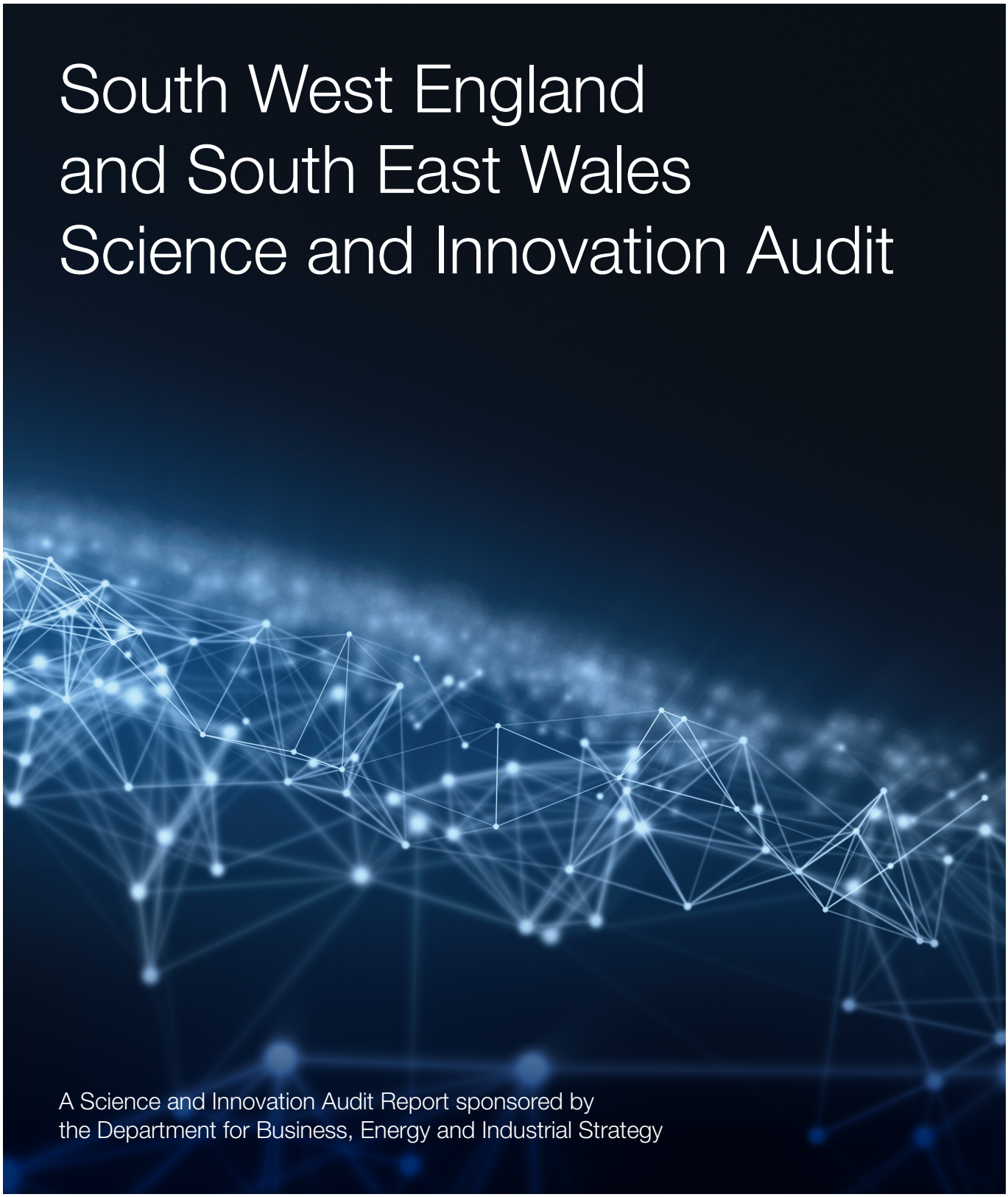
Department for
Business, Energy
& Industrial Strategy

South West England and South East Wales Science and Innovation Audit



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

Foreword

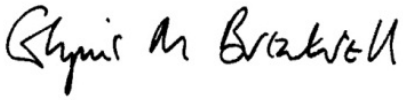
This Science and Innovation Audit has identified the world-leading research strengths and innovative industrial capacity of South West England and South East Wales and the enormous potential of the region to prosper in the new knowledge economy and, indeed, to lead in digital innovation and advanced engineering.

We have focused on the pre-eminent strengths in the region in aerospace and high value engineering, microelectronics, new energy systems, digital industries, and environmental technologies. It is clear that there is extraordinary potential to better integrate these sectors and to provide greater innovative potential by focused investment. We also identify the need for skills development in the new technologies that are being created in our region.

