bed for proposed new innovations (medicines, devices, diagnostics, apps and other digital health innovations) using data in de-identified form to provide opportunities for service transformation, research discovery and innovation across Oxfordshire. This in turn will lead to increases in employment in digital health, estimated to be an additional 300,000 jobs (33,000 in Oxfordshire) by 2030 combined with significant savings across the NHS likely to amount to at least £1.8 billion by 2030[141] (Table 5-5).

Table 5-5: Digital health targets

Science and technology area	**Jobs in 2030**		**UK Revenue by 2030 (£Bn)**	**Global Market by 2030 (£Bn)**
	Oxfordshire	**UK**		
Digital health	33,000	300,000	50	1,000

140 Source: *Oxfordshire SIA Digital Health Survey*, SQW, 2017

141 It is envisaged by the authors that at least £1.8 billion can be saved through efficiency gains including preventions and early diagnosis. Various sources: USA equivalences: Accenture – see *FDA-cleared digital health devices to save healthcare $100B by 2018*, mobihealthnews.com.
£1.8 billion savings by 2030 is based on Digital Health contributing to 1% savings of the NHS budget (for Oxfordshire this would be half of the 2% expected savings stated in the *Buckinghamshire, Oxfordshire and Berkshire West Sustainability and Transformation Plan*, NHS, 2017). NHS budget 2017 £123.7 billion (source: King's Fund) and 3% inflation rate. 1% savings through Digital Health is considered by the authors to be a conservative estimate: more extensive savings may be realised through Digital Health technologies given suitable investment in technology science and innovation, and commercialisation.

6. Space-led data applications

6.1 Space-led data applications incorporate an element of space-derived data to deliver information and insights for decision-making by business, government, NGOs and the public. Space data comes in a variety of forms: earth observation (satellite-based remote sensing of the Earth, including optical and radar imagery); satellite positioning (Global Navigation Satellite Systems such as GPS) and satellite communications. To develop solutions, this data can be processed and combined with other data sources such as in-situ or airborne sensors to provide comprehensive applications for end-users or system aggregators that solve problems.

6.2 Oxfordshire is at the forefront of developments in this field with an innovation ecosystem including space, data and software businesses together with the Satellite Applications Catapult, the Harwell Space Cluster, Wallingford organisations such as NERC's Centre for Ecology and Hydrology and HR Wallingford, the Science Technology Facilities Council (STFC) and the Universities of Oxford and Oxford Brookes. These organisations are well connected nationally and internationally to both space and complementary capabilities.

6.3 This SIA theme looks to evaluate the potential for Oxfordshire to leverage its existing research, facilities, entrepreneurial businesses and skilled people to develop a world-leading industrial base. It builds upon the county's competitive advantage of its reputation for scientific excellence, proximity to London and Heathrow airport and attractiveness to live in. The audit explores existing and potential future national and international links and the case for further targeted investment.

6.4 Specifically, the ***hypothesis*** is that ***Oxfordshire will have 10,000 across the space-led data applications value chain by 2030 (Space Industry target of 100,000 new jobs by 2030).***

6.5 This hypothesis links to the UK space industry target of reaching 10% of the global space market by 2030, which implies the UK market would be worth £40 billion revenue per annum[142] and create 100,000 new jobs. As noted in the 'Size & Health of the UK Space Industry 2016': The Space IGS ambitions creation of a further 100,000 space industry jobs since the starting point in 2007 of 19,100. Seven years later, in 2014/15, the space industry supported an estimated 38,522 direct jobs. To achieve the IGS ambition, a compound annual employment growth rate of 7.8% needs to be realised.

6.6 The hypothesis was tested with a wider group of organisations that were asked to consider:

- Current employment in space-led data applications in Oxfordshire.

142 See p.21 of 'Summary Report: the Size & Health of the UK Space Industry', UK Space Agency, Dec 2016

- How Oxfordshire's capabilities fit within a national and international context.
- Any gaps, and hence opportunities for growth, within the space-led data applications capabilities in Oxfordshire.
- Actions that need to be put in place to realise the opportunities, in an Oxfordshire context, including building upon existing mechanisms such as the Space Cluster at Harwell.

National and international trends and size of global markets

6.7 The broad definition of space-led data applications means that precise measurement of market opportunities in this area is challenging, so relevant and indicative information about the national and international landscape is presented below. Overall, this data highlights that this is a rapidly growing area of activity globally and currently the UK has a lead.

International context

6.8 'The Space Report', produced by the Space Foundation in 2016[143], showed the global space industry is worth US$ 323 billion. The largest sector of the industry, 'Commercial space products and services', including telecommunications, broadcasting and Earth Observation, grew by 3.7% year on year, to reach US$126 billion in 2015. This growth is the key driver for many recent investments in space-related companies. Space technology, combined with communication networks, is displacing traditional ways of observing infrastructure, populations, environmental and climate phenomena, biodiversity, interactions, and providing services.

National context

6.9 The 'Size & Health of the UK Space Industry' December 2016 Report[144] showed the industry continuing to grow ahead of the UK economy, reaching £13.7 billion of total income, an annual growth of 6.5%. It is estimated to have directly contributed £5.1 billion Gross Value Added (GVA) to UK economic output, equivalent to 0.27% of total UK GDP, and supported 38,522 jobs. The UK space industry's labour productivity (average GVA per employee) was £133,233 – 2.7 times the UK's average labour productivity (£49,815).

6.10 The UK space industry is dominated by large organisations, with 19 organisations accounting for 88.7% of total space related income, and 600 organisations making up just 3.5%. Only 97 organisations generate space income in excess of £5m. In

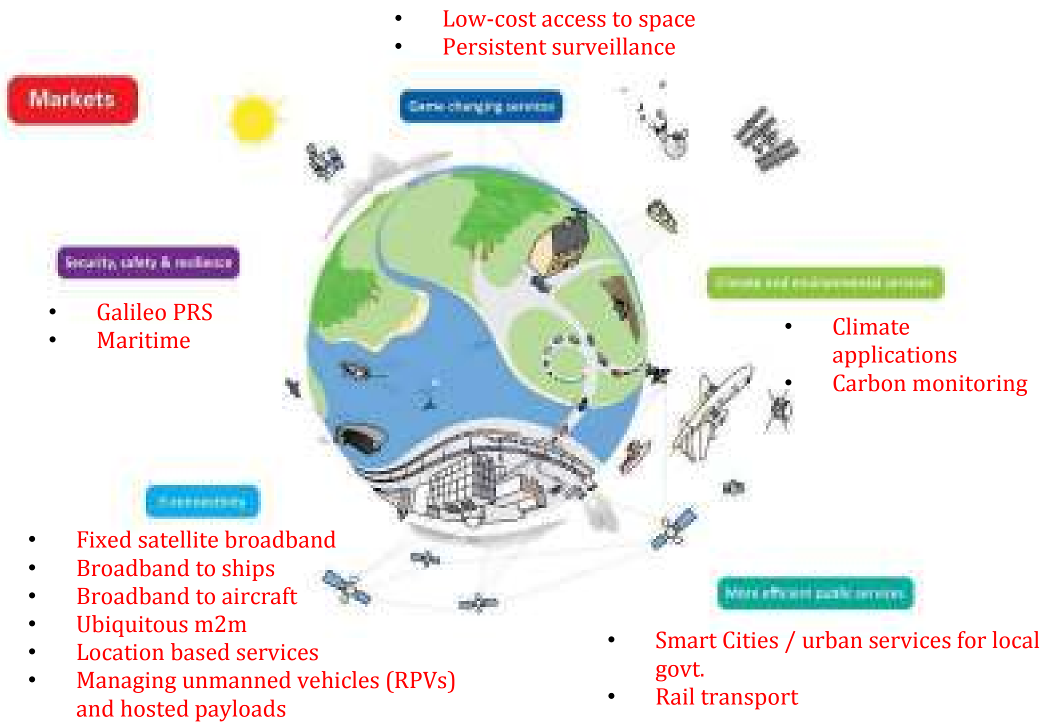
143 The Space Foundation (2016): https://www.spacefoundation.org/sites/default/files/downloads/The_Space_Report_2016_OVERVIEW.pdf
144 London Economics: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf

total, based on an aggregation of all industrial activities, the report estimated that space and satellite services support industries representing turnover of at least £651 billion, with more than £250 billion of wider UK GDP supported by satellite services, demonstrating that satellites are integral to the UK economy.[145]

National Innovation and Growth Strategy / Space Growth Partnership[146]

6.11 In 2010, UK space industry, academia and Government came together to coordinate actions towards the UK taking 10% of the global space industry by 2030 (from 6.5%). This included recommendations to establish the Satellite Applications Catapult and to promote Harwell as the major focus for coordination and delivery. A further 2013 report[147] detailed how this growth could be achieved, highlighting that the domestic market needs to grow from £7 to £15 billion and export markets from £2 to £25 billion, with the majority of growth in downstream space-enabled applications and services (increasing from £8 to £37 billion by 2030). This report identified fifteen high growth markets with the potential to be worth at least £1 billion each annually by 2030 (see figure 6-1). Further work has been conducted recently by the Satellite Applications Catapult to consider how to take advantage of the market potential, and is being taken forward by the Space Growth Partnership.

Figure 6-1: high growth markets for space-enabled applications and services



Source: National Innovation and Growth Strategy

145 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575786/LE-SHUKSI_2016-INFOGRAPHIC-FINAL_S2C171116.pdf
146 *The Space Innovation and Growth Strategy Main Report*, SpaceIGS (p.68)
147 *Space Innovation & Growth Strategy - Growth Action Plan 2014-2030*, SpaceIGS, November 2013

Technology Trends

6.12 Three technology trends could lead to a step-change in space-led data applications globally:

- High resolution imaging in satellites offer a wide range of new potential applications such as studying skylines of rapidly developing cities[148], monitoring mineral extraction[149] and looking at the suitability of properties for solar panel installation[150].

- New small satellite constellations: the UK has a world leading position in small satellites with Surrey Satellite Technology Ltd (SSTL) supplying to 40% of the world's rapidly growing small satellite export market (predicted to reach $1.42 billion this year)[151]. Although the resolution of these satellites may be lower, large constellations and higher repeat frequency offer additional benefits[152].

- Availability of free data from the EC funded Copernicus and Galileo programmes are allowing development of new business models.

Local science & innovation assets

6.13 We estimate that there are over 85 organisations employing over 2,500 people in Oxfordshire within the broad definition of space-led data applications. These organisations are primarily clustered in three locations:

- **Harwell Space Cluster**: the largest hub, comprising 75 companies, government and university-related organisations. Companies include growing SMEs (e.g. Oxford Space Systems, Rezatec), divisions of multi-nationals (e.g. Airbus Defence and Space, Thales Alenia Space, Telespazio Vega, Lockheed Martin, Elecnor Deimos); government-funded facilities include the Satellite Applications Catapult, STFC's RAL Space and the ESA Centre for Satellite Applications and Telecommunications (ECSAT). Both the Catapult and RAL Space have strong links to the University of Oxford through joint positions and collaborative projects.

- **Oxford**: The University of Oxford has a wide range of researchers across data science-oriented departments of Mathematics, Computer Science and Engineering Science and related fields of Physics, Earth Sciences,

148 https://dg-cms-uploads-production.s3.amazonaws.com/uploads/document/file/225/CyberCity3D_Case_Study.pdf
149 https://dg-cms-uploads-production.s3.amazonaws.com/uploads/document/file/219/VALE_CS2_Review5.pdf
150 http://www.energeo.co.uk/clean-solar-buildings
151 http://www.prnewswire.com/news-releases/small-satellite-market-report-2017-2027-300433630.html
152 More frequent refresh enables new services that rely upon more regularly updated data (hours / days vs weeks.) This is more important in some markets than others – crop monitoring requires a different refresh rate to car park monitoring, for example.

Geography, Zoology and Plant Sciences. Oxford Brookes University has strengths in Architecture, Built Environment, Computing and Communications Technologies. The city, Oxford Science and Business Parks and Begbroke Science Park contain a range of IT and spin-out businesses and international consultancies with interests in space-related data.

- **Wallingford**: The NERC Centre for Ecology and Hydrology, HR Wallingford, CABI, several environmental consultancies and sections of the Environment Agency, Met Office and British Geological Survey are situated around Wallingford, which has critical mass in water science and ecology.

Data and computing facilities

6.14 Oxfordshire is home to a large number of internationally and nationally important datasets and associated storage and processing facilities, with over 16 petabytes of data and over 5,000 computing cores, principally in the JASMIN facility, which incorporates a private cloud. Table 6-1 lists the different government-supported and academic facilities and capabilities.

Table 6-1: Space related data facilities and capabilities in Oxfordshire

Organisation	Facilities
Satellite Applications Catapult	Climate and Environmental Monitoring from Space (CEMS) service; operations centre for end-to-end mission capability; visualisation suite; far-field antenna test range; satcomms lab; security and resilience centre.
Rutherford Appleton Laboratory	Centre for Environmental Data Analysis (CEDA) incorporating NERC data services for Atmospheric, Earth Observation and Solar System Science, Intergovernmental Panel on Climate Change (IPCC) Data Distribution Centre; JASMIN e-infrastructure for petascale environmental data storage and processing; satellite testing equipment (RAL Space) including clean rooms, thermal vacuum chambers, ground station capability; scientific computing department; extensive spacecraft / sensor design and construction capability; science algorithm development; space weather monitoring; solar physics; astronomy; space debris monitoring.
University of Oxford	Research in machine learning, high performance data analysis, data management, numerical analysis, visualisation and visual analytics, search engines and data extraction, security and privacy.
NERC Centre for Ecology & Hydrology	Terrestrial and freshwater systems research in ecological processes, natural capital, environmental informatics, natural hazards, water resources, pollution and environmental risk, sustainable land management; hosts NERC environmental information data centre (EIDC), Biological Records Centre (BRC).
HR Wallingford	Civil engineering, environmental hydraulics, flood and water management, maritime and coastal management, energy industry engagement.

Organisation	Facilities
Met Office (hosted in CEH)	Long-term weather forecasting
British Geological Survey (hosted in CEH)	Groundwater research, flooding, climate, space weather
Ricardo Energy & Environment UK	UK air quality monitoring network; impact assessment, measuring, modelling and forecasting, emissions inventories, particle measurements, oil weathering and dispersant testing, agricultural services, odour measurement.
Broader SIA: European Centre for Medium-Range Weather Forecasts (ECMWF) Berkshire	Multi-petaflops resilient supercomputer facility (incl. two Cray XC40 systems). Large-scale data handling system (DHS) for users: weather data storage and modelling (includes Meteorological Archive and Retrieval System (MARS)). Regional Meteorological Data Communication Network (RMDCN): computer network infrastructure for the meteorological community. User support.
National Centre for Earth Observation, Leicester. OxTTA SIA is in contact with LLEP.	NERC Earth Observation Data Acquisition and Analysis Service (NEODAAS). Field Spectroscopy Facility (FSF) for optical sensing, and equipment for assessing spectral properties of earth components and organisms under varying conditions. CEDA holds two decades' worth of satellite data from a range of satellite missions.

6.15 The JASMIN facility ingests 150 TB from European Sentinel satellites per month; a huge archive for future analysis. The facility holds earth observation (2 PB), atmospheric science (0.8 PB) and climate model (1.2 PB) data with over 30,000 registered users and includes data from climate models, satellites, aircraft, the Met Office and NERC programmes and facilities. The JASMIN infrastructure supports primarily academic community users. The Satellite Applications Catapult provides industry access through CEMS, Climate and Environmental Monitoring from Space, on a commercial basis.

6.16 The NERC EIDC hosts nationally important terrestrial and freshwater datasets including on water quality, biodiversity, soil, climate change. Its drought portal provides 50 years historic drought data and the rainfall database enables mapping, plotting and downloading rainfall at a 1km grid resolution for the UK. A range of tools are built on top for analysis and modelling. The National River Archive, Climate change network and BRC (for 20,000 species nationally) are also held by CEH.

6.17 Whilst many of the University of Oxford's capabilities are distributed across its Departments and Institutes, its Advanced Research Computing resource enables access to High-Performance Computing for all researchers with associated training and support. Overall, this comprises 340 TB storage over several systems with associated software and tools[153].

153 *Advanced Research Computing: An Introduction*, ARC

Testing facilities

6.18 The Harwell Space Cluster is home to national test facilities, including the RAL Space Test Facility with assembly, integration, verification, and environmental testing, supporting the design and development of new sensors and satellites to provide future data for space-led data applications. Increasing numbers of small satellites, with shorter lifetimes (typically less than five years), are driving rapid replacement rates and accelerated development of sensors. A UK spaceport could offer launch facilities for these satellites anchoring the value chain in the UK. As the spaceport is likely to be at a remote location, Harwell would be a more accessible location for application and supply chain development.

Local Science & Innovation Talent

People

6.19 Oxfordshire generates a significant number of highly able graduates and post-graduates and attracts a substantial number of entrepreneurs and associated business support organisations (e.g. legal, finance, investment). In education, the Mathematics, Physical and Life Sciences Division at the University of Oxford trained 550 undergraduates and 2,237 graduates in 2016. 37% of Oxford Brookes' nearly 18,000 students are trained in subjects relevant to this area (6,610 students). This is a highly able pool of trained people to engage with growing, innovative businesses.

6.20 As part of the SIA workshop (see Appendix X), it was noted that there is competition for the best people as many of the skills are transferrable and not unique to space-led data applications. Highly mobile graduates need a combination of exciting and challenging opportunities together with sufficient remuneration for them to afford to live in the region.

Research

6.21 The Research Excellence Framework (2014) highlighted the University of Oxford as having the UK's largest volume of world-leading research, enabling the development of cutting-edge technology that sits behind space-led data applications. One recent example of this is machine learning for automating the processing and interpretation of data, connected through the Catapult to leading businesses and international applications.

6.22 An analysis of the scientific publications associated with space-led data applications authored by individuals and companies within the county from 2011-2016 (related to satellites and earth observation, at the highest level of discriminator, and excluding those relating to astrophysics) showed 183 publications with 2,692 citations yielding 14.7 citations per publication and a field-weighted citation impact of 2.33 (FWCI;

see table 6-2). Within the UK, this places the University of Oxford first in terms of number of publications and fourth, closely behind UCL, and the Universities of Reading and Cambridge in field-weighted citation impact. RAL and CEH also have high FWCI ratings.

Table 6-2: Scientific publications associated with space-led data applications

Organisation	No. of publications	No. of citations	Field-weighted citation impact
University of Oxford	183	2692	2.33
Rutherford Appleton Laboratory	60	411	2.21
Centre for Ecology & Hydrology (national figures)	33	453	2.22
Total	276	3,556	

Source: 'Oxfordshire SIA Space Led data' SciVal analyses, Elsevier Research Intelligence

National and international engagement

6.23 Space-led data applications use globally collected data and applies this to a global customer base. Most organisations are therefore generally active nationally and internationally. To support this, many have a wide footprint (see examples in Table 6-2). Reasons for being based in Oxfordshire include access to London and Heathrow airport and the global reputations and activities of Oxford and Harwell, in particular. The presence of major organisations such as ESA at Harwell has also encouraged companies, such as Deimos UK, to locate here[154], the UK subsidiary of Elecnor Deimos, with Group HQ in Madrid and subsidiaries in Lisbon and Bucharest, totalling 400 employees.