The overriding impression from this audit is one of strength of opportunity, backed by evidence of achievement but tempered by the concern created by the risks and challenges faced. Our international competitors are advancing and the innovation momentum in the region must be maintained.

With the significant opportunities sit real concerns that urgent action is required to optimise delivery of the Government's Industrial Strategy and to ensure that appropriate investments are made to maintain our lead over the rest of the world.

We are confident that our region can deliver a resurgence in manufacturing, building on the opportunities afforded by digital innovation and the strength of the science base. In this way we can drive innovation, increase productivity and deliver a sustainable flow of exports, GVA, growth and jobs to the benefit of the UK.



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Vice Chancellor, University of Bath

On behalf of the South West England and
South East Wales Science and Innovation Audit consortium

About Us

The South West England and South East Wales Science and Innovation Audit (SWW–SIA) has been undertaken by a consortium that brings together key organisations and businesses from South West England (Cornwall and Isles of Scilly, Gloucestershire, Heart of the South West, Swindon and Wiltshire, and West of England LEPs) and South East Wales. The SWW region has a population of 6.2m people and has 14 research institutions, 15 Higher Education Institutions, 27 Further Education Colleges, and over 35 science parks and innovation centres.

Executive Summary

In Autumn 2015 the UK Government announced regional Science and Innovation Audits (SIAs) to catalyse a new approach to regional economic development. SIAs enable local consortia to focus on analysing regional strengths and identify mechanisms to realise their potential. In South West England and South East Wales, a consortium was formed to focus on our strengths in *Aerospace and Advanced Engineering, New Energy Systems, Next Generation Microelectronics, Digital Living Innovation, and, Resilience, Environment and Sustainability*. This report presents the results which include broad-ranging analysis of the South West England and South East Wales consortia's capabilities, the challenges and the substantial opportunities for future economic growth.

The SIA reviewed the regional science and innovation asset base, in both academia and industry for each of the themes, and has identified where existing excellence, global market opportunity and industry trends, coupled with investment, ambition and drive will allow continued growth, both in areas for which the region is already globally competitive and where new opportunities exist in emergent areas.

The SIA concluded that these sectors can drive a resilient, high productivity, low-carbon economy in the SWW with extraordinary potential for job creation and industrial innovation. This can only be achieved, however, through specific investments with immediate impact, coupled to a long term plan, linked to the Government's Industrial Strategy, to integrate current activities and focus on new skills development.

In the immediate-term, the SIA underlined the importance of new capabilities afforded by the *Compound Semiconductor Applications Catapult,* and the proposed *Institute for Advanced Automotive Propulsion Systems (IAAPS),* and *Composites Excellence – with National Composites Materials Centre.* These selective investments will have a direct impact on research and innovation infrastructures identified in the SIA and are driven by existing industrial need.

The SIA also identified a very strong industry-pull to better integrate existing scientific and industrial activity to create pioneering new capacity in **Advanced Engineering** and **Digital Innovation**. This will drive significant added-value across a large section of the industries reviewed in the SIA, stimulating long-term economic growth.

The SIA recommends investment in High Value Engineering Design and Systems Integration capabilities, initially focused on the aerospace sector, but also designed to support the automotive, nuclear, marine engineering / energy and microelectronics sectors. This has very strong industry support and significant commercial leadership.

The SIA recommends establishment of an integrated network of Digital Innovation Hubs (DIHs) across the SWW to bring together academic and industry expertise in underpinning technologies, such as cloud computing and digital communication, with a focus on Smart Cities, Digital Media, Autonomous Systems, Digital Manufacturing, and Digital Health. Phase One will establish a Digital Innovation Hub in Bristol bringing together academic and industry expertise in underpinning technologies (e.g. cloud computing, communications etc.) and with a focus on SWW's specialisms in Smart Cities, Digital Media, Autonomous Systems and Digital Health. The first specialist DIH should be the Institute for Environmental Risk and Innovation, focused on the modelling and simulation of future climate and weather risks, coupled to the new Global Environmental Futures Campus linked to the Met Office in Exeter. This should be followed by a series of further DIHs to co-ordinate and integrate digital innovation across the region.

Aerospace and Advanced Engineering[1]

The SWW region is renowned for its aerospace sector and strengths in advanced engineering. These strengths have been built over decades and have resulted in a rich landscape of Industrial Primes; Systems / Structural Suppliers; Research Centres and renowned academic Institutes, all with related skills. This community has a long history of collaboration both within and outside the SWW.

This world-leading capability has delivered iconic products that the UK has taken great pride in being associated with, such as the Westland Sea King Helicopter, Dyson cyclone vacuum cleaner and the fleet of innovative Airbus aircraft

The overarching finding of the SIA is the strength of opportunity that the region can deliver, backed by evidence of achievement but tempered too by the concern created by the risks and challenges faced related to loss of long established capability which threatens the Government's Industrial Strategy.

The SIA concludes that a broader strategy to protect and enhance capabilities in the Industrial Value Chain is essential. Specifically, High Value Engineering Design and System Integration skills (e.g. whole structure, sub-structure and propulsion) are core to the region and core to the protection of longer term manufacturing competitiveness. Additionally, the co-location of capabilities around an Advanced Engineering Campus, at the Bristol and Bath Science Park and at Oceansgate in Plymouth, will build resilience and sharing across sectors. A campus will provide opportunities in developing Composite Capabilities and addressing life-long learning to manage the transition into the 4th Industrial Revolution – Industry 4.0, alongside business-led innovation in Advanced Automotive Propulsion Systems.

This underlines the importance of short-term investments identified by the SIA such as the *Composites Excellence – with National Composites Materials Centre an*d The Institute for Advanced Automotive Propulsion Systems (IAAPS), coupled to a new industry-led initiative in High Value Engineering Design and Systems Integration Capability.

New Energy Systems[2]

The SIA highlighted a number of clusters of industrial and R&D activity across the SWW, which have specific geographical requirements, and in some cases important synergies with neighbouring regions. An overriding finding was the need for greater integration of expertise across the diverse elements of the energy sector.

Marine Renewables – The SWW region is unique in the UK with all marine renewables resources accessible from ports and infrastructure, and with clusters of specialist industrial and academic activity spread across the region, but with significant infrastructure in the far South West. There is an important wider geographical linkage across to Southampton, which is reflected in the development of the South Coast Marine Cluster.

Hydrogen / Fuel Cells – a corridor of technical expertise, specialism and capacity exists along the M4, from the Hydrogen hub at Swindon through to Cardiff, including the research centres at Baglan (University of South Wales) and Bath.

Nuclear – activity is centred on the M5 corridor running from Gloucestershire (EDF Energy Generation at Barnwood, Magnox at Berkeley, and Horizon Nuclear in Gloucester), Bristol and Somerset, with the nuclear skills centre at Bridgwater, EDF's national learning and development centre, and new build at both Hinkley C and the proposed site at Oldbury.

The SIA also revealed an emerging cluster of excellence and good practice in underpinning technologies related to **distributed energy systems and smart grids**, which will have relevance across many new energy technologies. The need for innovation in digital technology capability was also strongly evident in this theme.

The SIA findings reveal where the region is ideally placed to develop its science and innovation capacity further, and by doing so drive development of new technologies where the UK can achieve global competitive advantage.

Next Generation Microelectronics[3]

The SWW has a long history of microelectronic, photonic and semiconductor companies, as well as world-leading system integrators such as GE and BAE systems. It is home to the largest silicon design cluster outside of the USA and will shortly host the Compound Semiconductor Applications Catapult. SWW universities have a strong track record in relevant cutting edge research and have recently made significant investments in the areas of compound semiconductors and quantum technologies.

The economic importance of the sector is widely acknowledged and forms a key component of the economic strategy of a number of the region's LEPs, including the West of England Skills Strategy and the Heart of the South West's Smart Specialisation Strategy. The latter emphasises that the electronics/photonics industry plays an important role both as a standalone sector and in supporting a number of other key sectors, including Aerospace, Telecoms and Biomedical. Similarly, the Welsh Government is co-investing heavily in compound semiconductor R&D, supporting both commercial and higher education partners in the SWW region.

Digital Living Innovation[4]

As a recognised and evidenced powerhouse of Electronics and Computing in industry and in academia, the SWW has taken a leading role in developing the digital technologies that have transformed our lives over the past 20 years. The SWW fully intends to continue in that mission through strong established partnerships with corporates, SMEs and universities.

The SIA findings have reinforced previous reports which have highlighted the strategic importance of the Digital Industries sector for the UK economy and the region's strengths and clusters of national and global importance, including for example the 2016 Tech Nation report[5] and the 2014 Centre for Cities report "Industrial Revolutions: capturing the Growth Potential".[6]

Through the SIA process, convergence has occurred around top level thematic application areas and technical underpinning, where the SIA findings support the conclusion that the region hosts world class industrial and academic research as well as innovation strengths. Thematic applications areas include digital health, digital creative economy, smart cities and transport. Underpinning technology areas include cloud computing (including communications and Internet of Things), Digital Media (including Virtual / Augmented Reality, Creative media), and Robotics / Autonomous Systems. The need for sustained investment in integration of expertise in digital innovation was clearly articulated in the SIA with a strong industry pull.