Table 6-2: examples of national and international connections

154 Space Intel Report https://www.spaceintelreport.com/uk-seen-as-good-importer-of-space-expertise-less-good-at-aiding-exports

6.24 As a result of these connections, Oxfordshire has strong connections to the rest of the UK, with internal transfer of innovation and ideas for the national companies and through awareness raising with the Satellite Applications Catapult Centres of Excellence (which are located in Scotland, North East, East Midlands, South West and South Coast), STFC and CEH. Organisations in Oxfordshire have strong links to universities across the UK.

6.25 Organisations in Oxfordshire already have strong links with international organisations. For example the University of Oxford works on international projects with the international space agencies of the USA (NASA), Japan (JAXA) and the European Space Agency (ESA). Similarly the Satellite Applications Catapult and RAL Space have worked with organisations in China, Australia and South America.

6.26 The organisations across Oxfordshire regularly meet and work on projects with others across the UK, in particular they have close links with:

- Thames Valley Berkshire: home to a wide variety of companies and organisations in Reading (including its University) and surrounding science and business parks such as Thames Valley Science Park (from autumn 2017), Microsoft, Oracle, European Centre for Medium Range Weather Forecasting and the Institute for Environmental Analytics. Newbury is also home to Vodafone.

- Buckinghamshire: There are growing links between Oxfordshire and Buckinghamshire, specifically the Westcott Venture Park, which is historically the UK’s main rocket testing site. Investment by the UK Space Agency in new test facilities, creating a national rocket propulsion test centre, and by the Catapult in incubation and innovation facilities, including a 5G test bed focussed on autonomous vehicles, are aimed at establishing Westcott Venture Park (which is historically the UK’s main rocket testing site) as a major test and verification facility for certain aspects of the UK space and related sectors.

- North East Local Enterprise Partnership: Through its Centre of Excellence, the Satellite Applications Catapult has built links with the North East, particularly looking at how supply chains can link into the manufacturing capability in the North East, particularly with relation to drone technology where there is a developing cluster. The North East is focussed on identifying problems rather than sectors and how to bring capabilities to solve these, drawing capability from Oxfordshire to the North East.

Wider Funding Landscape

6.27 In addition, there is space-related funding, enabling the UK space sector to develop its capabilities. This funding is from UK investments in the European Space Agency (e.g. ARTES Integrated Applications Programme), UK Space Agency through the National Space Technology Programme International Partnerships Programme (IPP; £150m) and the Space for Smarter Government programme, developing new and collaborative solutions to government and business challenges. RAL Space and the University of Oxford have also been successful at winning funding from NASA for space instrument development.

6.28 In addition to the already strong funding landscape in Oxfordshire, space has funding mechanisms for start-ups such as the ESA Business Incubation Centre (funded £2 million over the last five years) and the recently launched UK Space Tech Angels Network. National funding opportunities, such as the Seraphim Space Fund (£50 million) and Space Net Ventures Fund[155], are starting up, partly due to the activities of the Satellite Finance Network, supported by the Catapult, which actively promotes space amongst the financial community and helping space companies access capital.

155 FT article Friday 17th March 2017: 'Space – the final frontier for investors'

7. Technologies underpinning quantum computing

7.1 The next generation of quantum technologies (which includes quantum computing and its underpinning technologies), have the potential to profoundly change the world and all our lives over the next 20 years with new and diverse products that have astounding capabilities. A £1 billion future industry for the UK is envisioned with new industries and supply chains emerging to service them.[156]

7.2 In the 2013 Autumn Statement, the Government pledged £270 million over 5 years to translate the UK's excellence in quantum research into applications and new industries, and ensure the UK is a leading player in the global supply chain[157].

What is a quantum computer?	Example technologies underpinning quantum computing
A quantum computer is a revolutionary new type of computer that harnesses the strange laws of quantum physics to perform calculations that are considered impossible even on modern supercomputers. In the decades to come the impact will revolutionise many industries across Finance, Health, Chemical, Aerospace and Logistics, and create new and unimaginable commercial opportunities. It is worth remembering that when the world's first commercial computer, the "Ferranti Mark 1", was sold in 1951 (developed and built in the UK), Microsoft would be undreamt of for another quarter century.	The technologies underpinning quantum computing are diverse in their scope and include: ion traps, diamond crystals, superconducting circuits, quantum sensors, photonics, electronics, specialist equipment (such as lasers, microwaves, atomic clocks, cryogenic and vacuum systems), software (control systems, design, computation and simulation, programming), High Performance Computing, the development of new algorithms and machine learning

7.3 In 2014, the Government further announced that £120 million would be used to create a network of Quantum Technology Hubs involving 17 universities across the UK and 132 companies. Each hub is made up of a consortium of universities and partner organisations and specialise in the development of different quantum technologies: **quantum imaging** (led by University of Glasgow), **quantum sensing and metrology** (led by University of Birmingham), **quantum communications** (led by University of York) and **quantum computing** (led by the University of Oxford)[158].

7.4 Oxfordshire has a long and successful track record in inventing, developing and commercialising new innovations, and this remains true for quantum computing and

156 *Quantum Technologies - a new £1bn UK industry in the making*, Politics Home politicshome.com
157 Autumn Statement 2013
158 Quantum Leap as Clark unveils UK's network of Quantum Technology Hubs, EPSRC, November 2014

the technologies underpinning it. The University of Oxford leads a consortium of 9 universities across the UK and 25 partner organisations to form the £38 million quantum computing hub known as “Networked Quantum Information Technologies” or NQIT.

7.5 NQIT’s 5-year mission is two-fold:

- to build a quantum computer technology demonstrator by 2020
- to stimulate the quantum economy through world-class research, innovation, attracting investment, creation of intellectual property, spinning out technologies, skills and training, and connecting at regional, national and international levels.

7.6 The hypothesis to be tested in this Science and Innovation Audit for *Technologies Underpinning Quantum Computing* is the feasibility of **establishing a ‘Quantum Valley’ that will benefit the whole of the UK and beyond by 2030**, creating 10,000 jobs across the supply chain.

7.7 To help address this vision, we surveyed our commercial partners to understand:

- The strategic importance of quantum computing to their business, the barriers they face and how best to stimulate the fledgling quantum economy through this alliance.
- The attraction of Oxfordshire, its strengths, opportunities for industry and the contribution the region makes to the UK.

7.8 The case for focusing the UK’s quantum computing and the underpinning technologies in Oxfordshire is illustrated in Figure 7-1 below.

There is a vast effort centred in Oxfordshire bringing together many specialised contributors who are spread across the region (such as cryogenics), the UK (such as photonics and compound semiconductors) and globally (such as materials and software) to position the UK as an internationally competitive player in this fast-moving, transformative technology.

Oxfordshire's leading science and innovation capacity, as well as its highly conducive infrastructure and international connectivity (including investment), make it the best place in the UK for economic growth, business efficiencies and social benefits.

Figure 7-1 overleaf outlines the necessary factors, and regional and global capacities and connections.

Figure 7-1: The place and connectivity of Oxfordshire Quantum Computing

National and international trends and size of global markets

7.9 Quantum computing is an emerging technology and the market is primarily geared towards research rather than applications. This is reflected by the modest global market forecast for quantum computing of US $5 billion by 2020[159]. However, the growth in the market for quantum technologies is accelerating rapidly. Over the next few years, the rate of this growth depends on collaboration between academics, developers, industry specialists and end-users to prove the value of quantum computing by demonstrating the practical use cases.

7.10 There is a global race with companies and research centres around the world pursuing the development of the novel and complex technologies required to build a universal quantum computer. The commercial motivation is the transformational potential for established market sectors, whose estimated sizes are shown in Tables 7-1 and 7-2.

159 Quantum Computing Market Forecast 2017-2022, Market Research Media, June 2017

Table 7-1: Market potential of sectors potentially transformed by quantum computing

Global Market Sector	Estimated size
Advanced Materials	$102.48 billion by 2024[160]
Big data	$203 billion by 2020[161]
Biotech	$604 billion by 2020[162]
Chemical	$3 trillion [163]
Cybersecurity	170 billion by 2020[164]
Finance	$294 trillion[163]
Healthcare	$8 trillion[163]
Logistics	$4 trillion[163]
GPS	$94.44 billion by 2022[165]

7.11 The underlying systems and component technologies are large markets in themselves (Table 7-2), and the development of quantum computers will aid in their growth.

Table 7-2: market potential of technologies underlying quantum computing

Global Market Sector	Estimated Size
Semiconductors	$338.9 billion in 2016[166]
Photonics	$724.22 billion by 2021[167]
Cryogenics	$25.05 billion by 2022[168]
Enterprise Network equipment	$30.6 billion[169]
Spectroscopy	$15.6 billion in 2020[170]
Sensors	$241 billion by 2022[171]
Microelectromechanical Systems (MEMS)	$28.84 billion by 2024[172]

7.12 Large multinationals such as IBM, Microsoft and Google are investing millions into developing their own approaches to quantum computing. For example, in 2014, IBM announced a US $3 billion research initiative in a range of technologies including

160 Advanced Materials Market Estimated to Reach US$ 102.48 Bn by 2024; Global Industry Analysis, Cision PR Newswire, Dec 2016
161 http://www.idc.com/getdoc.jsp?containerId=prUS41826116
162 http://www.grandviewresearch.com/press-release/global-biotechnology-market
163 The Commercial Prospects for Quantum Computing, NQIT, Dec 2016
164 Cybersecurity Market Reaches $75 Billion In 2015; Expected To Reach $170 Billion By 2020, Forbes, Dec 2015
165 http://www.businesswire.com/news/home/20161018006653/en/Global-GPS-Market-2016-2022-Market-Generated-Revenue
166 Global semiconductor sales reach 339 billion in 2016, Semiconductor Industry Association (by subscription)
167 http://www.marketsandmarkets.com/Market-Reports/photonics-market-88194993.html
168 http://www.grandviewresearch.com/industry-analysis/cryogenic-equipment-market
169 http://www.strategyr.com/pressMCP-7020.asp
170 https://www.bccresearch.com/market-research/instrumentation-and-sensors/spectroscopy-equipment-markets-ias004f.html
171 https://www.i-scoop.eu/global-sensor-market-forecast-2022/
172 http://www.grandviewresearch.com/press-release/global-mems-market

quantum computing[173]. IBM was the first to open up its early-stage quantum computer prototype to the world over the Internet[174], and are planning to commercialise research access to selected companies when they release their latest prototype in late 2017[175].

Other investments

7.13 Many countries in addition to the UK have research programmes on Quantum Computing with substantial funding from Governments and companies. Examples are included in Table 7-3.

Table 7-3: Examples of countries with major quantum computing research programmes

Country	Size of investment
Australia	More than AU$ 135 million from Australian Government, Commonwealth Bank of Australia and Telstra [176]
Canada	CA$ 150 million from Canadian Government, Ontario and the private sector [177]
EU	€1 billion quantum technologies flagship [178]
Netherlands	€135 million from Dutch Government [179] $50m investment from Intel with Delft University of Technology and TNO [180] Microsoft also invested an undisclosed sum into TU Delft [181]
Singapore	US $218.7 million for quantum technologies [182]
UK	£38 million – part of the £270 million investment in quantum technologies over a 5 year period [183]
USA	US Government allocates $200m per year to quantum research [184] Google, IBM, Lockheed Martin, Microsoft, NASA investments are undisclosed.

Start-ups

7.14 New quantum technology companies around the world are being created, attracting interest and private investment. For example, Rigetti Quantum Computing, based in California, has raised $64m in venture capital in early 2017[185].

7.15 In Oxfordshire, multi-million pound investments have been committed in new spinouts from Oxford University and more new ventures are already being

173 https://www-03.ibm.com/press/us/en/pressrelease/44357.wss
174 http://www.wired.com/2016/05/ibm-letting-anyone-play-quantum-computer/ Wired, 5 Apr 2016
175 https://www.cnet.com/news/ibm-quantum-computers-business-moores-law-qubit/
176 http://minister.industry.gov.au/ministers/hunt/media-releases/major-leap-forward-australian-quantum-computing
177 http://quantumvalleyinvestments.com/quantum-technologies-national-priority-canada/
178 https://ec.europa.eu/digital-single-market/en/news/european-commission-will-launch-eu1-billion-quantum-technologies-flagship
179 https://www.nwo.nl/en/news-and-events/news/2015/135-million-euros-for-development-of-quantum-computers.html
180 https://newsroom.intel.com/news-releases/intel-invests-us50-million-to-advance-quantum-computing/
181 https://qutech.nl/microsoft-and-tu-delft-collaboration-started/
182 https://www.futurereadysingapore.com/2015/quantum-computers-a-revolution-on-the-business-horizon.html
183 NQIT Hub Launch, NQIT, 28 January 2015
184 The Quantum Computer Revolution Is Closer Than You May Think, National Review, May 2, 2017
185 Rigetti Computing, Cision PR Newswire, Mar 28, 2017

developed. Oxford University is the most prolific university innovator in Europe[186] and the Oxfordshire region has attracted many notable investors specialised in technology startups and spinouts, including Oxford Sciences Innovation, a private £580 million fund dedicated to investment in spinouts from Oxford University and the Harwell and Culham science communities.

National trends

7.16 In the UK, there are ongoing efforts to stimulate the market with funding competitions from Innovate UK and the Engineering and Physical Sciences Research Council (EPSRC) to develop quantum technology prototypes or establish technical or market feasibility. The first-round fund was £19.5 million in 2016, with a further round of £14 million in the first quarter of 2017.

7.17 In recognition of the importance of Quantum technologies to the UK economy, the following reports have been produced:

- National Quantum Technologies Strategy[187]
- National Quantum Technologies Roadmap[188]
- The Blackett Review –The Quantum Age: technological opportunities[189]
- Building our Industrial Strategy: green paper[190]

7.18 The national strategy is to build and support a pipeline from basic research, academic engineering, through to technology transfer and finally production and sales. This strategy requires continuing and long-term funding and support from the Government as mentioned in the Blackett Review.

Impact Examples

7.19 Companies within the UK are already experiencing the positive impact of the UK National Technologies Programme. Three examples are shown in Table 7-4.

Table 7-4: Examples of UK companies benefitting from research on quantum computing

Company	Description
M-Squared Lasers Revenue: £8.5 million (2016) Employees: 62	M-Squared Lasers was founded in 2005 and is based in Glasgow, Scotland. It manufactures lasers for the scientific, medical and defence sectors. Quantum computing is a growth area for the company. For the 12 months to May 2016, the company saw growth of 40% with more than half of sales to the USA[191].

186 http://www.ox.ac.uk/news/2017-01-09-oxford-most-prolific-university-innovator-europe
187 https://www.epsrc.ac.uk/newsevents/pubs/quantumtechstrategy/
188 https://www.epsrc.ac.uk/newsevents/pubs/quantumtechroadmap/
189 https://www.gov.uk/government/publications/quantum-technologies-blackett-review
190 https://www.gov.uk/government/consultations/building-our-industrial-strategy
191 Scottish lasers used in 'global quantum computing race' secure £1.65m, The Telegraph, June 22, 2016

Company	Description
Gooch and Housego Revenue: £86 million (2016) Employees; 675	Founded in 1948 and based in Somerset and Torquay, Gooch and Housego is a supplier of photonics technology. One of their products, the FIBER-Q® 780nm Fiber Coupled Acousto-Optic Modulator, has been sold since 2015. They have seen a 70% growth in sales in 2016 and estimate a 300% growth in sales for 2017. They believe this product is exclusively used for quantum applications.
Oxford Instruments Revenue: £361.6 million (2016) Employees: 2077	Founded in 1959 and based in Abingdon, Oxfordshire, Oxford Instruments is a provider of high technology tools for research and industry, and is a great success story for the region. At the University of Oxford, one of the technologies under active research for quantum computing is superconducting circuits, and is the only effort of its kind in the UK. This research requires expensive cryogenic systems to cool experiments down to fractions above absolute zero (~10 millikelvin). To accommodate all the experiments, Oxford Instruments have built and supplied their largest ever dilution refrigeration fridge at a cost of £750,000. This is an exciting new product development being put through its paces at NQIT.

Local science and innovation assets

University of Oxford

7.20 University of Oxford leads the UK's most significant endeavour in the development of a scalable networked quantum computer: the Networked Quantum Information Technologies Hub (NQIT), a £38m project involving 9 universities and 25 companies across the UK and globally. A significant proportion of the technology development is happening in Oxford, with a team of world-leading, record breaking physicists, engineers, materials scientists and computer scientists collaborating to build a demonstrator of the new technology and applications which solve complex problems for industries which cannot currently be solved by classical computing.

7.21 University of Oxford has also received a large number of grants from major competitive funders for research into quantum computing, as evidenced by Gateway to Research, Oxford has received more than £14.5m in RCUK research funding and more than £35m in EU research funding relating to quantum computing in the last ten years alone (not including NQIT).

7.22 Oxford has recently been ranked first in the world by the Times Higher Education (THE) Rankings. The Research Evaluation Framework exercise conducted in 2014 found that Oxford had the country's largest volume of world-leading research. The units assessed which support quantum computing in Oxford received THE rankings following the REF exercise as shown in Table 7-5 overleaf.

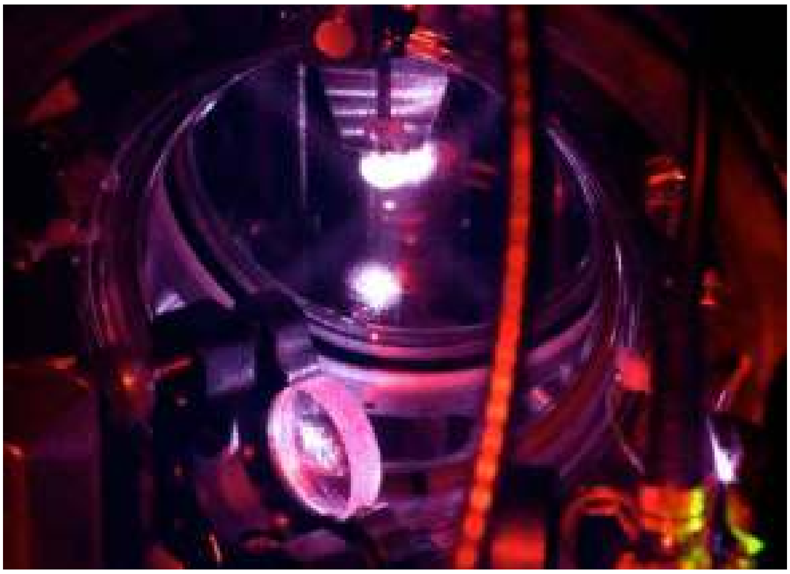
Table 7-5: University of Oxford THE ranking for relevant subjects

University of Oxford Department	Total students	Research Ranking
Physics	1,024	Ranked 2nd overall with the highest volume of 4*research activity, at 43%
Mathematical Institute	1,200	Ranked 1st overall with 59% of 4* research activity
Computer Science	More than 700	Ranked joint 7th overall with 53% of 4* research activity
Engineering	More than 700	Ranked 1st overall with 55% of 4* research activity, and the top ranking for impact (84% at 4*)
Materials Science	More than 300	Ranked 2nd overall with 60% of 4* research activity

Companies

7.23 There are already companies based in Oxfordshire which produce the type of technologies which quantum computing would require; for example, in cryogenics Oxford Instruments has provided NQIT with unprecedented new dilution refrigeration solutions, including the coldest ever system, with an investment from the NQIT capital budget of around £0.75m for one ground-breaking device for superconducting quantum computing. There are also other relevant technologies based in Oxfordshire, for example CryOx and Element 6 at Harwell.

7.24 Oxfordshire has a great opportunity to lead on a new economy for the UK: NQIT is working on spinning out companies and devising an engineering company which would help to provide some of the advanced solutions required for quantum computing for which there is currently no supply chain.



Photonics – Fluorescence of Rubidium atoms used for cooling an ensemble of atoms down to 0.0001K in a magneto-optical trap. Credit: Annemarie Holleczek

Local science and innovation talent

7.25 To create and build the technologies underpinning quantum computing you need:

- **highly skilled scientists**: physicists, mathematicians, engineers, material scientists and computer scientists
- **an effective network of diverse skills** for support, including administration, technicians, software engineers, technology transfer specialists, event organisers, entrepreneurs and investors
- **local and national supply chains**: providing specialised systems and components
- **infrastructure** for research and testing, meeting and conference venues, business incubators, housing, transport, access to healthcare, good schools and shopping facilities.

7.26 Oxfordshire has an outstanding scale and range of relevant scientific expertise, and a network of diverse supporting skills in the high tech cluster (see Chapter 2). Increasing the availability of specialist skills is a priority for NQIT, which runs a unique training programme for academics, researchers, students and industrialists from across the country to convene in Oxford to develop skills in relation to technologies underpinning quantum computing. For example, in systems engineering, quantum computing applications, and developing business skills for those aiming to spin-out technologies developed or start companies to exploit those technologies. The skills programme has received enthusiastic feedback endorsing the need for this type of training. Most of the people giving training at the event are based in Oxfordshire, either as academics or people working in local companies, emphasising the strength of local talent.

7.27 The University of Oxford has also committed 25 of its EPSRC-funded Doctoral Training Partnership places for students to start within the first three years of the NQIT grant and across the NQIT institutions, contributing to the training of future quantum leaders across the country.

7.28 While expertise in quantum computing and surrounding technologies is evidently strongly present in Oxfordshire, and many new developments are likely to emerge from this area, such developments are likely to support an emerging industry across the UK as a whole – for example through collaborations with companies such as M-Squared Lasers in Scotland who can help to build photonics components with the experts in Oxford.

National and international engagement

7.29 The awareness of quantum computing is increasing globally and NQIT welcomes interested parties from within the UK and internationally.

7.30 Of the £38m used to establish the NQIT hub, around 10% is dedicated towards a partnership fund to target new opportunities, including co-funding projects with industry and creating new quantum technology programmes such as a quantum computer emulator platform. There is an industrial engagement team based in Oxford to manage this process and proactively seek out commercial opportunities.

7.31 Since the hub's creation, NQIT has engaged with:

- **80 organisations** across Aerospace, Consultancies, Defence, Finance, Government, Logistics, Medical, Investors, Oil & Gas, Quantum technologies, Research, Scientific & Technology, Software, Space, Telecoms. 70% of these based in the UK
- **50+ events** with 60% in Oxford and the rest throughout the UK. Industry focused events such as the Quantum Technologies Showcase, NQIT User Forums and training events. Public engagement including science fairs, Responsible Research and Innovation workshops, public talks and a TV appearance on “The Gadget Show” (Channel 5, UK). Hosting visitors from within the UK and abroad who interested in quantum computing, including ministers of state and representatives of foreign governments
- **Commercial activities** including: **14** co-funded industrial research projects with multinationals, SMEs and start-ups; **10** quantum technologies patents applied for; **5** spinout companies in progress; targeting strategic sectors for applications such as drug discovery and chemical simulation.

7.32 NQIT has also produced a variety of free reports which are distributed globally:

- NQIT Annual Report 2016
- Technical Roadmap for Fault-Tolerant Quantum Computing
- Thinking Ahead to a World with Quantum Computers
- The Commercial Prospects for Quantum Computing: Issue 1

7.33 NQIT is in regular contact with other quantum centres around the world and the wider academic quantum community through conferences and special events.

Development in wider funding landscape

7.34 The UK has invested £270 million over 5 years on the National Quantum Technologies Programme and further investment is required to capitalise on the momentum and enthusiasm already established. Professor Sir Mark Walport, the

Government Chief Scientific Adviser, recognises that the UK plays a leading role in the development of new quantum technologies but a greater commitment from industry is needed[192].

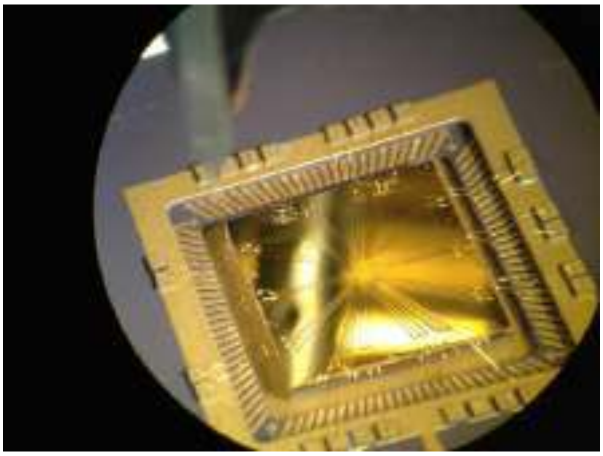
7.35 Even if the UK stops its quantum programme, other countries will continue to invest in their own programmes, leaving the UK far behind. In April 2015, the UK annual spend in quantum technologies was fourth highest in the world at £61 million, with Germany, China and the USA investing £70, £127 and £208 million respectively[193]. In addition, Companies like Intel and Microsoft have made significant investments in quantum computing research and engineering – in the Netherlands and not the UK. Making the UK attractive for large investors is therefore an important priority.

7.36 Within Oxfordshire there are a range of private investment companies and angel networks for innovation (see paragraph 2.32) who are excited by the disruptive potential of quantum technologies.

7.37 Successful high technology companies have visited NQIT at the University of Oxford and expressed interest in investing large sums. However, they are looking to the Government to see if NQIT's future is secure through a further extension of the quantum technologies programme. This is of national importance and the Government must act decisively to boost confidence for inward investment.

7.38 In 2016, the European Commission announced its €1 billion quantum technologies flagship to be launched in 2018[194]. With Brexit and the triggering of Article 50 it is unclear if the UK can benefit directly from this and depends upon the negotiated agreements.

7.39 Overall the wider funding landscape remains unclear for quantum computing, but interest in investment is growing as larger companies seek to pursue a quantum advantage.



Ion trap chip: Microwave ion trap chip for quantum computation
Credit: Diana Prado Lopes Aude Craik & Norbert Linke

192 Making the leap into quantum technologies, Civil Service Blog, gov.uk
193 Global developments Quantum Technologies, Ministry of Economic Affairs, Netherlands, May 2015
194 European Commission will launch €1 billion quantum technologies flagship, European Commission, May 2016

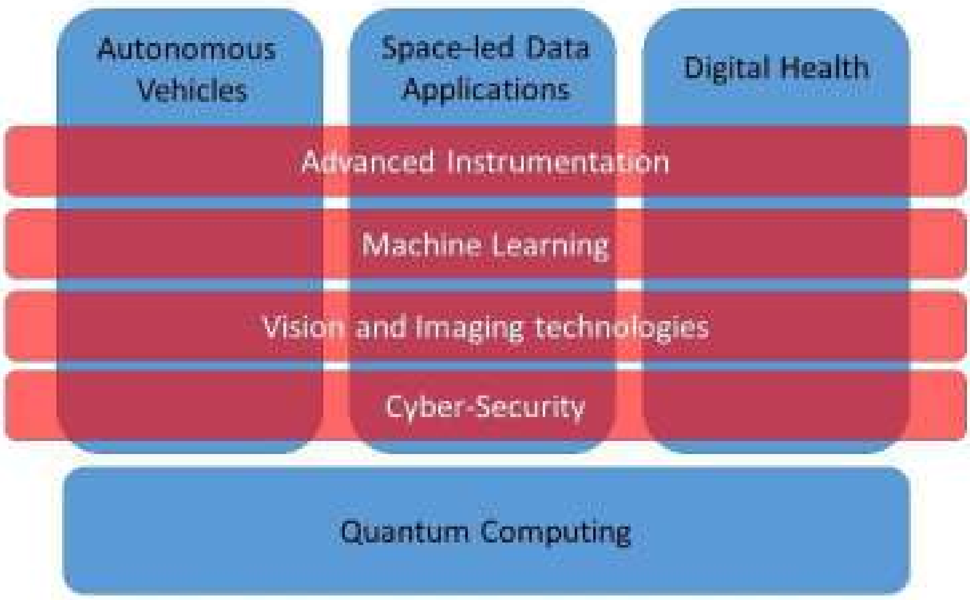
8. UK's global USP: innovations at the intersections between themes

Opportunities for applications that combine technologies, for added value of investment and social benefit

8.1 Oxfordshire is uniquely placed to exploit inter-relationships between themes for local and national benefit, because of the diversity of the science and technology cluster in the county, as well as its strength. The dynamic interactions between researchers, businesses and residents that are made possible by proximity means that opportunities at the interfaces between themes can readily be identified, understood and exploited: Oxfordshire can work as a living lab for the testing and roll out of new technologies developed in combination. The strength of the Oxfordshire cluster means that new ideas are more likely to secure funding and attract the technical and management skills needed (see Chapter 2) to generate economic and social benefits from those ideas locally, nationally and internationally.

8.2 The focal technologies have factors in common. They all depend upon or contribute to advanced instrumentation, machine learning, computer-based vision and imaging, and cybersecurity. Figure 8-1 illustrates these commonalities. The advent of quantum computing will be a game-changer: currently it is a nascent technology, but it will provide a radical level of change which will inevitably alter the capabilities arising through the other technologies. These interdependencies present innovation opportunities which can be identified and realised more quickly through co-location.

Figure 8-1: Cross-cutting science, technologies, and governance



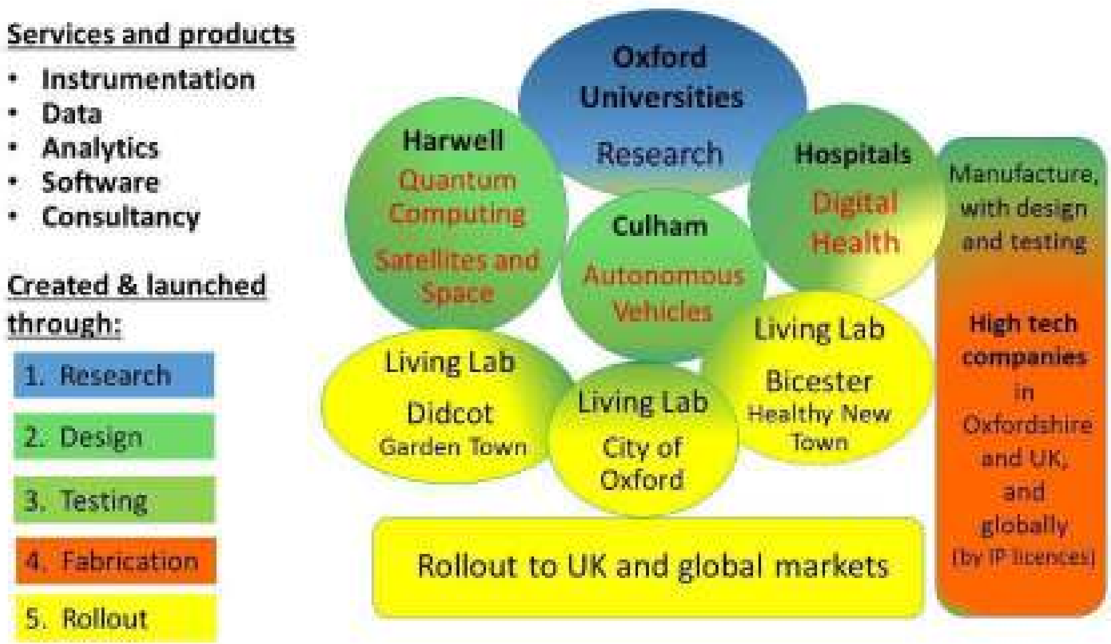
8.3 The Living Lab model is the opportunity through which products and services can be tested, refined, and proven as fit for purpose. This will best be achieved, for the UK, where the commonalities (illustrated in red in Figure 8-1) are also effectively researched with capacity and excellence. This is place-based innovation.

8.4 As shown in Figure 8-2 below, also common to all 4 technologies is that they have "hardware" (physical components and products), and "software" in the form of data and its analysis, as well as services based around access to data and its interpretation. This is as true of Autonomous Vehicles and Digital Health products and solutions as it is of mobile phones. Similarly, a quantum computer and space-led data applications rely on integrated packages of technology and instrumentation with software and services to support the use of the technologies. Accelerated hardware and data-based services are best developed together, in order to maximise the learning benefits of test beds, and rollout via Living Laboratories.

Figure 8-2: Integrated, co-located hardware and software development, fabrication and testing

8.5 The place-based model for co-location of technologies (Fig. 8-1), their components (Fig. 8-2), and Living Laboratories is illustrated in Figure 8-3: the science-intensive Oxfordshire-based model of how this should function:

Figure 8-3: Oxfordshire Transformative Technologies Alliance model of the creation and launch of services and products to capture innovation at the intersections between technology sectors



Intersections between the Transformative Technologies

8.6 The four thematic areas can readily be envisaged to work together in future, and this has been accelerated already through the SIA process. For example, quantum computers will enable smart infrastructure to intelligently optimise and direct the route of autonomous vehicles in real-time, taking into account all of the vehicles in the region at once, reducing journey times and accidents. Space-led data applications are already an important input for autonomous vehicles and through the SIA process the Satellite Applications Catapult and RACE have started working more closely to explore future opportunities for new applications. Similarly space-led data applications are input to digital health, particularly those that visualise real-time, location based data, through the SIA process the Satellite Applications and the AHSN are considering how health outcomes will be transformed by the ability to monitor and analyse personal health data in real time, and develop more effective self-health interventions in parallel. Quantum computing could further accelerate the capability and speed of these applications.

8.7 Figure 8-4 and Table 8.1 illustrate the inter-relationships between the four themes and the potential for mutual benefit resulting from co-location in Oxfordshire

Figure 8-4: Inter-relationships between the four themes and regional strengths, into national strengths

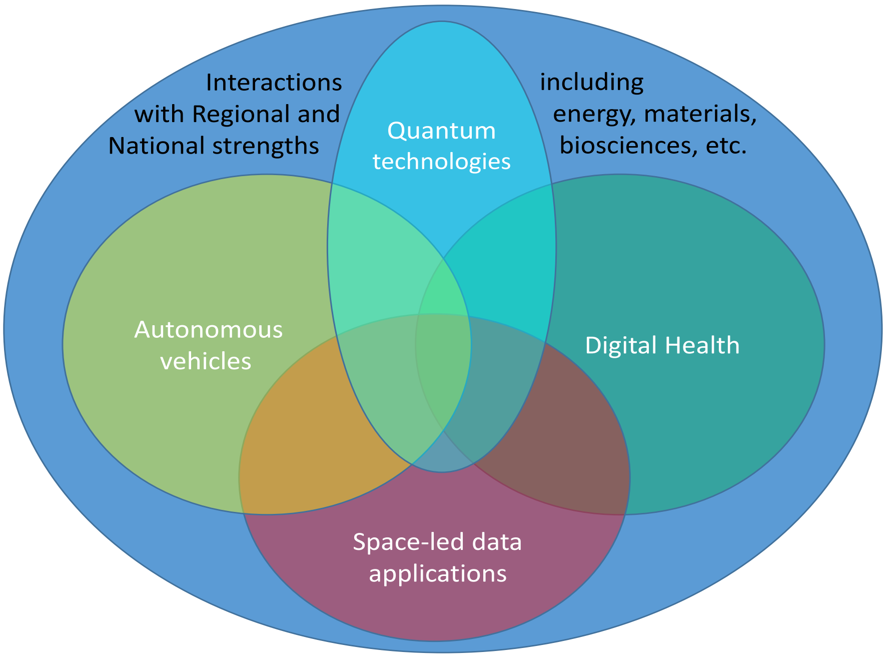


Table 8-1: Specific examples of inter-relationships between the four themes

	Digital health	Space-led applications	Quantum computing
Autonomous vehicles	Autonomous vehicles will provide real time monitoring of the health of passengers and of their environment (e.g. air quality) Computer vision	Autonomous vehicles will make use of space-led data providing positioning, communications and earth observation	Improving artificial intelligence and machine learning Software verification and validation of complex code Optimisation (routing problems) Encryption of vital systems
Digital health	---	Digital health will benefit from space-led data applications to provide new services and productivity improvements, helping deliver more care remotely and improving the cost effective management of resources.	Faster searches through "data lakes" New quantum sensors for medical applications Data analytics and data protection Tackling complex problems such as drug discovery
Space-led applications	Space-led data applications have benefitted from the machine learning developed in Digital Health and is now using this to develop new applications to solve challenges in Digital Health. Computer vision, image recognition and optics	---	Quantum technologies will improve the processing and security of satellite data in the future. Technologies such as cold atoms interferometers will produce new instruments and new data and applications

Source: Theme leads

Cross-cutting science, technologies, and governance

8.8 The four transformative technologies all interact with common, cross-cutting, and underpinning science, technologies and governance, as described in Figure 8-1: advanced instrumentation, machine learning, computer-based vision and imaging, and cybersecurity. There are many examples already underway in which these commonalities are providing benefits to at least one of the four technology themes.

8.9 These benefits are reciprocal: innovation in transformative technology themes boosts, tests and develops the innovation and application of those cross-cutting aspects.

Computer vision

8.10 Advanced computer vision techniques enable features from images to be extracted and interpreted to provide information. Computer vision is an increasingly important element of space-led data applications as computers are used to identify features within satellite images to speed up processes and stimulate new capability. The Satellite Applications Catapult is working closely with the University of Oxford computer vision and machine learning specialists examining satellite imagery, automatically extracting features such as cars, planes, ships and roads for such diverse projects as identifying illegal fishing around the world and searching for illegal logging in Malaysia.

8.11 These techniques, developed by groups in Oxford form the basis of automated feature recognition by cameras on autonomous vehicles – both in the UK and in Germany – and Oxford experts are in demand from all groups working in the autonomous vehicle space. Finally, of our 4 areas, the key constraint to deployment of these systems once developed is the computing requirements for both processing and storage of large amounts of data. Quantum computing offers a potential speed-up in data searches (such as Grovers algorithm), shortening the training period for machine learning datasets (quantum machine learning), and faster algorithms for image processing. Investment in growth of both research scientists and innovative companies in this field is necessary to underpin UK growth in two of our four sectors.