Resilience, Environment and Sustainability[7]

The SIA has surfaced the extensive, vibrant and internationally excellent capability, assets, university and research organisation activity in the region and builds on a broad environmental goods and services sector, alongside regional priority sectors in environmental futures, agri-food / tech, energy, digital, water, low carbon and high value manufacturing.

Over a quarter of the UK's major environmental research organisations have a base in the SWW[8] and there are almost 2,000 scientists[9] working in relevant areas and 25,000 enterprises in the region based in sectors relevant to the theme, with 153,000 jobs.[10]

This theme is aligned with global drivers, such as the recent development of the UN Sustainability Goals[11] and the Paris Climate Agreement in 2015[12]. Regional strengths and support for the climate

change and sustainable development agendas, challenges and opportunities are extensive. Addressing these challenges means there is an urgent need to utilise environmental data to tackle risks from natural hazards and protect the resilience of socio-economic systems. There is also a huge opportunity for the SWW to lead development of new technology and innovation that will be required to live sustainably.

Building on this evidence, the SIA identified two areas where the region has the potential to be globally competitive: Environmental Risk and Data, and Sustainable Technologies and Development. These are, critically, underpinned by the need for better integration of Digital Innovation capacity.

Conclusions

The SIA has provided in-depth analysis of the SWW region's research capabilities and the innovation strengths in SWW industries. This leads us to conclude that SWW core science and innovation capabilities cut across the SIA themes, and closer collaboration and cross-theme working will be vital in order to unlock the true potential of the SWW. As a result, the SIA focuses its conclusions in two areas: Advanced Engineering and Digital Innovation. The underpinning capabilities span the whole region but require further integration, co-ordination and sustained investment, if they are to realise their full potential.

Underpinning the findings of the SIA is a clear and urgent need to upskill the current and future workforce of the SWW so that we have the right people in place to fill the high-end, advanced engineering and high tech digital jobs that these new industries require.

Advanced Engineering

The future of the world-leading aerospace sector in the SWW demands continual technological advancement to keep its global lead ahead of very strong competitors. We look to protect and enhance SWW capabilities within the value chain, specifically in High Value Engineering Design and Systems Integration, where we have identified an urgent need to address a growing "capability gap" where a number of factors have contributed to a situation where the UK aircraft design capability has suffered decline for a number of years. This now threatens the future of the UK Aerospace Industry. Other advanced engineering sectors face similar challenges, and opportunities to provide cross-sector support and benefits have already been identified, such as low carbon propulsion and lightweight structures for cars and planes.

As a result the SIA has identified a critical need for a new initiative in **High Value Engineering Design Capabilities and Systems Integration**. A full industry-led business case is now in development to define the components of this new initiative, in terms of resources, infrastructure and skills development.

Additionally, the SIA identified development of the UK's composite capabilities, focused in the SWW area, as critical to industry competitiveness. There is an urgent need to address the skills needed to transition to Industry 4.0; and seize the opportunities associated with sustainable development. Investment in such capabilities can not only drive continual success in aerospace, but also in related advanced engineering sectors and their supply chains – namely in automotive, nuclear, space, marine and marine renewables, and microelectronics for the benefit of both the SWW area and the UK.

The unique natural environment and marine renewables assets of the SWW provide a well-equipped marine renewables testbed. We need to build on collaborative R&D to better utilise SWW academic strengths, for example in simulation, modelling and visualisation as well as in real-world testing to make best commercial benefit from these.

Opportunities to derive economic benefit from nuclear new-build and fleet operation are significant, and an existing cluster of industrial and academic nuclear expertise is being aligned to realise nuclear innovation, skills, technology development and supply chain development opportunities. Linking SWW energy capabilities provides potential for a large-scale distributed energy demonstrator from cities to peripheral rural areas, incorporating nuclear, marine renewables and hydrogen fuel cells.

Digital Innovation

The high-tech digital excellence in microelectronics, wireless, data analytics, autonomous systems, vision, remote sensing, satellite applications, cloud computing, quantum engineering, cyber security and virtual reality forms the basis of high growth digital industries in the SWW region. Existing business expertise and world-leading research provide building blocks to underpin not only SWW advanced engineering sector (Industry 4.0), but also world-scale industries in digital health, digital creative industries, smart cities and communities, distributed smart energy and environmental resilience.