Artificial Intelligence and machine learning

8.12 'Machine learning' techniques include handling the integration of complex heterogeneous datasets, calculating uncertainties and addressing gaps in data, as well as looking for patterns that cannot readily be seen through conventional analytical techniques. Data-focused machine learning is a strength in Oxfordshire's research, and in some emerging businesses in healthcare and satellite applications. Considering the amount of research in this area, the number of highly skilled people being produced is currently small, given the strong demand from industry for skilled employees, and for solutions.

Cybersecurity and data ethics

8.13 The county has strengths in cybersecurity both in research and industry (e.g. Sophos). Cybersecurity is a strength of Oxfordshire, with an academic and training centre in the University of Oxford with good ties to the nearby GCHQ proximity to the Malverns. The University is successfully growing a data ethics programme with leading businesses funding research, including Google, Microsoft and other major firms.

9. Conclusions and next steps

Oxfordshire and UK growth opportunities

9.1 The wider consortium formed for the purposes of this SIA (including the Thames Valley Berkshire LEP, the Greater Cambridge Greater Peterborough LEP, the Enterprise M3 LEP, and the North East LEP) was formed in order to develop inter-relationships between Oxfordshire and other areas, and to ensure opportunities created through the four Oxfordshire themes are fully exploited for the benefit of the UK economy, whether commercial exploitation and scale up is based in Oxfordshire or elsewhere in the country.

9.2 There are, for example, strong complementarities between the wider consortium members in supporting economic growth. For example:

- 20% of the North East's economy is manufacturing (which drives another 15% of the region's economy). If Oxfordshire research-based companies were to build supply chain links into the North East, this would play to the strengths of both areas
- The quantum computing theme in Oxfordshire is linked to the rest of the UK through academic research, industrial engagement and skills & training. This model means that the research and commercialisation of innovative technologies are distributed across the country
- From an industrial perspective, Oxfordshire is both a customer and a supplier of specialist technologies that underpin quantum computing. Two such examples are the Photonics and Cryogenic industries.
  - ➢ The quantum computer technology demonstrator being built by NQIT will consist of at least two quantum computing modules that are optically linked. Photonic products are essential to its operation and include: lasers, lenses, optical waveguides, photon sources, photon detectors, beam splitters, polarisers and fibre optics. There are around 1,500 photonics manufacturing companies in the UK, employing over 70,000 people and having an economic output of £10.5 billion[195].
  - ➢ Oxfordshire has a strong cryogenic cluster supplying the region, the UK and international markets. Oxfordshire's local cryogenic community is supporting three of the four Quantum technology hubs, with Oxford Instruments supplying NQIT, RAL Space at Harwell providing laser cryogenics for the Birmingham hub, and the Planck Space Cooler is being repurposed for the Glasgow hub.

195 Map of photonics in the UK, UK Photonics Leadership Group

9.3 An existing example of **industrial connection** is RouteMonkey, a Scottish provider of route optimisation software for the logistics industry. RouteMonkey engaged with NQIT on an industrial collaboration to discover new quantum algorithms for vehicle routing. During the SIA process, RouteMonkey expressed a keen interest to explore the market potential of autonomous vehicles, and it was a simple matter to connect them with our theme partner.

Gap analysis

9.4 There are common issues and gaps affecting all four themes, and others which are theme specific. Table 9-1 considers these issues and potential solutions. The GAP analysis was conducted through workshops for each of themes, with a wide representation from industry, academia and public sector (listed in Annex A).

9.5 The most pressing issues common to all themes are skills retention and shortages and housing costs. Measures are being taken to address both problems locally, but they are national issues which cannot be solved entirely within Oxfordshire (and which could be exacerbated by national policy changes, such as restrictions on recruitment from abroad).

9.6 There are also specific issues in relation to each theme: for example, for Digital Health the lack of incentives for hospitals/clinicians to adopt new technologies within the NHS, and for Space the need to integrate data and solutions with other datasets and approaches to visualisation.

Table 9-1: Gap analysis and potential solutions

Gap/issue	Solutions, recommendations and further observations
Common to all four themes	
Skills and labour retention and shortages	Oxfordshire is a supplier of specialist skills to the rest of the country. Whilst Science and technology focused Oxfordshire business are keen to retain Oxfordshire graduates locally in our clusters, it is important at the same time to increase training in specialist skills nationally, as well as in Oxfordshire. There is a strong case to increase the availability of generic skills (e.g. digital, data analytics) and for new courses (e.g. quantum computing or artificial intelligence) It is also essential to ensure Oxfordshire's universities, research organisations and companies can continue to recruit the brightest and best from overseas without undue bureaucracy and delays
High housing costs, which add to labour supply issues	Implement Local Plans to build more housing in Oxfordshire, to enable more people to afford to live close to their work. National housing investment should include 21st century 'smart technology'. The challenge of future proofing investment, when we expect digital solutions to disrupt domestic, social and business activities, is perhaps the biggest challenge for infrastructure strategy.

Gap/issue	Solutions, recommendations and further observations
Uncertainty in the continuation of EU funded research programmes	Taking action to support and preserve the rich culture of science and innovation through funding, and as far as possible continued engagement in and leadership of European programmes.
Greater co-operation and collaboration between different sciences	Overcome traditional cultural barriers for inter-disciplinary collaboration. This requires an open innovation environment that brings together customers with challenges, solution providers and academia together in one environment with affordable and flexible space to allow companies to grow. Increase in innovation centres and environments around our universities and research campuses.
Autonomous vehicles	
Engagement with the public	'Driverless vehicles' are now regular front page news but studies of public awareness show both optimism and scepticism in equal measure. A programme of public engagement and responsible research run alongside our other efforts is necessary to improve both public acceptance of technology, and the importance of public consultation and engagement in R&D programmes. The combination of our living laboratory, plans for smart communities along with the leading edge social science capabilities available in Oxfordshire position us strongly to monitor public attitudes to driverless vehicles.
Investment in vehicles	Despite the high profile achieved by autonomous vehicles the number of such vehicles regularly on UK roads is small compared to US programmes where hundreds of vehicles are driving thousands of miles every day. The quality of UK efforts continues to allow us to punch above our weight, but investment in more autonomous vehicles to develop the economy would help the UK compete. As autonomous vehicle become mainstream car companies will have to expand their supply chains to include providers of specialist software and hardware. Oxfordshire companies, such as Oxbotica, are developing such technology, and could emerge as a Tier1/2 supplier to global OEMs.
Test facilities	We have identified that the strength of the UK economy and an area in which we can compete globally is the development of digital solutions. This is because the innovation cost for advanced digital solutions is lower than for manufacturing. However, we must invest to secure CAV in the UK. Our recommended strategy is to invest both in research and testing as the 'next step' towards building markets and ensuring strong, local, supply chains are in place.
Digital health	
Lack of clarity around clinical and economic data requirements	Increase clarity in regulatory and procurement processes.
Difficulty gathering clinical and economic data required by the NHS	This includes difficulties in recruiting sites, getting access to data and organising trials to gather required evidence. Connect and close the loop of data along the care pathway.
Inappropriate procurement process for digital health	Accelerate timescales for uptake and procurement processes, to avoid finding that the product is out of date by the time it is adopted.

Gap/issue	Solutions, recommendations and further observations
National adoption beyond the initial test bed sites is difficult	Companies identified the lack of incentives for hospitals/clinicians to adopt new technologies within the NHS. This leads to some firms first launching their product internationally rather than within the UK.
Market access knowledge missing for international markets	In order to access international markets, companies have to hire specific market experts or consultants in order to inform the launch of a particular product. DIT can play an important role in conjunction with these proposals
Space led applications	
Lack of integration between datasets to provide a single solution with common visualisation.	End users require comprehensive solutions that provide a one-stop shop for all their needs, rather than a mix of solutions. This is a national and global opportunity that Oxfordshire has the capability to fulfil by bringing together its variety of data sources and solution building capability.
Lack of capacity within leading research groups to apply their knowledge to commercial challenges	Satellite Applications Catapult is developing further translational activities itself and will work with the Universities and STFC to further increase their capabilities
Lack of multinational customers in the county to procure space-led data applications	Support local space related companies to promote solutions nationally and to develop export capability
Quantum computing	
Uncertainty in the technical design of the quantum computer	Working towards a blueprint for a quantum computer will build confidence.
Early quantum computing machines will have limited usefulness	Identify use cases where small quantum computing machines will have the most impact.
Lack of tools to create applications for quantum computers	Create a dedicated institute to develop software toolkits and algorithms for quantum computing.
Demonstrating the benefits of quantum computing to businesses.	More impact case studies are needed, but getting good examples takes time.

Targeted opportunities

Cross cutting opportunities

9.7 Three main areas for intervention have been identified to maximise the opportunities to exploit inter-relationships between themes, relating to places, networks and data.

Ongoing work based upon the findings of this report will develop our understanding of the gaps and opportunities, anchored in the national industrial strategy context.

Places

9.8 Oxfordshire aspires to curate a series of living labs: spaces and parts of the community within which there will be a virtuous circle between research, applications and learning. We believe Living Labs will be essential to secure the UK's digital future. Oxfordshire has specific initiatives underway which already include elements of the living lab concept, or could do so with some intervention. These include, Bicester Healthy Town, Culham Smart Community (3,500 houses adjacent to the Culham Science Centre and Culham Railway Station identified in the Local Plan); Didcot Garden Town (25,000 houses and the major refurbishment of the area around Didcot Parkway); Osney Mead Knowledge Quarter adjacent to the Oxford West End development (including upgrade of Oxford Railway Station and new housing linking the station with the £400M Westgate centre) and Barton Healthy New Town development (on the outskirts of Oxford). All of these provide opportunities for autonomous vehicles, smart living, advanced demonstrators for digital health and healthy communities some of which are already under way or part of the planning process. The planned Oxford to Cambridge Expressway will bring further opportunities, especially for autonomous vehicles.

9.9 However, the greatest opportunity that we hope to realise is in linking these distinct initiatives by creating a countywide living lab, connecting experiments in autonomous vehicles, healthy living and satellite data applications to pool data and work together. To maximize these opportunities, some funding is needed to specifically target high risk, high return opportunities which may otherwise be lost, and to enable greater engagement with local residents to secure support for change. To fully realise this will require engagement with developers and local authorities to ensure that more than “standard” roads and housing are built and a better understanding of the options. We propose that the government resource and commission the Smart Oxford group (which contains most of the appropriate technology and local authority actors) to conduct a review of Living Lab options in order to build consensus and a detailed business case for Oxfordshire's Living Lab Road Map that will deliver for the UK

Regional and national skills gaps may be addressed by bringing the research and training closer to the application points, through the living lab model. There are opportunities to engage practitioners more closely with high level training, for example through module delivery. Greater connectivity between these technologies, and cross-connections into the industry sectors which use them, may increase the career choice for individuals with the skills to develop the four transformative technologies, making such training a more attractive proposition.

Our place-based living lab model is proposed also to address the identified gap of collaboration between sciences, to accelerate innovation. This is essential in achieving the region's and UK's potential share in the competitive global markets for these transformative technologies.

Networks

9.10 Oxfordshire already has a large number of well-established networks. Many are sector focused; some are cross cutting. To strengthen the effectiveness of the cluster further, action is under way to improve support for cross theme and cross sector linkages, such as the newly established Advanced Oxford network of knowledge intensive businesses. OxLEP's Network Navigators programme has worked well with very limited resources which we would expand if more resource were available. Given the extensive activity we do not seek more networks, but we intend to use the SIA as a focus to ask existing networks to develop better cross-sector linkages.

Data Lakes

9.11 A common issue across all four themes is the need for more capacity in data analytics. Quantum computing provides the means to transform the capacity for large scale data analysis, on which the other three themes depend. The recent establishment of the Big Data Institute (BDI) at Oxford University will enhance further the local collaborative opportunities between all four themes, but more capacity is needed to train and deploy data analysts to exploit the huge benefits that data from space and quantum computing can provide in areas such as autonomous vehicles and digital health, and more generally across society.

9.12 Current and developing techniques allow useful analysis of very large aggregations of data – so called "data lakes". The BDI and the work of the Satellite Applications Catapult, as well as other activities at Culham, Harwell and Oxford are generating significant data lakes in different domains, as well as communities of experts skilled in use of the data. This locally coexisting data analytics nodes will prove opportunities for pooling of data between domains and movement of skilled people between companies and indeed sectors. We believe that Oxfordshire could become a site to establish a regional Data Lake, where interoperable systems could function across care pathways and an innovation ecosystem that brings inward investment from industry to enable improvements in health treatments and outcomes in partnership with the NHS.

Autonomous vehicles

9.13 Some specific opportunities have already been identified, including the Culham Smart Community and the DRIVEN AV project which will culminate by 2019 with vehicles travelling autonomously from London to Oxford as a public demonstration of the viability of the technology. Beyond the immediate priority of getting these projects fully operational, it is essential that support is available to transform these experiments into the mainstream of developing sustainable and attractive places, together with the infrastructure that connects them and enables them to work efficiently.

9.14 Autonomous vehicles' integration with housing development and transport infrastructure is a specific way to explore solutions to the housing challenge gap faced by the region's growth plans. Investment will be needed for the essential public consultation aspects of developing genuine solutions through the region's living labs, to inform the effectiveness of broader rollouts.

Digital health

9.15 The central issue is how to define value for a digital health product within the context of patient, clinical and economic benefit. Healthcare systems across the world are struggling with this issue, and looking to shift from a supply-driven health care system organised around what physicians do to a patient-centred system organised around what patients need: in short, moving towards outcome-driven health care delivery. Digital health will have a central role to play in this transformation.

9.16 The steps involved in building a clear definition of value for a digital health product and/or service are set out in the five stages shown in Figure 9-2.

Figure 9-2: Key stages in digital health integration

9.17 There are two proposals to deal with issues at each stage:

- *Data-enabled ecosystem for innovations*: (1) a single data lake that sits on top of existing platforms for health economies – across provider trusts, primary care and social care so that the patient pathway is a closed loop for analysis. (2) Links between the city and the rural regions – making the region work better together.

- *Support for companies across the development pathway*: Providing access to an end-to-end treatment pathway test-bed pilot where new Digital Health technologies can be tested to generate the necessary data for CE marking or gathering RWE.

Space led data applications

9.18 To achieve the goal of 10,000 jobs in space-led data applications in Oxfordshire by 2030 the above gaps need to be addressed. The focussed workshop on the space-led data applications theme, discussed how to enable organisations to offer a single solution integrating capability from a number of organisations and increasing the capacity to address multiple challenges. The conclusion led to two proposals:

- **An application focussed geospatial data analytics Centre**. This would bring all the Oxfordshire based organisations together to develop applications in parallel on common datasets. This would help to address the lack of capacity in research groups by providing more translational capability. It would also address the identified gap of data integration, regionally and nationally, for development of better integrated and coordinated solutions services. Such strategic development of integrated solutions is intended to enhance the region's inward investment proposition.
- **A Disruptive Innovation for Space Centre that would encourage companies** capable of developing new sensors and platforms for use within the space sector (e.g. small satellites) to work closely together to drive step changes in innovation. This would draw on technologies from outside of the sector that could benefit the space centre, this is likely to link directly to the other themes in the SIA.

Other activities that the SIA process continues to support and encourage are:

- **Continue to focus and promote** the Harwell Space Cluster, this will include continuing to encourage inward investment (a third of employees at the Harwell Space Cluster work at inward investing companies, e.g. Thales Alenia Space and Deimos UK)
- **Improved marketing of the region and its assets and capabilities,** highlighting Oxfordshire as the "place to solve complex problems". This could include a catalogue of services available in Oxfordshire.
- **Focus on medium-sized company retention** through ensuring support and the availability of facilities as they grow.

Technologies underpinning quantum computing

9.19 If the UK remains at the forefront of international competition to develop a quantum computer, it will be an outstanding opportunity for economic growth in the UK. Such growth, export opportunities and international competitive advantages will derive from a new quantum technology industry itself and also from the new capabilities, quantum computing will offer to existing UK-based business sectors. To grasp this opportunity for global leadership in a transformative industry we must strengthen the NQIT project in the near to mid-term and develop a long term strategy for the future.

9.20 A key opportunity for the UK is to further build upon the collaborative strengths of NQIT and establish a dedicated National Quantum Computing Technologies Centre linked to key organisations and institutions across the country. Based in Oxfordshire, this ambitious vision will be the first of its kind for the UK and will be unique in the world, attracting talent and industry both nationally and globally.

9.21 The Centre will have the following mission:

- To be a globally trusted source of quantum computing;
- Champion and showcase quantum computing for the UK in a globally emerging but highly competitive sector;
- To host the UK's networked quantum computing infrastructure, the start of a new industry for the UK;
- To encourage and enable UK industry transition to quantum computing applications and give a decisive international advantage by providing a dedicated centre for quantum algorithms and data analytics;
- Grow the UK quantum economy through a variety of commercial activities, including industrial engagement, attracting investment and bringing new advancements to market;
- Continue the excellence in research to advance quantum computing and its underpinning technologies, working with universities and organisations across the UK in a national framework. These include the photonic industries in the Glasgow and Innovate South regions and the Compound Semiconductor Applications Catapult in South Wales.
- Drive a national skills and training programme for education, research and industry with key stakeholders throughout the UK. This should include apprenticeship schemes and secondments with the aim of distributing skills to other regions;
- Continue the work begun by this consortium and forge links across different sectors and disciplines in the region and beyond.

Follow-up SIA exercises

9.22 Some of the possible sector areas not selected for this SIA (such as bio-sciences) have indicated that they would be interested in conducting further Oxfordshire SIA exercises in their sectors. We suggest that, post wave 3, the government introduce a rolling programme of SIA exercises that allow further data gathering by interested local groups to add to the resources available for planning industrial strategy.

A note on Data Gathering on businesses

9.23 During this exercise we have found it much easier to access data on national science activity through universities and government bodies than to gather data on business and business activities. Discussions with other SIAs have revealed the same challenges. In many cases the data we sought did not exist, or where it did exist it was categorised in such a way that it was not useful for our purposes. Data on businesses tends to be organised along more traditional business sector lines, and does not read across to the sort of future-facing science and technology derived industries that we (and many other SIAs) have been considering. We would urge the government to invest in a national effort to improve data on business activity across all science and innovation areas, drawing on lessons learned from SIAs. Such an effort would provide better data for future similar exercises, and would support implementation of the industrial strategy.

Annex A: stakeholders involved in the SIA process

The process of producing this SIA has involved close collaboration between members of the core consortium (OxLEP, Oxford Brookes University, University of Oxford, STFC, UKAEA, the Satellite Applications Catapult, and Oxford AHSN) and the involvement of a wide range of industrial partners and other stakeholders. This has been conducted overarchingly at the level of the whole SIA, and also at the theme-specific level. This has involved the active participation of a total of 33 industry representatives, and 18 non-business organisations, many of which have a business representation role and are in regular contact with business regionally, nationally, and internationally (listed under Figure A-1 below).

Four other LEPs (Thames Valley Berkshire, Greater Cambridge Greater Peterborough, Enterprise M3 and North East) were also included in the wider, active grouping because of the strong inter-relationships within the four themes between research and innovation organisations in Oxfordshire and each of these other regions.

A Strategic Advisory Board was convened, comprising senior representatives of the business, research and academic communities, in Oxfordshire and more broadly across the UK, and with insights into global trends, markets, and opportunities. This Board included representation from the LEPs named above.