By investing in 'digital innovation' we can drive this revolution in the SWW and the UK, and build world-beating specialised capability. We plan to do this through investment in expert integrated hubs in which researchers, entrepreneurs, students, industry and users create the technologies, policies, practices, business models, and businesses for the digitalised society we are building – these will have two initial hotspots.

We are developing full business cases to support investment in a network of **Digital Innovation Hubs**. Phase One will establish a Hub in Bristol bringing together academic and industry expertise in underpinning technologies (e.g. cloud computing, digital media etc.) and with a focus on SWW's specialisms in Smart Cities, Digital Media, Autonomous Systems and Digital Health; and a specialist Hub, the Institute for Environmental Risk and Innovation at the Global Environmental Futures Campus in Exeter, allied to the new Met Office supercomputer provided through BEIS investment.

The SIA also identified maximising opportunities from the new Compound Semiconductor Applications Catapult based in the SWW as important as a means of enhancing economic growth from this national centre.

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Section 1: Introduction to the region and SIA process

The South West England and South East Wales Science and Innovation Audit (SWW–SIA) has been undertaken by a consortium that brings together key organisations and businesses from South West England (Cornwall and Isles of Scilly, Gloucestershire, Heart of the South West, Swindon and Wiltshire, and West of England LEPs) and South East Wales.[13]

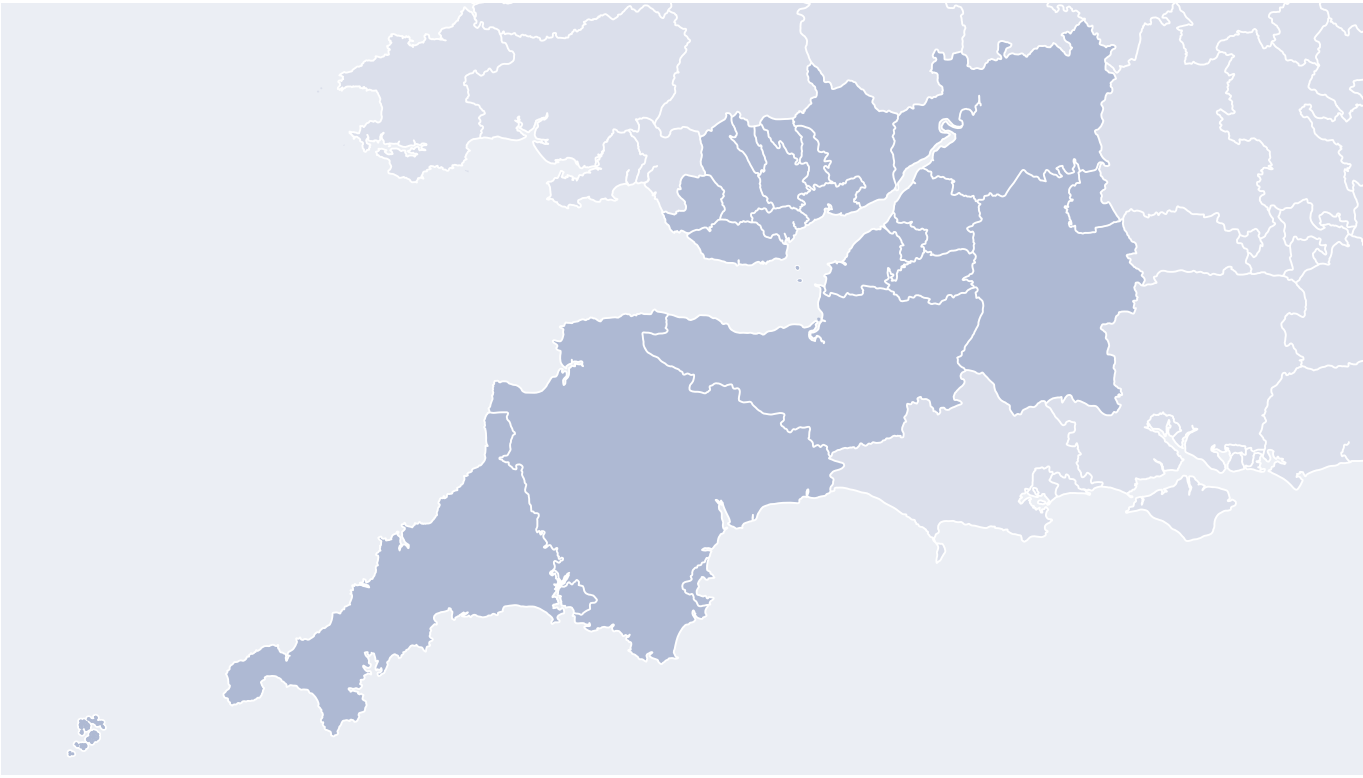

Figure 1. South West England and South East Wales SIA consortium area

The geographic region covered by the SIA has a combined population of 6.2m people; and is less urbanized than England and Wales as a whole with 71% of the population living in an urban area compared to the national average of 82%. Four built up areas have populations over 250,000: Bristol (617k people), Cardiff (447k), Newport (307k) and Plymouth (260k).[14] The South West England and South East Wales Region is referred to throughout the SIA as the SWW.

Labour Market

With 62% of population of 'working age'[15] the SWW has a similar age distribution as the country as a whole. The remainder of the population is broadly evenly split between residents who are aged under 16 (18%) and those who are aged over 65 (20%) – the later ranging from 17% in the West of England to 24% in Cornwall and Isles of Scilly.[16]

Looking ahead, SWW population is projected to increase by more than 400,000 people between 2014 and 2024.[17] However, the working age population is projected to increase more modestly, increasing by 64,300 over the same period.[18]

Latest estimates[19] suggest that the SWW has an employment rate that is slightly above the UK level but is around four percentage points below 'full employment'. Almost 143,000 people are unemployed. The unemployment rate is lower than the national average in all parts of the region and is lowest in Heart of the South West and in Swindon and Wiltshire. Almost ½m people living within the SWW region are self-employed. The rate of self-employment locally is particularly high in Cornwall and Isles of Scilly and Heart of the South West where rates are the highest of all the LEP areas in England.

Human Capital and Talent – "The Skills Pipeline"

While overall the percentage of school leavers achieving five good passes at GCSE including maths and English across the SWW is broadly equivalent to the national average, there is considerable variation in achievement at local authority level.[20] The take up in STEM subjects at A-level shows a 2% decline during 2010–15, with no clear trend across subjects.[21] Almost 8,200 apprenticeships were completed in STEM-related frameworks in 2014–15.[22] These were mostly in engineering and manufacturing technologies but also in information and communication technology – aligning well with the SIA themes.

Within Higher Education there are 160,275 undergraduate students (FPE), of which 48.1% are STEM students (compared to 45.7% in England and Wales), and a further 43,390 postgraduate students (42.1% STEM, compared to 42.5% nationally).[23] Graduate retention data suggest that students domiciled in Cornwall and Isles of Scilly and Wales were most likely to remain within their local area to work upon graduation (with 74.9% and 72.7% retention, compared to 60.7% in Gloucestershire).[24]

Overall the SWW has a very similar proportion of 'science, research, engineering and technology' professional and association professional occupations to the UK average, comprising 7% of all residents in employment. Within the SWW area, Swindon and Wiltshire and West of England LEPs had higher shares of employment in these occupations, ranking 5th and 7th respectively of all LEP areas on this measure.[25]

Qualification levels[26] across the SWW are broadly in line with the UK average but with notably higher percentages of the population qualified to degree level or above in the West of England (44%) and Gloucestershire (41%) (UK=36.9%). When ranking with other LEP areas across England, they rank 5th and 9th respectively. Notwithstanding this, more than ¼ m people aged 16 to 64 living in the consortium area do not have a formal qualification.

Skills Shortages

At the time of the last UK Employer Skills Survey (2015), there were an estimated 81,200 job vacancies in the SWW area of which almost one-quarter (24%) or 19,300 were proving hard-to-fill because of skill shortages. The density of skills-shortage vacancies (i.e. the proportion of vacancies that were hard-to-fill because of skill shortages) was marginally higher than in England and Wales as a whole (23%) and was highest in Swindon and Wiltshire (30%) and Heart of the South West (29%).[27]

Working Futures[28] projections suggest a net requirement of an additional 123,600 workers in the South West and Wales within SIA related sectors between 2014 and 2024. Most of these will be required to replace workers leaving the industries (e.g. through retirement or moving to other sectors) although an additional 15,800 will be required to accommodate growth in the sectors.[29] Most of the increase in demand for workers within these industries will be within professional, associate professional and technical or managerial occupations and will require qualification at QCF4 or above (degree level or above). The net requirement for workers with qualifications lower than QCF2 will fall.

Business Landscape

The number of active enterprises in the SWW has followed the UK trend closely, and at 2012 was showing similar recovery from the recession. Business births in the consortium area dropped considerably during the recession before increasing again from 2010 onwards, in line with the UK trend. However, unlike at the national level, business births did not yet outnumber business deaths in the consortium area at 2012.[30]

Productivity is summarised as follows:

– Measures of labour market productivity[31] show that in SWW LEPs GVA per capita was between £15,403 (Cornwall and Isles of Scilly) and £26,820 (West of England), compared to the SWW average of £20,785.