The Strategic Advisory Board:

- Dr Sarah Bee, RouteMonkey
- Dr Tim Bestwick, STFC
- Dr Steve Chappell, Oxford Instruments
- Lord Paul Drayson, Drayson Technologies Group, and member of Council, University of Oxford
- Dr Stuart Martin, Satellite Applications Catapult
- Mr Laurent Morlet, Johnson & Johnson Innovation
- Professor Ray Ogden, Oxford Brookes University
- Mr Richard Peckham, UKspace
- Chair: Professor Ian Walmsley, University of Oxford; Chair, OxLEP Innovation Sub-Committee

The SIA has been further informed by exploring complementarities and opportunities for national benefit, with other regions, notably the Midlands Engine SIA and Glasgow Economic Leadership SIA.

The Strategic Advisory Board, or a body of broadly similar stakeholder representation and purpose, will continue to oversee initiatives resulting from the SIA.

Theme-specific level collaborations

The Oxfordshire Transformative technologies Alliance SIA has been substantially informed by companies and non-business organisations, senior representatives of which attended SIA-specific collective workshops and meetings (or participated remotely) for the development of hypotheses, and to inform data and evidence acquisition, to advise on global national capacity and global competition and opportunities, and to develop strategy and solution propositions.

Figure A-1

* denotes the 18 non-business organisations, most of which have a business representation role and are in regular contact with business regionally, nationally, and internationally.

Connected and autonomous vehicles (CAV)

	Representative	*Company / organisation*
1	Head of Strategic Development	Siemens
2	Director Smart Data and Technology Consultant	Amey
3	Chairman and CEO, Zeta Specialist Lighting	Zeta Group
4	Research Fellow	Nominet
5	Academy Director	TRL (Transport Research Laboratory)
6	Director	Arup
7	Director	Ernst & Young
8	Director	Hausmate
9	Various	Oxbotica
10	Coordinator	* Smart Oxford
11	Researcher	* Transport Systems Catapult
12	Senior Innovation Fellow	* Satellite Applications Catapult
13	Autonomy Lead, Project Manager	* STFC
14	Head of Dept of Computing and Communication Technologies, and lead academic in Artificial Intelligence	* Oxford Brookes University
15	Service Manager; Infrastructure, Innovation & Development	* Oxfordshire County Council
16	Enterprise Zone Manager	* Vale of White Horse and South Oxfordshire District Councils
17	Head of Regional Engagement and Corporate Projects	* Cranfield University
18	Director, and Lead Technologist	* UKAEA: RACE

Digital Health

	Representative	*Company / organisation*
1	Director Health and Life Sciences	Microsoft
2	COO	Brainomix
3	Director	The Hill Oxford
4	Medical and Environmental Sciences Director	Drayson Technologies
5	CEO	Drayson Technologies
6	CEO	Isansys
7	Director	SQW
8	Innovation Delivery Director	Oxford Computer Consultants
9	Head of Innovation	Perspectum Diagnostics
10	Director Digital Health - New Ventures	Johnson & Johnson
11	Sales Engineer	Intersystems
12	MD	Incuna
13	Knowledge Transfer Manager	* KTN-UK
14	Dept of Computing & Computing Technology	* Oxford Brookes University
15	Research & Business Development Office	* Oxford Brookes University
16	Director of Commercial Development	* Oxford AHSN
17	Deputy Head of Technology Transfer - E-Health and Bioinformatics	* Oxford University Innovation
18	Project Officer, Knowledge Exchange and Impact	* University of Oxford
19	NQIT Technology Associate	* NQIT

Space-led data applications

7 companies were directly involved in the formation of the conclusions for the Space-led data applications theme (Airbus, Deimos UK, ERM, GMV, HR Wallingford, Satellite Applications Catapult, SeaSpace Research), along with 3 universities (Nottingham, Oxford, Oxford Brookes) and 9 organisations (CEH, European Space Agency, KTN, Oxford University Innovation, Oxford AHSN, NQIT, STFC, UK space Agency, USAF).

Many of these organisations are in regular contact with businesses (large and small) in the Oxfordshire area and beyond, so were able to reflect their views, for example ESA, Satellite Applications Catapult and STFC regularly meet the 75 space organisations at the Harwell Space Cluster.

1	SeaSpace Research
2	GMV
3	HR Wallingford

4	Deimos UK
5	ERM
6	SQW
7	Airbus
8	CEH
9	* USAF (United States Air force)
10	* STFC
11	* Oxford AHSN
12	* European Space Agency
13	* Satellite Applications Catapult
14	* University of Nottingham
15	* UK Space Agency
16	* Oxford University Innovation
17	* Oxford Brookes University
18	* NQIT
19	* University of Oxford
20	* KTN-UK

Technologies underpinning quantum computing

1	QxBranch
2	Routemonkey
3	Gooch & Housego
4	e2v
5	Oxford Instruments
6	* NQIT
7	* University of Oxford

QxBranch - (start-up quantum computing & data analytics)
Routemonkey - (start-up logistics and early customer of quantum algorithms)
Gooch & Housego - (parts of the supply chain)
e2v - (parts of the supply chain)
Oxford Instruments - (parts of the supply chain).

Annex B: High level business cases for key interventions needed to realise opportunities and/or address gaps

Quantum technology critical mass attracts global quantum tech business

UK National Quantum Computing Centre
The UK will build a Quantum Computer by 2021. £250M from public and private funding is needed to create the essential infrastructure to run the first fully functional quantum computer demonstrator. This will keep the UK among the global leaders in quantum computing, and will generate business. • Build a quantum computer • Develop, test, and prove the data applications and services which quantum computing makes possible for industry and governments • Give the UK a global lead in *developing and applying* the technology, including component manufacture in UK industrial heartlands • Scale up the technology and services, for UK benefits and for global markets • Export UK technology, services and expertise, as transformative solutions and rollout packages Quantum technology is being developed in many countries. The UK has a global lead, which can be maintained. We are approaching the point of assembling the first quantum computer in the UK, and we need to prepare the infrastructure to do so, and – crucially – to generate business from it. This will require a national focal point, where components will be assembled, and where theory is put into business-ready practice. This will secure the investment interest that has been generated, to make the technology applicable, and scalable.
1: Strategic Case Quantum computing is an inevitable technology. There is a global race to build functioning quantum computers, with significant international security implications. Early breakthroughs, by companies or nations, may be prohibitively expensive, or not for sale. In the information age, quantum computing brings a new age of opportunities, and threats. The UK's participation - at scale - is crucial. Much UK work is done in relative isolation, without regional critical mass to secure interest from international technology participants, investors, and agents of change. The UK needs a focal point: a geographic consolidation, for speed and efficiency in developing the technology, and for critical mass to establish a national centre where

the technology will be applied, and interested companies will need to locate.

There are two current quantum computing technologies yielding promising progress in creating a quantum computer, with scalability. These are “superconducting circuits” (the technology being researched by Google and IBM) and “ion traps” (being developed in the UK by NQIT).

The software and services which will run under a quantum computer are relatively unaffected by which of the two technologies achieves dominance. As is true with conventional computing (or comparable technologies such as communications), the software and services are expected to contribute more to workforce development, business applications and benefits, and to the UK economy, than are hardware development and sales.

The UK has achieved a strong global position in quantum technology, through early advantage and concentrated research excellence. A consolidated national strategic effort, with consistently prioritised funding, is essential if the UK is to gain the economic and social benefits of this global position by exploiting the technology here, rather than allowing commercial exploitation of UK ideas to be done overseas.

Early movers in developing a skilled workforce will be in a position to export technologies, skills and services.

A UK National Quantum Computing Centre will position the UK as a global player, and leader.

2: Economic Case

Outcomes and benefits of the project

The UK National Quantum Computing Centre will yield £100M/year contribution to the UK economy, in real terms, by 2023. 100,000 new UK jobs will be created.

Of these, £10M/year in income and 10,000 jobs will be in Oxfordshire.

Quantum technology will increase business efficiencies. Through this SIA, there will be substantial early benefits in digital health, autonomous vehicles, and space-led data applications.

Quantum development will benefit other sectors and global challenges, e.g. energy, and land management.

Industry and government will benefit by ensuring the economic and social impacts of the technology are captured for the UK, rather than lost overseas. This has huge implications for increased productivity and efficiency across many economic sectors.

As quantum technology becomes prevalent, software & services will become a major part of the workforce. Developing a workforce skills base in quantum technologies, early on in the global development of quantum computing, will place the UK in an excellent position to take a global lead in exporting applications, services, and expertise. Customers are likely to include government administrations as well as companies.

There are two potential quantum technology types: “ion traps” and “superconducting circuits”. The UK is leading in the ion trap approach. High R&D investment costs make it prohibitive for economies to invest significantly in both types. National investment of at least £500M would be needed to catch up with globally leading superconducting circuits R&D (led by Google and IBM). There is currently no expectation that either approach offers a more likely solution.

Alternative locations

The reasons for concentrating quantum technologies investment in Oxfordshire are based on the criteria for success and value of investment.

- **Effectiveness and value** are underpinned by excellence and capacity in machine learning, Artificial Intelligence, cybersecurity, and other data technology services and dependencies.
- **Existing capacity** and commitment is already at the forefront of the UK’s regional capacities: the region is already a national strength.
- **Scaleup**, including investment combined with public engagement and endorsement, depends upon test beds, and is greatly enhanced by living labs. (Didcot and Bicester initially. Then wider, through the Healthy New Towns platform). The comparative advantages of Oxfordshire in supporting scale up will be (i) the ready availability of specialist expertise; (ii) the availability of long term risk capital; (iii) the specialist environments in which scale up can be managed, delivered and demonstrated, including the living labs.
- **Delivery** is dependent upon determined leadership (Harwell and University of Oxford, and the region’s ability to attract internationally outstanding CEOs for new companies), and workforce satisfaction (Oxfordshire is a desirable place to live)
- **Economic benefits** depend upon technology transfer effectiveness (OUI, spinouts) and investment attraction (OSI, and regional venture capital excellence), with global reach. Oxfordshire is a net contributor to the national exchequer.
- **Spillover** benefits are greatest where there is excellence in innovation in related science areas and technologies (our breadth and depth of excellence, with large capacity, is shown through REF and R&D investment).

Weakness in any of these criteria would increase risk and could compromise the intervention proposition. Our SIA’s region is excellent, by national and international standards, in all criteria. Developing comparable skills, capacity and infrastructure elsewhere in the UK would require greater investment, with greater risk.

Many UK regions will benefit from the scale up of technology and services made possible by the early development of a full scale, operational quantum computer in Oxfordshire.

3: Commercial Case

The Oxfordshire region has proved effective at generating capacity in high-tech sectors, such as life sciences and motorsport. Harwell Campus is home to 200 high tech companies. Harwell can deliver infrastructure, pull, and access to users.

Oxford University Innovation is Europe's most successful University-based technology transfer organisation.

4: Financial Case

Investment proposition for the UK National Quantum Computing Centre

Total investment: £250M to 2021. £400M to 2023.

We expect part-funding from industry, leveraged with national investment.
Input: £100M national investment over 3 years, to secure £150M private and regional investment over 3 years, rising to £300M over 5 years.
Outputs: £250M demonstrator centre and cluster of companies by 2021. £400M-scale national, functional quantum computing hub by 2023. Huge downstream economic impacts and benefits resulting from being the leaders in the application of quantum computing to other sectors such as financial services and aerospace.

Investment will achieve

- Running a warehouse sized building on the existing Harwell science campus
- Performance management and monitoring: a bank of computers with dedicated engineers
- The UK platform to test and prove applications, and to scale up

The Harwell Campus provides experienced management, human capital and infrastructure, well connected to national and global clients and investors. Investment here will be highly cost-effective.

The physical computer is made of multiple modules, each consisting of an ion-trap, vacuum, lasers and microwave systems optics, electronics, power supply, and cooling. A functional quantum computer - that will solve research and industrial problems beyond the capabilities of conventional computers - will need 50 x 5 qubits ('quantum bits') modules.

- Each module is estimated initially to cost £250,000 to build, decreasing to £200,000 over a 3-year period as the technology and manufacture becomes better understood.
- Phased, modular manufacture achieves early functional demonstrator capacity, attracting investment as applications for the technology are developed and proven to function effectively

The Centre will offer business training, apprenticeship schemes and consultancy services. The services solutions will develop as a national and global sales model.

The Hub will be a nucleation point, attracting global interest and engaging with public, industry, investors and government. It will create and demonstrate the next generation of computer-relevant solutions, for business, science, government, and leisure.

5: Management Case

- NQIT Oxford has been established, using public funding, as the national hub for early investigation and consortium building in quantum technology, in conjunction with other UK centres and hubs.
- Oxford University Innovation is Europe’s most successful University-led technology transfer office.
- The region attracts internationally experienced and innovative CEOs.
- Harwell Science Park has extensive, proven management capacity for global scale exceptional technology (the Diamond Light Source is an example).

Building a UK CAV Ecosystem and embedding CAV into the UK's next generation of smart infrastructure

Living Labs to Test CAV: Culham Smart Community
The £51Bn estimated value of CAV to the UK economy is largely based on indirect impacts rather than design and manufacture of CAV themselves. When deployed widely CAV will have a disruptive impact on transport of people and goods in both the public and private spaces. We expect CAV to have an impact on national infrastructure spend affecting housing and transport as well as the design of hospitals, transport termini and industrial facilities. The societal change envisaged is no less than a revolution and indeed the development of robotics and artificial intelligence has been called the next industrial revolution. Whilst companies will develop an amazing array of products and services it is essential that those responsible for 'making it all work together' have enough evidence to make timely decisions. We believe that this will require significant investment in Living Labs to collect verifiable evidence in much the same way that drugs are not released onto the market for public consumption without establishing both efficacy and also side-effects. Culham Smart Community has been proposed as a new housing development adjacent to the growing UKAEA's Culham Science Centre site that will address local housing need. The site is adjacent to the under-utilised Culham Railway Station that provides rapid links to employment sites in Oxford, Reading and London. We propose that this housing and transport infrastructure receives extra investment so that developers build a smart community to explore the community impact not only of CAV but of other smart technologies too. Such a living lab will attract multinationals who are developing digital solutions and businesses as well as investors and of course those who wish to learn from and replicate successes. Furthermore this community is ideally placed to become a node in a national plan that invests in Didcot Garden Town and Oxford West End as well as the transport infrastructure including the Oxford Cambridge Expressway. A 21st century challenge for the UK is how to compete in global markets whilst at the same time integrating new and old infrastructure. Living Labs have the potential to address both issues by demonstrating the solution and creating profitable enterprise that will increase UK tax revenues.

1: **Strategic Case**
Due to its complex social dynamics, population density, and variety of industrial/commercial organisations Oxfordshire presents, within a relatively small geographic area a good cross-section of the challenges that need to be addressed if CAV platforms are to be 'proven' as a viable technology. The combination of a varied network of roads including motorway, nationally significant trunk roads, urban, semi urban and rural lanes together with a canal and rail network, overlain with a vast cycling network means that the county faces pressing, real world, transport and mobility challenges of a scale that is larger than some large metropolitan cities. These challenges are however, offset by the presence of supportive local government, a vibrant CAV focused SME community, world class universities and a growing apprentice population. This mix means that Oxfordshire is a near perfect test bed for CAV technology, because vehicles can be tested in a wide range of driving environments in close proximity to thought-leading organisations and facilities. Transport is rarely disconnected from housing and facilities and we expect future car ownership models will have an impact on use of land for garages as well as roads and parking. In turn this will change house and facility design. In a world of digital disruption foreknowledge of impending change will be essential.
2: **Economic Case**
Estimates of the impact of new digital technologies are typically 'trillions' globally and 'billions' for national economies, but the assumptions that drive these estimates are hard to substantiate. For instance, it has been proposed that CAV may be part of a Digital Health revolution that enables preventative health case rather than reactive treatment. Primary benefits are that the technology can bring forward in time the realisation of fuel savings, reductions in accidents, productivity gains, reduced congestion, and transformation in the way we view and access mobility services.
3: **Commercial Case**
This rests on both the ability to meet a national and local need (lack of housing and road congestion, poor air quality) in ways which attract both housing and transport investment and also commercial supply chain interest to relocate to the area. Because these issues are of global importance there is significant opportunity to attract global inward investment.
4: **Financial Case**
We estimate that we would need to invest an extra 20-30% over and above the cost of a 'standard' housing development. There is also a need to address local road infrastructure including a new bridge over the River Thames that will enable a link

between the overloaded A34 near Harwell via Didcot, Culham and beyond to the M40, all south of Oxford. Addressing these issues piecemeal will create islands of innovation that will under-deliver on impact.

5: Management Case

Delivering such a project requires huge support. Within Oxfordshire we have built this support with councils, universities, national labs and industry and we have the ability within our universities, industry and national labs to deliver large and complex projects. Of course we would want to link with other centres of excellence across the country both to work with the most capable partner, and also establish exploitation routes to ensure that learning is rapidly disseminated and that resulting jobs and growth are distributed nationally. Integration of the work and sustaining the appropriate partnerships places a high demand of the central hub or management capability.

Development of test-bed infrastructure for development and testing of Digital Health products and solutions:

a Digital health accelerator pathway to support local innovators and attract global digital health companies

Digital Health Regional Test Bed
The aim would be to build an end-to-end regional pathway and test bed for innovators and companies to accelerate their products and services more rapidly from concept to market. The challenges facing industry in accessing the NHS include a clear understanding of the problem to be addressed in healthcare delivery, the generation of clinical and real world evidence, and effective strategies to support adoption of new digital health solutions at scale and pace. The Oxfordshire test bed would provide the necessary support infrastructure, access to resources and expertise, and care settings that would accelerate a company's journey along the whole development pathway. This support would enable companies to generate the necessary evidence (clinical, real world and economic) to form a robust business case for adoption of the digital health solution into the healthcare system, and provide a springboard for national adoption as well as international commercialisation strategies. Spillover benefits and economies of scale can be achieved by co-locating and linking digital health technology development with complementary transformative technologies, in collaborative "Living Lab" test beds and demonstrators (see, for example, Culham Smart Community CAV Living Lab).
1: Strategic Case The rapid growth of digital health across all types of care settings will provide opportunities for improved patient outcomes, health system benefits and efficiency gains. The aim of the test bed will be to: • Accelerate the path to market of digital health innovations, and ensure better adoption of fit-for-purpose products and services • Provide a joined up ecosystem across the whole development pathway that will provide a one-stop shop for companies • Attract inward investment from companies that will see Oxfordshire as a launch pad for development and commercialisation of digital health • Enable the regional healthcare system to have access to best in class digital solutions that will provide savings to the NHS both at a regional level and nationally as uptake is accelerated across the country • Build on the opportunities for technology convergences and synergies within the digital space to make Oxfordshire a hub for knowledge exchange and translational development of new digital health opportunities, for example, AI, Big Data, virtual reality, human factors design Oxfordshire is a strategic focus region for this innovation priority because: (i) there is already a strong presence of large and small digital health companies

(ii) two NHS Trusts in Oxfordshire (Oxford University Hospitals NHS FT Oxford Health NHS FT) are Global Digital Exemplars, providing strong institutional and market support for the initiative

(iii) Oxfordshire's outstanding track record in attracting inward investment by innovative firms and people

2: Economic Case

Significant benefits have been identified through the creation of an additional 300,000 jobs by 2030 (of which 33,000 in Oxfordshire) and NHS savings of £1.8 billion across the system. Across Oxfordshire the test bed will provide a significant boost to the UK's market share of global revenues.