– As of 2014, total regional GVA was estimated as £121bn in South West England and £54bn in Wales. South West England exhibited a 4.0% growth in GVA compared to 2013, and Wales 2.4% growth.[32]

– Average annual gross full-time pay within SWW LEPs lies between £24,196 (South East Wales) and £32,955 (West of England), the latter of which is higher than the SWW (median) of £28,775.[33]

These figures show that the SWW contains significant variations in economic performance in GVA and full-time pay, and that although some parts of the SWW perform well and indeed exceed the national average, there are significant areas of the SWW that are amongst some of the most deprived and low wage areas in Europe – specifically Cornwall and Isles of Scilly, and parts of the Heart of the South West and South East Wales. This disparity requires Government intervention, and provides a strong justification for investment in the SWW.

15–16% of SWW businesses are 'fast-growing firms', i.e. start-ups surviving three years and reaching £1m turnover. 4–7% of £1m turnover businesses in 2011 grew to a minimum of £3m by 2014. The SWW 3–year survival rates range from 57% in Heart of South West to 70% in South East Wales.[34]

Business has been vocal about the importance of infrastructure in enabling business growth – and that poor infrastructure is a significant restraint on growth.[35]

Transport infrastructure is a significant issue in the SWW and improvements are necessary to stimulate regional activity and growth. Strategic infrastructure has good coverage, but is incomplete: with insufficient capacity, uncompetitive travel times, and incidents and extreme weather threating our resilience.[36]

Availability of superfast broadband in the South West of England (as a % of premises) is consistently below the England average of 85%,[37] and varies between 55% (Heart of the South West) and 81% (West of England). By contrast, in South East Wales, coverage of Superfast and Fibre connections (>30 Mb/s) is generally higher than the Welsh average of 80%, with the exception of Monmouthshire (73%).

Our Hypothesis

By identifying, acting on and investing in innovation opportunities, we will transform partnerships between academia and industry to deliver business growth, productivity and global comparative advantage to the region, for the benefit of the UK.

By 2020 we expect to see a significant increase in highly skilled jobs and growth in the chosen themes, with further spill-over effects from cross cutting technologies that underpin each theme, as the innovation capability and capacity of the region is enhanced.

SWW innovation opportunities were identified by assessing where there was significant research excellence in the knowledge base alongside either existing or emerging industry strengths. This approach identified five broad themes, which were then assessed in depth.

Rationale for Themes

The SIA themes are based on objective assessment of the capacity and interest of existing firms with a regional presence, the research strengths of SWW Universities and Research Organisations, and the potential for breakthrough knowledge to provide a global comparative lead.[38] Theme Rationale. This includes themes of existing global comparative advantage which we need to maintain and build. It also includes themes where a world-class science offering and key industry building blocks need integration and growth to achieve a global position in new and emergent industries. As a result, we undertook the SIA across five themes:

- Aerospace and Advanced Engineering
- New Energy Systems
- Next Generation Microelectronics
- Digital Living Innovation
- Resilience, Environment and Sustainability

We used these themes to analyse the alignment of existing capabilities in the SWW to market needs, to foster development of previous and current investments and to identify additional factors and investment required to deliver a step change in successful innovation, jobs, productivity and economic growth.

SWW Approach and Consortium

To test initial ideas during the preparation of the Expression of Interest, and throughout the SIA process, a wide consortium of interested parties was drawn together. This consisted of business, business organisations, Universities, Research Organisations, Catapults, Local Enterprise Partnerships and Local Authorities within the SWW geographic area. Annex A: Consortium Membership provides a full list. We used a six phase approach to the SIA (see Figure 2).

Figure 2. SIA 6-step process

To determine appropriate actions, we undertook an iterative process, outlined in Figure 3, with stakeholders to identify our proposed opportunities for investment. This was to ensure our proposed actions addressed our evidence base for direct economic benefit.