The strategy will also support the creation of new Unicorn businesses and it is estimated that 6 new £bn companies will be created by 2030, along with an additional 450 digital health companies across the Oxfordshire and Thames valley region.

The test bed will also provide an opportunity to create new international partnerships with key hubs across the globe in high growth markets such as the United States (East and West Coast), Europe, China, India and other emerging economies. These digital health partnerships will help create two-way flows of ideas and products, thereby offering more rapid strategies for international commercialisation.

Equally significant will be the opportunity to realise a vision of a healthier population across Oxfordshire supported by digital solutions that provide early warning monitoring for disease onset, improved health management of chronic diseases, and improved care pathways across secondary, primary and community care.

3: Commercial Case

The industrial, academic and NHS ecosystem is served by the Academic Health Science Network at a regional level, and through the Academic Health Science Centre which provides a platform for translational research across the two universities and the two NHS providers. Greater connectivity between the various stakeholders offers an opportunity for both organisations to provide a connected development pathway from concept to market. The Oxford AHSN has developed a digital health pathway and has the capability to integrate all the key elements along the pathway in collaboration with the university and NHS partners.

Bottlenecks, in the digital health pathway's route from science to market, are recognised by innovators, companies, the NHS, and other stakeholders. These include (i) clinical pathway mapping, (ii) fit-for-purpose clinical development, (iii) evaluation and the generation of real world evidence, (iv) health economics and pricing, and (v) generation of a viable commercial/financial model, which takes into account national and international markets. The commercial incentives to address these barriers are recognised by stakeholders, including the potential for NHS savings of £1.8 billion across the system by 2030.

4: Financial Case

Currently there is limited funding for this approach through the AHSN budget and proposals under consideration in the Accelerated Access Review. However, neither will provide sufficient funding to implement this opportunity at scale and pace so that a portfolio of digital health opportunities could be accelerated within the test bed. Additional funding would be required to build capacity and capability.

Investment proposition:

£50 million over 5 years to 2022, £100 million to 2027.

Investment of £10 million per year would provide sufficient capacity and capability to take through up to 20 digital health products and services on the pathway per year. This funding would be matched by industry on a minimum of a 1:1 basis, thereby increasing the combined investment to £100 million over the next five years.

5: Management Case

The opportunity is achievable. Oxfordshire has the necessary skills to implement the test bed although some scale-up and training would be required to deliver the numbers set out above. In particular expertise in health economic and change management skills across complex healthcare systems would be required.

The necessary management and operational skills are available to support this scale up, and the Oxford AHSN is already running courses in areas such as practical adoption of innovation in the NHS, supported by the EIT Health programme. The brand and skill base in Oxfordshire will ensure that there is a supply of individuals with the necessary background skills to be able to fill the gaps.

Analytical power solutions: a consolidated approach to developing globally applicable and attractive data analytics, products and services

Geospatial Analytics Centre
The aim is to establish a geospatial analytics centre to transform the application of advanced data analytics such as machine learning, computer vision and big data analytics to complex geospatial datasets. These have application across a wide range of challenges from transport, water, energy, agriculture, marine and other sectors for businesses, governments and others. Oxfordshire is a rich resource of datasets and compute and storage facilities, however the widespread advanced analytics expertise, especially in the University of Oxford, has only just begun to be applied in small projects to individual challenges. Whilst the county has the potential to be world-leading in this area, there is yet to be the critical mass of activity to attract graduates to remain in the county and for this to leverage substantial inward investment. Key partners in the centre will be the University of Oxford, Satellite Applications Catapult, NERC Centre for Ecology & Hydrology and STFC, working with a group of interested companies.
1: Strategic Case The UK Space sector target of £40Bn p.a. turnover by 2030 is predicated on 70% of the growth being in satellite applications, as compared to upstream satellite companies. This growth is being enabled by significant improvements in data storage, processing and solution provision. However, aside from standard incremental improvements in data analytics, there is an even greater acceleration pathway through the use of machine learning, computer vision and big data analytics techniques, with substantial investment in the US, in particular, going into satellite data analytics companies. Oxfordshire has the data handling and storage capabilities and domain knowledge experts for many applications, however skilled talent in the universities is not sufficiently impacting regional businesses. The aim is to deliver a new geospatial analytics capability to translate data into applications to address complex challenges in an accurate and timely manner. The objectives are to (1) develop novel business solutions, creating new businesses and empowering growth of existing businesses (2) generate the necessary skills for this area of applied data analytics, retaining and attracting talent to Oxfordshire (3) accelerate the pathway for translation of research into applications. This capability will not replace existing strengths in sector and domain-specific organisations but rather enhance their offerings and opportunities for partnerships leading to growth and impact.

2: Economic Case

The SIA has tested the potential of the county to develop new jobs both for the county and the UK. Within the aim to grow to 10,000 jobs in the county (and 100,000 in the country) by 2030, advanced data analytics will be a key enabler of this growth.

The Satellite Applications Catapult has worked with over 2,300 businesses in the last 4 years, many of which are looking to improve their data analytics capabilities. Smart analytics is now one of the main themes of the Catapult. The University of Oxford contains a wide range of research groups in data analytics (>900 researchers) and is part of key UK initiatives including the Alan Turing Institute. An investment in making the most of these combined strengths and opportunities to develop new solutions for challenges of rapid, accurate insights for decision-making, automation of systems and handling complexity, will yield significant dividends for Oxfordshire and the UK.

An investment of £40m could lead to more than £400m in business value, bringing a further 2,000 jobs to Oxfordshire and 10,000 to the UK.

3: Commercial Case

A new partnership approach will be needed to establish the centre which will comprise a combination of state-of-the-art laboratories and specific breakthrough projects designed to transform data analytics and develop novel solutions. The partnership will comprise the leading source of data analytics expertise (University of Oxford) and the leading body for commercial development and support of geospatial data solutions (Satellite Applications Catapult) working together closely and with the skills and facilities of STFC and the NERC Centre for Ecology & Hydrology in managing and processing complex environmental datasets.

This activity will build upon several smaller scale collaborations between the partners in machine learning, computer vision and optimising data handling and processing.

Whilst these organisations will be the hub for developments, a wider range of organisations and partners in county and across the UK will be engaged to ensure that the regional benefits are leveraged for the nation. The majority of these developments will also have significant international impact as the UK is at the leading edge and is well-connected. It will be vital to ensure global impact through international partnerships and projects.

4: Financial Case

The financial support for the Centre will be £40m over 5 years, with an initial outlay of up to £15m to ensure buildings and facilities are made ready and available for activities. As far as possible, the Centre will make use of existing facilities in each of the main areas in the county (Oxford, Harwell and Wallingford).

A budget of £35m for breakthrough projects is based upon the funding of large-scale long-term projects which enable the development of new

capability and its translation into practical solutions. This is not primarily research funding, although research is likely to form a minor component of several projects. The funding is to be focussed on translating the knowledge through, for example, software development from algorithms to develop applications. Projects are likely to range from £3-7m and be 4-5 years in duration. They will often feature several components which together can form a capability for future exploitation both in terms of analytics techniques and in terms of highly skilled people. It is estimated that the £40m will leverage co-funding of at least another £40m into these projects together with a further £40m spent within partner companies. However, the major impact will be the generation of high growth businesses and substantial inward investment from software, data and satellite companies into the region and the UK, yielding a further £320m value to the economy. The ongoing running of the centre beyond 5 years will be through a combination of commercial and grant funding.
5: Management Case The investment in a geospatial data analytics capability will be a stimulus to the region in terms of its capabilities. However, it is not anticipated that a further separate entity should be delivered under this initiative but rather that hubs and spokes will be developed through competitive processes that will enable the development of expertise around specific capabilities. The funding will therefore be distributed between the partner organisations and their collaborators through existing contract and grant funding mechanisms. The management of the Centre will be through a Steering Group of partner organisations, with legal responsibility for delivery with an independent industry chair, supported by a business-led advisory board. The organisation will be driven by the pull from businesses for commercial solutions, supported by new research-led developments that will be translated into practical solutions.

Disruptive Innovation for Space Centre (DISC)
The Satellite Applications Catapult is seeking to create a Disruptive Innovation for Space Centre (DISC) to tackle a number of critical challenges faced by the UK space industry to speed up the process of design to prototype and testing to low volume production. DISC will bring organisations with expertise together to drive innovation across this process and enhance the translational capacity from academic research to commercial realisation.
1: Strategic Case The current pace of change in the space sector is leading to significant opportunities for equipment manufacturers. However, businesses looking to scale up production to fulfil demand from the new generation of satellite constellations are discovering high capital costs for upgrading production facilities, which are not justifiable for just one large order. DISC will ensure the integration of existing solutions and, with the equipment and expertise in one place, increase the capacity of organisations to develop new innovative solutions and grow their businesses. DISC will also support the creation of new university start-ups and technology transfer from academic research into industry through the co-location of research groups from the University of Oxford and others inside the DISC. This will provide increased capacity for translational research. It will address the UK skills gap via a dedicated apprenticeship scheme and formal ties with Didcot UTC.
2: Economic Case The 'Size & Health of the UK Space Industry' December 2016 Report[196] showed the industry continuing to grow ahead of the UK economy, reaching £13.7 billion of total income, an annual growth of 6.5%. The Space Innovation and Growth Strategy is targeting 10% of the global space industry by 2030, which could imply £40 billion of UK space industry revenue. To address this rapidly growing market at a time of considerable change in the space industry the UK needs to be at the cutting edge of developments and using a cross-section of expertise. DISC will put the tools and the co-location of organisations in place to enable UK businesses address these challenges and deliver the anticipated growth.
3: Commercial Case Over the past two years the Satellite Applications Catapult has consulted with over 100 companies about DISC and has received a consistent message that the challenges are real and the solutions offered by DISC will deliver major benefits to UK businesses across the country. It is also proving to be an important draw for inward investors.

196 London Economics: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/575769/Size_and_Health_summary_report_2016.pdf

Supported by Innovate UK, the Satellite Applications Catapult, has already created interim-DISC, which provides specialist equipment at existing facilities to industry and academia to enable collaboration on design, development, simulation and first stage manufacture of products targeted at addressing capability gaps in the downstream market. This will demonstrate the potential of DISC and the latent demand for it.

4: Financial Case

DISC requires a £50 million investment in capital costs over four years, with annual running costs at the end of that period in the range of £1.5-2 million. DISC would be self-financing by 2022 as companies pay to use the facilities and capability. DISC will attract 250 space and non-space organisations to Oxfordshire during the first five years of operation, delivering a regional impact of £50 million per annum in revenues and 500 new jobs by 2022. This forecast assumes an average of 250 organisations pass through the DISC every five years, consistent with the results of our consultations and market analysis. Extrapolating these figures over 15-years, it is estimated that the DISC will stimulate £400 million/annum and 4,000 jobs in the region by 2035. It will also contribute to a further £600 million/annum and 6,000 jobs as disruptive innovation penetrates the wider domestic and export markets.

DISC will deliver at least 12 separate business collaborations within the first year of operation and establish more than two new supply chains by the end of the second year of operation.

5: Management Case

Satellite Applications Catapult’s interim-DISC capability is ongoing and already working closely with the High Value Manufacturing Catapult to prove the DISC concept. It is envisaged that DISC will be set up as a separate entity by the Satellite Applications Catapult, which will encourage other organisations within Oxfordshire and beyond to get involved and drive disruptive innovation.

DISC will develop solutions determined by market led requirements associated with UK launch capability, Wireless Interoperability for Next Generation Systems (WINGS), Robotics and Autonomous Systems (RAS) etc. DISC would work with existing partners, including other Catapults, Harwell Cluster organisations, academia across the UK to provide the opportunities for companies across the UK to benefit from DISC and drive new supply chains across the UK.

Combining Transformative Technologies for Novel Solutions to societal needs

The Transformative Technologies Cross-disciplinary Living Laboratory

Oxfordshire is a hotbed for transformative technologies in Connected Autonomous Vehicles (CAV), Digital Health, Space-led data applications and the emerging technologies of Quantum Computing. However, many of the real-world benefits of these technologies will be derived by exploiting them in combination – for example intelligent transport infrastructure that is aware of the current local environment or AI assisted tele-medical healthcare interventions.

To develop such multi-discipline applications to the point where they are commercially viable and can be rolled out to the general population will require a representative real-world test bed, or Living Laboratory, where the relevant expertise can be brought together alongside the necessary infrastructure. This could be incorporated, for example, into the new housing development at Harwell where specific challenges could be addressed. Specific, high-impact challenges would be identified, followed by a comprehensive horizon scanning of available technologies that would address these challenges in the most efficient way.

This exercise would establish specific projects to test and develop within the Living Laboratory.

1: Strategic Case

Technology advances across several fields can by exploited in combination to greatly magnify the economic and societal benefits in, for example, transport, healthcare and management of resources and the environment. The creation of a dedicated living laboratory will accelerate the development of combined sector applications and stimulate new thinking to further exploit their combined impact.

It will:

- Create an action tank that brings together experts from diverse fields to identify opportunities, along with community-based networks that can interact and provide input
- Involve and forge collaborations between a broad range of industries associated with the technological pillars
- Accelerate the adoption of multidisciplinary technologies within novel solutions creating economic impact and public good across the UK
- Provide a joined up ecosystem across the whole development pathway that will provide a one-stop shop for companies
- Attract inward investment from companies that will see Oxfordshire as a launch pad for development and commercialisation of cross-disciplinary solutions to societal challenges

2: Economic Case

The economic case for a Living Laboratory is driven by a number of factors:

- Investment in the testing and real world evidence generation for a range of products and services that have been developed by industry; this not only applies to businesses within Oxfordshire, but also to those with a national and international footprint. The application of multi-disciplinary technologies in a real world context is likely to be very attractive to industry, especially when synergies and business sector connections can be developed across the four key themes of the SIA
- Living laboratories will also provide a means to identify system and societal challenges, such as healthy ageing, maintaining independence in old age so as to reduce social care costs, and in preventative approaches to the onset of chronic diseases. Other applications could include linking environmental monitoring with health prevention activities and AV opportunities. Significant savings will be generated through health prevention and public health, enhanced monitoring and data analytics.
- By building a living laboratory that draws on capabilities across Oxfordshire, international businesses will be drawn to the opportunity through the unique combination of technology offerings that will available.

3: Commercial Case

There will be a need to develop an organisation to pull together and manage the various opportunities that will be presented through the Living Laboratory. This will necessitate the creation of new partnerships across multiple stakeholders, drawn from different sections of the ecosystem, including industry, academia, the local councils and the NHS.

4: Financial Case

Currently there is no funding or dedicated infrastructure to encourage the development of new services and capabilities across technology silos. Such a stimulation is needed to encourage the commercial sector to collaborate across discipline boundaries to develop novel solutions and provide core, common infrastructure that will allow such applications to be trialled, developed and tested ahead of full commercial roll-out.

Investment proposition:

£50 million over 5 years to 2022, £100 million to 2027.

Investment of £10 million per year would provide platform funding for infrastructure and real-world trials, encouraging industry to take up high-risk, high-reward challenges and close business cases for such new ventures. Industry match funding on at least a 1:1 basis would be required, thereby increasing the combined investment to £100 million over the next five years.

5: Management Case

The opportunity is achievable. Oxfordshire has the necessary skills to implement the living laboratory but additional training would be required to create the necessary cross-sector expertise and oversight of the development process. An overall coordination function would need to be put in place to ensure proactive engagement and stimulation of ideas. The unique high-end capabilities of Oxfordshire make this the ideal platform for initiating this new approach and carrying through successfully.

Annex C: case studies

Digital Health improving care while reducing admissions: Drayson Technologies partnership

Drayson Technologies is a “digital” pharmaceutical company with expertise in regulated diagnostic and therapeutic product development and marketing, digital health sensor networking, wireless technology, Big Data and machine learning. It focuses on creating new products for new care pathways for the diagnosis and treatment of chronic disease. In essence the company is developing a whole patient approach to the development of digital pharmaceuticals that fuses medical and environmental data across the whole care pathway from @hospital to @home. The company was founded in 2015 and is based in London, with offices in Oxford, Mexico City and Silicon Valley.

In early 2017 the company signed an agreement with the University of Oxford and Oxford University Hospitals NHS FT to develop and commercialise three new products:

SEND, a system for vital-sign observations in hospital patients, which has enhanced the clinical care of over 80,000 patients over the past two years.

EDGE, a system for the management of chronic obstructive pulmonary disease, showed a 17% reduction in hospital admissions during a 12-month clinical trial.

GDm-health, a system for monitoring gestational diabetes in pregnant women, tested in over 1,000 patients, showed a 25% reduction in clinic visits, when evaluated at the Royal Berkshire NHS Foundation Trust

The collaboration will involve further clinical testing followed by commercialisation of these products across the NHS.

> ‘These products have shown in clinical trials that they improve patient health outcomes and reduce costs for the NHS. We are delighted to be working with Oxford University and the Oxford University Hospitals NHS Foundation Trust to complete clinical evaluation and deploy these products more broadly across the NHS.’
>
> *- Lord Paul Drayson, Chairman and CEO of Drayson Technologies*

Deimos Space UK

Deimos Space UK (subsidiary of the Spanish company Elecnor Deimos) decided to base itself at Harwell in 2013, as the space cluster was developing and already included the European Space Agency, UK Space Agency and the then recently formed Satellite Applications Catapult.

Deimos Space UK addresses the UK and UK-export market for space systems, services and applications. Its commercial R&D portfolio covers diverse satellite applications from smart cities to precision farming and marine operations.

As the Harwell Space Cluster has developed so has Deimos Space and now employs 20 people, and has a turnover of £1.6 million. Deimos Space has built strong relationships across the Space Cluster, particularly with the Satellite Applications Catapult and RAL Space, regularly working on projects together, and across Oxfordshire, recently benefitting from working closely with the University of Oxford to improve its machine learning capability for analysing satellite data.

Deimos Space has been able to reach out to SMEs and academics, across Oxfordshire, through the multitude of networking opportunities at the Harwell Space Cluster, the UK, through the Satellite Applications Catapult Centres of Excellence programme, and beyond working on international projects to drive future export opportunities through the UK Space Agency International Partnership Programme. For example in the SAFIY project Deimos worked with Ordnance Survey International, the University of Oxford and STFC to develop analytic tools to support environmental monitoring in the United Arab Emirates. With a location based service product that is suitable for remote tracking of people and assets, Deimos is actively looking at opportunities in the Digital Health and AV areas.

> 'We believe that now is an exciting time for the satellite applications market globally, but particularly in the UK, where industry, Government and academia are all aligned to drive new developments and markets. Oxfordshire is key to this through the Harwell Space Cluster.'
>
> *– Michael Lawrence, Business Development Director*

deimos
elecnor group

deimosimaging

Oxford Instruments Plc


[197]

In 1959, a spin-out from the University of Oxford created its first product from a garden shed, a superconducting magnet for research that led to the development of the world's first magnetic resonance imaging (MRI) system. That company is Oxford Instruments.

With headquarters in Abingdon, Oxfordshire, revenue in excess of £360m and employing over 2,000 people across its various businesses, Oxford Instruments is a great success story for the region. The company maintains strong links with the University of Oxford for R&D and as a test bed for new products.

With almost sixty years of innovation, Oxford Instruments is applying the lessons learned for the next sixty years – in the development of next generation products for the quantum age. One example is supplying the University of Oxford with their latest and largest prototype cryogenic dilution fridge for research into quantum computing with superconducting circuits. This development enhances their product portfolio across a global market, with the technology being proven in a research environment.

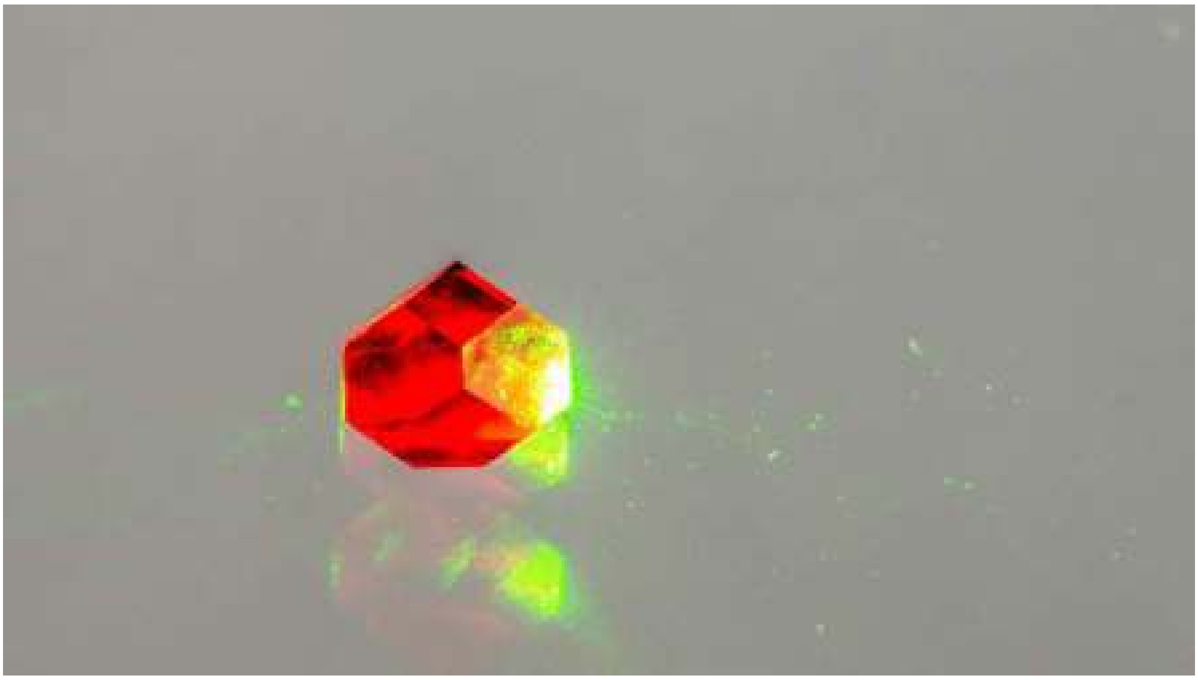
197 Oxford Instruments Plc case study photo & credit: Riccardo Manenti setting up a superconducting qubit experiment using a dilution fridge / David Fleming

Bruker GmbH

With $1.6bn in revenues and over 6,000 employees, Bruker GmbH is a global manufacturer of high-end analytical instruments. Partnering with NQIT (led by the University of Oxford), Bruker were keen to assess the commercial viability of diamond-based sensing technology for diagnosing heart conditions through magnetocardiography (MCG).

With special diamond crystals supplied by Element6 based in Harwell, Oxfordshire, NQIT researchers at the University of Warwick have produced an early stage prototype diamond magnetometer which offers the benefits of robustness, significantly lower costs and portability for patient comfort.

This project demonstrates the strength of Oxfordshire to connect with other regions of the UK and facilitate the development of revolutionary technologies with multinational companies.



[198]

198 Bruker GmbH case study photo & credit: Diamond containing nitrogen vacancies fluorescing due to illumination with green light - Jon Newland

Oxbotica

Oxbotica, a leading Artificial Intelligence firm based in Oxford, is bringing self-driving cars to the streets of the UK. Oxbotica's autonomous operating system, Selenium, is platform agnostic and navigates autonomously around cities, warehouses and off-road environments, using data from lasers and cameras placed on vehicles. Encompassing the areas of navigation, perception and planning, their innovative approach combines state-of-the-art techniques with tried and testing engineering solutions.

Founded in 2014 as a spin-out of Oxford University's Oxford Robotics Institute, Oxbotica helps its clients integrate over 200 person-years' worth of work in autonomy into their own products. With a highly skilled team, an autonomous vehicle fleet, a dedicated testing facility at RACE, in Culham Science Centre, and a new 'galactic headquarters', Oxbotica is growing rapidly to provide viable, safe and affordable solutions to a growing market.

Oxbotica has played a key role in numerous national CAV trials including Autodrive and Gateway and was recipient of the prestigious 2017 Financial Times ArcelorMittal Boldness in Business Award.

Oxbotica is leading an ambitious £13.5 million project called DRIVEN. This will see a fleet of fully autonomous vehicles being deployed in urban areas and on motorways, culminating in multiple end-to-end journeys between London and Oxford in 2018-19. These vehicles will be operating at Level 4 autonomy, with the capability of performing all safety-critical driving functions and monitoring roadway conditions for an entire trip, with zero-passenger occupancy. Other consortium partners include The Oxford Robotics Institute, RACE, XL Catlin, Telefonica, Oxfordshire County Council, Nominet, Transport for London, TRL, and Westbourne Communications.

No connected and autonomous vehicle trial at this level of complexity and integration has ever been attempted anywhere in the world.

Oxehealth: the world's first continuous contact-free monitoring of vital health signs

Spun out by Oxford University Innovation in 2012 from the Institute of Biomedical Engineering and Oxford University Hospitals NHS Trust, Oxehealth is an excellent example of an early stage university spinout.

It is the first company in the world to deliver continuous, medical-grade contact-free vital signs monitoring through low-cost digital video camera sensors. The technology can be used to care for the vulnerable, sick and elderly more effectively and efficiently. The technology has been tested in major NHS mental health hospitals and the UK Police Force and aims to reach police forces, mental health hospitals, acute hospitals and care homes worldwide.

Oxehealth is an example of the University and Trust working together to develop and validate a new technology. Oxehealth raised £500k at seed round from IPGroup plc, and obtained additional funding from Ora Investment among others. Currently, it has around 11-50 employees and is expected to grow rapidly over the next few years.

Oxehealth

Annex D: additional information on the themes

INDEX:

Figure D-1

Research Excellence of Oxfordshire's universities, as applies to the four technologies, by sector area and disciplines: Ranked first in the UK for research, and other rankings

REF 2014 derived data

REF output of institutions in the SIA area in selected Units of Assessment

Research Excellence by sector area and disciplines			
In the UK the University of Oxford is ranked:[1]			
Digital Health	**Space-led data applications**	**Autonomous Vehicles**	**Technologies underpinning Quantum computing**
1st in UK for Clinical medicine (REF UoA1) 1st for Public health, Health services and Primary care (UoA2) 1st for Psychology, Psychiatry and Neuroscience (UoA4) 1st in UK for Physics (UoA 9) ranked by research Output 1st for Mathematical sciences (UoA10) 5th for Computer science and Informatics (UoA 11) by research Output 2nd for Electrical and Electronic engineering, Metallurgy and Materials (UoA13) 1st for General engineering (UoA 15) 1st for Social work and Social policy (UoA22) Oxford Brookes University has well-respected research in tools and analysis for digital diagnostics and expertise in the provision of nursing care, for which 90% of Oxford Brookes' Impact is 4* world-leading or 3* internationally excellent: see Allied health professions, Dentistry, Nursing and Pharmacy (UoA3)	1st in UK for Earth systems and Environmental sciences (UoA7) 1st in UK for Physics (UoA 9) ranked by research Output 1st for Mathematical sciences (UoA10) 5th for Computer science and Informatics (UoA 11) by research Output 2nd for Electrical and Electronic engineering, Metallurgy and Materials (UoA13) 1st for General engineering (UoA 15) 6th for Geography, Environmental studies and Archaeology (UoA17)	1st in UK for Earth systems and Environmental sciences (UoA7) 1st in UK for Physics (UoA 9) ranked by research Output 1st for Mathematical sciences (UoA10) 5th for Computer science and Informatics (UoA 11) by research Output 2nd for Electrical and Electronic engineering, Metallurgy and Materials (UoA13) 1st for General engineering (UoA 15)	1st in UK for Physics (UoA 9) ranked by research Output 1st for Mathematical sciences (UoA10) 5th for Computer science and Informatics (UoA 11) by research Output 2nd for Electrical and Electronic engineering, Metallurgy and Materials (UoA13) 1st for General engineering (UoA 15) 1st for Philosophy (UoA32)

[1] see Times Higher Education for REF 2014 rankings

Figure D-2

Harwell Campus: expanded table of National and Internationals centres, facilities, research and technology organisations and agencies

Scientific research and innovation centres on the Harwell Campus

The most relevant transformative technologies supported are in parentheses, and stated as "All 4" where a facility or service pertains to all four.

Centre	Summary description
Diamond Light Source *(CAV, Digital health, Technologies underpinning quantum computing)*	Diamond Light Source at Harwell is the UK's national synchrotron science facility. Its purpose is to produce intense beams of light which can be used as a series of `super microscopes' for virtually all fields of scientific research. These range from investigating the structure and properties of a wide range of materials, to studying proteins to provide information for designing new and better drugs, and exploring engineering components such as a fan blade from an aero-engine. Diamond is open to both academic and industrial users, serving over 5000 scientists a year and supporting over 100 companies in proprietorial research. Diamond is one of the most advanced scientific facilities in the world, and its unique and pioneering capabilities are helping to keep the UK at the forefront of international scientific research. Diamond also hosts a suite of integrated facilities which include a physical and biological electron microscopy centre, the UK free electron sample preparation hub for biology, and a crystallisation laboratory for membrane proteins. Examples of companies using Diamond include: GlaxoSmithKline working on the detection limit for the presence of a solvate within a manufactured drug batch; Rolls-Royce working on the application of surface treatment to fan blades; Heptares Therapeutics to help develop a treatment for Parkinson's disease; Hewlett Packard labs to improve the energy efficiency of LCDs; BP for enhanced oil recovery research; General Motors working on hydrogen storage.
ISIS Neutron & Muon Spallation Source *(CAV, Digital health, Technologies underpinning quantum computing)*	ISIS is a world-leading centre for research in the physical and life sciences. It operates in a similar and complementary way to a synchrotron, using beams of neutrons (and muons) rather than light to investigate the structure of matter at an atomic scale. ISIS is one of a handful of such facilities around the world and supports a national and international community of more than 3000 scientists to research subjects ranging from clean energy and the environment, pharmaceuticals and health care, through to nanotechnology and materials engineering, catalysis and polymers, and on to fundamental studies of materials. As with Diamond, there is a wide range of sectors to which ISIS is relevant. Examples include: Schlumberger Research examined how asphaltenes behaved in different circumstances allowing more efficient extraction of hydrocarbons; Orla Protein Technologies used ISIS to ensure their protein surfaces were reliable for manufacturing; Powerwave UK used ISIS to provide a more efficient means of recreating the firing stage of ceramic components; Airbus investigated the integrity of welds in aluminium alloys.
Medical Research Council Harwell Institute (*Digital health*)	MRC Harwell has over 60 years' experience of genetics research, specialising in the use of genetically altered mouse strains to study the relationship between genes and disease. It leads the International Mouse Phenotyping Consortium (IMPC), a global multimillion pound project aimed at characterising every protein-coding gene in the mouse genome and making the data freely available to other scientists. It is also the site of the Harwell Ageing Screen, a large-scale ENU mutagenesis project aimed at studying the genetics of ageing. MRC Harwell's International datacentre manages, controls and archives large amounts of data from the international partners of IMPC.
PHE Harwell (*Digital health*)	Public health England (PHE) is an executive agency, sponsored by the Department of Health. PHE has had an important presence at Harwell since the 1970s. PHE's Centre for Radiation, Chemical and Environmental Hazards is located at Harwell, focusing public health with regards to the environment. PHE meets its responsibilities through the development and conduct of world-class science, provision of knowledge and intelligence, advocacy and advice, through facilitating partnerships and by providing specialist public health services. PHE has further national centres and a network of local units, one of which, the Thames Valley Health Protection

Centre	Summary description
	Team is located at Harwell.
Central Laser Facility *(All 4)*	The Central Laser Facility (CLF) at Harwell is one of the world's leading laser facilities providing scientists from the UK and Europe with an unparalleled range of state of the art technology. CLF is a partnership between its staff and the large number of members of UK and European universities who use the specialised laser equipment provided to carry out a broad range of experiments in physics, chemistry and biology. Wide-ranging laser applications include accelerating subatomic particles to high energies, probing chemical reactions and studying biochemical and biophysical processes. The CLF laser facilities range from advanced, compact tuneable lasers which can pinpoint individual particles to high power laser installations that recreate the conditions inside stars. A vigorous development programme ensures that the facilities maintain their international competitiveness.
Harwell Research Complex *(All 4)*	The Research Complex at Harwell (RCaH) is a multidisciplinary laboratory that provides facilities for researchers to undertake new and cutting edge scientific research in both life and physical sciences and the interface between them. It is located adjacent to the Diamond Light Source at Harwell and close to other leading facilities on the campus: the ISIS neutron source, Central Laser Facility, Membrane Protein Laboratory, MRC Harwell, and a Biological Solid State NMR Facility. RCaH is open, on a competitive basis, to research teams from UK universities, and also to Diamond and RAL staff. The MRC is leading the RCaH project on behalf of RCUK, in partnership with BBSRC, EPSRC, NERC, STFC and Diamond
RAL Space *(Space-led data applications, CAV, Digital Health)*	RAL Space at the Rutherford Appleton Laboratory (RAL) is part of the Science and Technology Facilities Council. They work alongside the UK Space Agency (UKSA) which co-ordinates UK civil space activities. RAL Space has around 200 staff and provides world-leading research and technology development, space test facilities, instrument and mission design, and studies of science and technology requirements for new missions. Much of their work is in collaboration with UK university research groups and a range of institutes around the world. Most of these collaborations have been set up to support the European Space Agency (ESA) and NASA missions, although RAL is also working on projects with other countries and organisations including Australia, Japan, Morocco, Pakistan, Russia and the European Union. They provide opportunities for hosting scientists and engineers on sabbatical leave, visiting scientists on short term visits and for university sandwich course students on one-year placements. RAL Space also provides graduate engineer training and CASE (Cooperative Awards in Science and Engineering) studentships. A Concurrent Design Facility and a robotics test laboratory are operated by RAL Space.
Satellite Applications Catapult *(Space-led data applications)*	The Satellite Applications Catapult, based at Harwell, is one of a network of Research & Technology Organisations (Catapults) established to foster innovation and accelerate the take up of emerging technologies. Its objective is to promote, develop and facilitate the commercialisation and advancement of the UK's satellite applications industry. The Satellite Applications Catapult has a wide range of facilities, platforms and laboratories to enable the best businesses, researchers and end-users to work together to develop new satellite-based products, moving ideas from concept to market.
STFC (All 4. Mainly *Space-led data applications and Digital Health)*	STFC activities include the ESA Business Incubation Centre, designed to bridge the gap between a technology transfer idea and getting the project off the ground, assisting its development into a viable business.
ECSAT *(Space-led data applications)*	ECSAT (European Centre for Space Applications & Telecommunications) is the most recent addition to ESA's operational sites across Europe. First opened in 2009, ECSAT is being further developed by ESA following agreements reached between the UK and ESA in November 2012. It is currently supporting activities related to telecommunications, integrated applications, climate change, technology and science.
UK Space Agency *(Space-led data applications)*	The UK Space Agency is an executive agency of BEIS, made up of about 70 staff based in Swindon, London and the UK Space Gateway at Harwell. It is responsible for all strategic decisions on the UK civil space programme and provides a clear, single voice for UK space ambitions. It ensures that the UK retains and grows a strategic capability in space-based systems, technologies, science and applications. It leads the UK's civil space programme in order to win sustainable economic growth, secure new scientific knowledge and provide benefit to all citizens.

Source: Consortium members

Figure D-3

Employment analyses, Oxfordshire: BRES Analysis including mapping of SICs to Technologies
SQW, 11Apr2017

Employment in Oxfordshire 2011 and 2015

	2011	*2015*
Number in employment (Oxfordshire: All in Employment, and 'High Tech' Employment in Oxfordshire)		
All in Employment	**334,700**	**363,800**
'High Tech' Employment	**44,900**	**50,400**

Employment in Oxfordshire 2011 and 2015 by sector theme

Number in employment (Autonomous vehicles definition)		
26511	800	700
(29100)	Disclosive data (unreported)	Disclosive data (unreported)
29310	0	0
(29320)	300	400
71121	1,400	1,500
71122	1,300	1,200
'Autonomous Vehicles' Employment	**9,300**	**11,400**

Number in employment (Digital health definition)		
(21100)	Disclosive data (unreported)	Disclosive data (unreported)
(21200)	400	200
(62012)	1,600	2,500
(72110)	100	400
86900	100	200
86220	7,700	7,900
'Digital Health' Employment	**9,900**	**11,200**

Number in employment (Space definition)		
(30300)	100	100
51220	0	0
61300		
(74901)	100	500
'Space' Employment	**200**	**600**

Number in employment (Quantum definition)		
24410	0	0
26110	200	100
26120	0	0
26200	1,300	0
26800	0	0
72190	5,500	7,600
'Quantum' Employment	**7,000**	**7,700**

Source: ONS, Business Register and Employment Survey (NOMIS)
All figures are rounded to the nearest 100, therefore figures in the table may not equal the total.

Definitions

High Tech sectors – Broad definition – based on Eurostat but with additions (Oxford Innovation Engine)

Industry Category
254 : Manufacture of weapons and ammunition
302 : Manufacture of railway locomotives and rolling stock
303 : Manufacture of air and spacecraft and related machinery
304 : Manufacture of military fighting vehicles
309 : Manufacture of transport equipment n.e.c.
325 : Manufacture of medical and dental instruments and supplies
741 : Specialised design activities
749 : Other professional, scientific and technical activities n.e.c.
20 : Manufacture of chemicals and chemical products

Industry Category
21 : Manufacture of basic pharmaceutical products and pharmaceutical preparations
26 : Manufacture of computer, electronic and optical products
27 : Manufacture of electrical equipment
28 : Manufacture of machinery and equipment n.e.c.
29 : Manufacture of motor vehicles, trailers and semi-trailers
58 : Publishing activities
59 : Motion picture, video and television programme production, sound recording and music publishing activities
60 : Programming and broadcasting activities
61 : Telecommunications
62 : Computer programming, consultancy and related activities
63 : Information service activities
71 : Architectural and engineering activities; technical testing and analysis
72 : Scientific research and development

Autonomous Vehicles sectors definition

Industry Category
26511 : Manufacture of electronic instruments and appliances for measuring, testing, and navigation, except industrial process control equipment
(29100 : Manufacture of motor vehicles)
29310 : Manufacture of electrical and electronic equipment for motor vehicles
(29320 : Manufacture of other parts and accessories for motor vehicles)
71121 : Engineering design activities for industrial process and production
71122 : Engineering related scientific and technical consulting activities
72190 : Other research and experimental development on natural sciences and engineering

Note: 72190 repeated in Quantum definition

Digital Health sectors definition

Industry Category
(21100 : Manufacture of basic pharmaceutical products)
(21200 : Manufacture of pharmaceutical preparations)
(62012 : Business and domestic software development)
(72110 : Research and experimental development on biotechnology)
86220 : Specialist medical practice activities
86900 : Other human health activities

Space sectors definition
Industry Category
(30300 : Manufacture of air and spacecraft and related machinery)
51220 : Space transport
61300 : Satellite telecommunications activities
(74901 : Environmental consulting activities)

Quantum sectors definition
Industry Category
24410 : Precious metals production
26110 : Manufacture of electronic components
26120 : Manufacture of loaded electronic boards
26200 : Manufacture of computers and peripheral equipment
26800 : Manufacture of magnetic and optical media
72190 : Other research and experimental development on natural sciences and engineering

Note: 72190 repeated in Autonomous vehicles definition

Note on the data

This note on the use of SIC data applies to uses of SIC data in this report, and in other reports.

Categorisation is indicative of these future-facing transformative technologies and sectors across the next 13 years to 2030, as well as at present. Beyond the industry categories listed under each sector, many more industry categories not included here will include workers contributing to the sector. The list of relevant SIC codes is thus not exhaustive. Equally, not every job in each listed sector is currently working on the specified technology. The data thus recognise the limitations of SIC codes in identifying a specific technology's workforce.

All four transformative technologies will exert an increasing influence on many industry sectors. For example, with Autonomous Vehicles (AV), those jobs will be relevant, many or most or all will work on AV to an extent, and all will be affected by the advent and mainstreaming of AV. This is equally the case for the other technologies, e.g. technologies underpinning quantum computing.

At the time of production of this wave of SIAs, SIC codes are the best available data, being representative of technologies' workforces (rather than attributing a percentage of each industry sector which is (and increasingly will be) directly fully contributory to the technologies, and increasingly affected by the technologies).

Figure set D-4

Transformative Technologies research publications including FWCI, Elsevier & SciVal

Oxfordshire's research publications are highly influential nationally and globally in all of the four transformative technology sectors. The diagrams below show the impact of the SIA region's publications in each of the four technologies. There is also an analysis for transformative technologies as a whole, showing the potential for cross-fertilisation and spillover into other technological innovations, business sectors and markets, with further societal benefit.

The broad consortium area accounts for 4.9% of the UK's REF-submitted university researchers, who contribute a proportionally higher national share of REF submitted publications (5.1%) and Doctorates (5.4% in the 2008-2012 period).[199]

The diagrams below compare the SIA region's publications against the UK average, and the global average. The analyses are on citations (the number of times that other researchers and organisations have referred to a publication), this being the primary indicator of the impact of published research.

Analyses cover 1) the pure number of citations, and 2) the proportion of publications which are among the highest 10% in terms of citations. Because some scientific disciplines are more highly cited than other disciplines, those analyses might not accurately reflect relative strengths across the four technologies. For this reason the analyses also include 3) the Field Weighted Citation Impact (FWCI), which is the method for standardising the citation analyses of different fields of science.

In all cases, the green line's area shows the extent to which the SIA region's research publications are very significantly more impactful than the UK average, and the global average.

Figure D-4.1: Research publication impact, by average number of citations

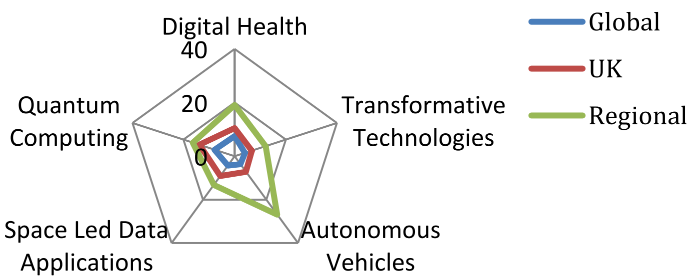
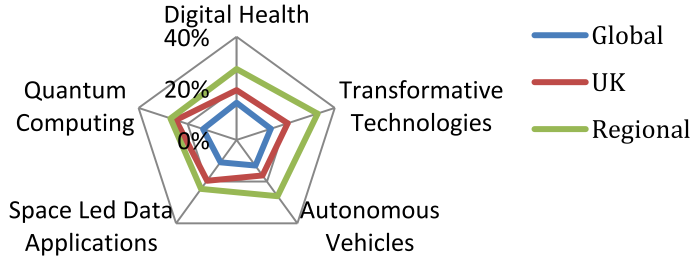


Figure D-4.2: Research publication impact, by %age of documents in top 10% most cited globally



199 Technopolis SIA core data analysis, 'Science and research assets': REF 2014

Figure D-4.3: Research publication impact, by Field Weighted Citation Impact (FWCI)

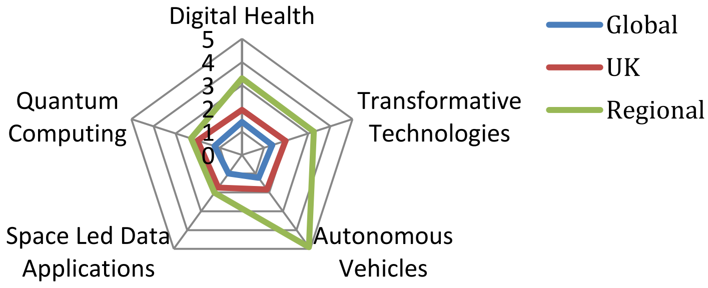


Figure D-4.4: Field-Weighted Citation Impact (FWCI): description

1. FWCI indicates how the number of citations received by an entity's publications compares with the average number of citations received by all other similar publications in the data universe
2. A FWCI of 1.00 indicates that the entity's publications have been cited exactly as would be expected based on the global average for similar publications
3. Oxford has a FWCI of 2.30 for period 2011-2015 meaning your research is cited 2.3 times more than the world average
4. The UK had a FWCI of 1.55 for the same period
5. The Russell Group had a FWCI of 1.77 for the same period

Figure D-5

Elsevier SciVal analyses: research publications, publication collaborations, and international patent citations of research publications

Autonomous Vehicles

Metric (2011-2016)	Global	UK	Regional
Documents	130973	6762	392
Citations	467808	48310	10532
Average Citations per document	3.6	7.14	26.9
FWCI	1.22	1.84	4.91
% of documents in top 10% most cited	12.30%	17.10%	27.00%
% international collaboration	16.80%	51.90%	59.90%
Number of patents citing documents	907	83	19
Number of documents cited by patents	506	45	9

Digital Health

Metric (2011-2016)	Global	UK	Regional
Documents	483889	72742	5169
Citations	3,625,390	763,373	98,888
Average Citations per document	7.5	10.5	19.1
FWCI	1.42	1.94	3.3
% of documents in top 10% most cited	14.40%	19.30%	27.50%
% international collaboration	26.00%	49.10%	58.90%
Number of patents citing documents	3877	702	128
Number of documents cited by patents	2102	322	43

Space-led data applications

Metric (2011-2016)	Global	UK	Regional
Documents	62341	3546	255
Citations	266656	32379	6997
Average Citations per document	4.3	9.1	13.3
FWCI	0.99	1.74	2.01
% of documents in top 10% most cited	10.70%	19.60%	23.50%
% international collaboration	24.30%	68.30%	73.70%
Number of patents citing documents	198	20	1
Number of documents cited by patents	146	14	1

Technologies underpinning quantum computing

Metric (2011-2016)	Global	UK	Regional
Documents	10,735	913	163
Citations	84,344	12627	2666
Average Citations per document	7.9	13.8	16.4
FWCI	1.24	2.01	2.3
% of documents in top 10% most cited	13.70%	24.80%	27.00%
% international collaboration	29.40%	69.20%	66.30%
Number of patents citing documents	126	20	6
Number of documents cited by patents	93	12	4

All 4 Transformative Technologies (combined data)

Metric (2011-2016)	Global	UK	Regional
Documents	198283	13017	751
Citations	802407	87704	9060
Average Citations per document	4	6.7	12.1
FWCI	1.37	1.97	3.25
% of documents in top 10% most cited	13.90%	20.80%	33.00%
% international collaboration	19.30%	53.10%	60.50%
Number of patents citing documents	1842	243	31
Number of documents cited by patents	969	104	9

Figure D-6

Elsevier SciVal sample analysis in presentation format (example: Autonomous Vehicles)

Citing-Patents Count

	Citing-Patents Count
Worldwide	198
Europe	78
United Kingdom	30
University of Oxford	13

Patent-Cited Scholarly Output

	Patent-Cited Scholarly Output
Worldwide	102
Europe	45
United Kingdom	13
University of Oxford	5

Most active Institutions in this Research Area

Export Shortcuts

Show top 10 contributing institutions in the U... in this Research Area, by number of publications

Institution	Publications	Authors	Field-Weighted Citation Im...
1. University of Oxford	81 ▲	73 ▲	5.23
2. Imperial College London	55 ▲	93 ▲	3.79
3. Cranfield University	40 ▲	45 ▲	3.04
4. Heriot-Watt University	34 ▲	39 ▲	1.55
5. University College London	32 ▲	37 ▲	1.52
6. University of Surrey	32 ▼	42 ▼	0.59
7. University of Essex	27 ▲	23 ▲	1.06
8. University of Leeds	25 ▼	37 ▼	3.52
9. University of Strathclyde	23 ▲	30 ▲	1.87
10. University of Cambridge	22	33 ▲	1.72

Figure D-7

Top 20 research active organisations in Oxfordshire

Organisation	No of participations	Organisation	No of participations
University of Oxford	4,077	Sharp Laboratories of Europe	34
NERC Centre for Ecology and Hydrology	231	EURATOM/CCFE	31
STFC - Laboratories	196	Oxford University Hospitals NHS Foundation Trust	29
Oxford Brookes University	162	ISIS Facility	28
Diamond Light Source	121	ANSYS	23
Science and Technology Facilities Council	64	NIHR Oxford Biomedical Research Centre	21
Oxford Instruments plc	50	Oxsensis Limited	21
H R Wallingford Ltd	50	Satellite Applications Catapult	20
Green Biologics Limited	39	John Radcliffe Hospital	19
Oxitec Ltd	37	Delta Motorsport Limited	18

Source: Gateway to Research – based on number of participations in public-funded research projects and programmes, 2006-16

Figure D-8

Strength and competitiveness in Research (national): Top-20 research themes in the consortium geography

Technopolis core data analysis: content from 'Science and Innovation Audits: Oxfordshire', Technopolis Group, January 2016

The organisations located in the consortium geography account for a total of 3,837 projects, worth £2.7b in funding from the seven UK research councils, according to data from the Gateway to Research (GtR) for the period 2004-2016. This represents 8.4% of the total funding allocated across all institutions in the UK during this period.

The research theme receiving the largest share of the total funding within the consortium area during this period was Atomic and molecular physics (7.3%, £193.2m), followed by Plasma physics (3.9%, £104.7m) and ICT (2.4%, £64.5m). The table below shows the top-20 research themes, according to their funding awarded within the consortium geography, alongside the consortium geography's share of the total UK funding under each theme (highlighted in blue if it is above the geography's total share of UK funding, across all research themes). The data thus highlight research strengths for the consortium area.

Table D-3 - Top-20 research themes in the consortium geography, based on the value of their funding

#	Research subject	Number of projects	Funding (£, millions)	UK total number of projects	UK total funding (£, millions)	Share of funding in UK total
1	Atomic and molecular physics	14	193.2	137	257.6	75.0%
2	Plasma physics	19	104.7	125	163.4	64.0%
3	ICT	146	64.5	2,683	1,243.9	5.2%
4	Particle physics (experiments)	53	50.5	647	420.9	12.0%
5	Materials sciences	75	41.8	1,166	518.6	8.1%
6	Astronomy (observation)	61	39.4	737	396.2	10.0%
7	Tools, technologies and methods	96	34.2	1,167	482.8	7.1%
8	Mathematical sciences	97	32.2	1,298	387.6	8.3%
9	Energy	46	30.7	811	578.0	5.3%
10	Superconductivity, magnetic and quantum fluids	36	19.9	312	163.0	12.2%
11	Climate and climate change	71	19.6	715	172.3	11.4%
12	Geosciences	70	18.8	1,087	241.1	7.8%
13	Mechanical engineering	32	18.2	591	262.0	6.9%
14	Chemical synthesis	44	18.1	582	281.1	6.4%
15	Optics, photonics and lasers	30	17.2	429	231.8	7.4%
16	Biomolecules and biochemistry	36	15.8	499	201.8	7.8%
17	Medical and health interface	36	15.6	712	332.0	4.7%
18	Ecology, biodiversity and systematics	50	14.9	565	143.3	10.4%
19	Sociology	34	14.3	739	217.3	6.6%
20	Economics	31	12.7	496	224.9	5.7%
…	…	…	…	…	…	…
	Total (all research themes)	**3,837**	**2,654.6**	**68,327**	**31,421.9**	**8.4%**

Note: Sorted in descending order according to funding (£). Figures are based on fractional counting (as the same project could have been assigned to one or more research themes).

Figure D-9

Strength and competitiveness in Research (international)

Technopolis core data analysis: content from 'Science and Innovation Audits: Oxfordshire', Technopolis Group, January 2016

The SIA area accounts for 12.0% of the UK's REF-submitted international income (Oxfordshire only). A total of **£486.47m in research income from international and EU sources** was declared through the 2014 REF exercise by the consortium area's institutions (Oxfordshire only). Analysis of these figures highlights that the **highest proportion related to Clinical Medicine** (36%, £174.63m). The next highest proportion is in **Public Health, Health Services and Primary Care** (17%, £85.12m).

The study team has used a calculation to assess the relative specialism of the consortium in the REF subject areas based on the relative importance of international income. Greater international income provides indication of the international outstanding of consortium area on a given (REF) subject area. This calculation **complements** the findings emerging from the REF indicators shown above.

The calculation divides:

- the SIA area's share of the total international funding for the UK for a given subject (numerator), by
- the SIA area's share of total international funding across all subjects (denominator), which in this case is 12.0%.

The calculation results in a score that indicates areas of strength. A score greater than 1.0 indicates that the share of international income in a subject area is greater than the share of international income overall (e.g. 14.8% for Biological Sciences versus 12.0% overall).

The consortium area (Oxfordshire only) shows a strong specialism in funding for Public Health, Health Services and Primary Care (2.22), which is of relevance to the thematic interests declared for the SIA.

International income amounts and specialisations, Oxfordshire only

Main Panel	Unit Of Assessment	Name	International Income 2008-2012 (£m)	International Income Specialisation
A	1	Clinical Medicine	£174.63m	1.77
A	2	Public Health, Health Services and Primary Care	£85.12m	2.22
A	3	Allied Health Professions, Dentistry, Nursing and Pharmacy	£0.44m	0.03
A	5	Biological Sciences	£55.38m	1.24
B	8	Chemistry	£22.62m	1.03
B	9	Physics	£15.14m	0.69
B	10	Mathematical Sciences	£17.45m	2.18
B	11	Computer Science and Informatics	£15.11m	0.53
B	12	Aeronautical, Mechanical, Chemical and Manufacturing Engineering	£0.00m	-
B	13	Electrical and Electronic Engineering, Metallurgy and Materials	£5.91m	0.28
B	14	Civil and Construction Engineering	£0.00m	-
B	15	General Engineering	£12.57m	0.36
C	16	Architecture, Built Environment and Planning	£0.13m	0.03
C	17	Geography, Environmental Studies and Archaeology	£9.97m	0.95
C	18	Economics and Econometrics	£6.78m	2.04

Source: Data from REF

Analysis of participation in Horizon 2020 (the 8th European Commission Framework Programme) shows the consortium's performance in securing European competitive funding. The consortium area (Oxfordshire only) accounts for 3.4% of all UK drawdown from the Horizon 2020 programme. The table below summarises the consortium area's drawdown by programme area, and sets out each programme area's share of the total drawdown for the consortium area. It also highlights programme areas in green where the consortium has attracted a relatively larger share of the UK total drawdown.

In particular, three areas are highlighted: Health, demographic change & wellbeing (39.5% of the consortium area's drawdown and 5.3% of the UK's total share). This is of particular relevance to the areas of interest declared for the SIA. Next is Climate action (11.6% of the consortium area's drawdown and 4.5% of the UK's total share), and third, Secure societies (9.6% of the consortium area's drawdown and 4.5% of the UK's total share).

Participation in Horizon 2020

Rank	Programme	EC contributions in SIA area (EUR, millions)	EC contributions in UK total (EUR, millions)		Programme share of total EC contribution in SIA area (%)	SIA share of UK total EC contrib. per programme (%)
1	Health, demographic change & wellbeing (soc. challenges)	11.3	211.7		39.5%	5.3%
2	ICT (industrial leadership, LEIT)	3.8	202.6		13.2%	1.9%
3	Climate action, environment, etc. (societal challenges)	3.3	74.7		11.6%	4.5%
4	Secure societies (societal challenges)	2.8	60.7		9.6%	4.5%
5	Secure, clean and efficient energy (societal challenges)	1.6	61.8		5.7%	2.6%
6	Smart, green and integrated transport (societal challenges)	1.4	85.0		4.7%	1.6%
7	Advanced materials (industrial leadership, LEIT)	1.2	12.2		4.2%	9.8%
8	Food security, sustainable agri., etc. (societal challenges)	1.1	65.5		3.7%	1.6%
9	Nanotechnologies (industrial leadership, LEIT)	1.0	2.4		3.5%	41.2%
10	Space (industrial leadership, LEIT)	0.6	26.7		2.1%	2.3%
11	Europe in a changing world (societal challenges)	0.5	34.2		1.7%	1.4%
12	Innovation In SMEs (industrial leadership)	0.2	4.6		0.6%	3.4%
13	Biotechnology (industrial leadership, LEIT)	0.0	5.3		0.0%	0.0%
14	Access to risk finance (industrial leadership)	0.0	0.7		0.0%	0.0%
15	Advanced manuf. and proc. (industrial leadership, LEIT)	0.0	0.0		0.0%	0.0%
	Total across all programmes	**28.6**	**848.1**		**100.0%**	**3.4%**

Source: CORDIS (2016)

Annex E: Authors

Authors:

Phil Clare
Matt Smart
Chris Green
Richard Byard
David Hartley
Barbara Ghinelli
Lesley Thompson
Nick Scott Ram
Rob Buckingham
Rupesh Srivastava
Simon Jackman
Joanna Hart
Garry Staunton
Kirsty Allen
Victorian Sanchez
Geraldine Murphy
Fred Kemp

With thanks to Elsevier Limited