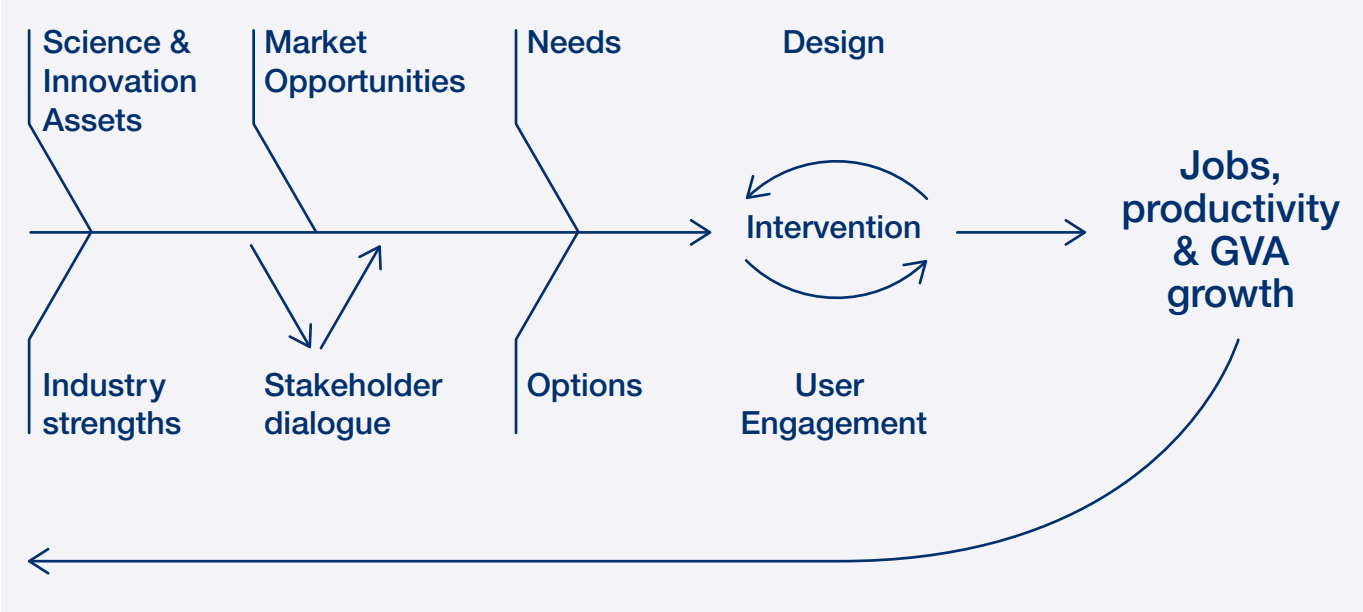

Figure 3. Identifying our proposed opportunities for investment

Our Themes

We now introduce the five SIA themes, which are detailed more fully in Annexes G – K.

Aerospace and Advanced Engineering

The current Aerospace and Advanced Engineering (AAE) activity in the SWW is built on over 150 years of engineering pedigree. Advanced engineering strengths fall into three broad sectors: aerospace, automotive and marine, each with defence and civil applications.

Aerospace – Fourteen of the fifteen largest aerospace companies in the world have research and development, and manufacturing facilities in the SWW[39] with a particular concentration in the West of England which has been a cradle of aviation innovation since the British Empire and Colonial Aeroplane Company opened in Bristol in 1910. There has been over 100 years of continuous development, design and manufacture at this site, which includes global companies such as Airbus, BAE Systems, GKN Aerospace, MBDA Rolls-Royce, Leonardo (Somerset) and QinetiQ (Wiltshire) making it the largest aerospace cluster in the UK, and the second in Europe.

Automotive – industry is concentrated at locations along the M4 with Honda UK Manufacturing in Swindon; and the Ford Engine Plant in South East Wales, as well as high-end manufacturers in Somerset (Ariel Motor Company), West of England (Bristol Cars) and Cardiff (Aston Martin). The SWW is also a home to a spoke of the Advanced Propulsion Centre UK with the internal combustion engine system efficiency centre based at the University of Bath which conducts technology development with automotive companies from across the UK and around the globe, such as Ford, JLR and McLaren.

Marine – SWW strengths lie in marine engineering, historically through the Royal Navy and more recently firms like Babcock, MSubs, Viper Subsea and Princess Yachts. Plymouth has the highest proportion of its employment in manufacturing of any city in Southern England based on marine engineering and ship building is also concentrated in Falmouth (A&P is the UK's largest ship-repair

complex) and North Devon, (Appledore). Marine defence organisations are also located in the SWW region e.g., BMT Defence Services in Bath.

SWW strengths in AAE have grown up alongside the **steel** industry in South Wales.

Additionally, there is significant cross over between the AAE theme and marine renewables within the New Energy theme, as well as Industry 4.0 in Digital Living and sensors in the Next Generation Microelectronics theme; with many AAE firms supported by common supply chains in these related areas.

New Energy Systems

In New Energy Systems there are both important clusters of industrial and R&D activity, and synergies with neighbouring regions.

Marine renewables – The SWW is unique with all renewable resources accessible from ports and infrastructure, and with clusters of specialist industrial and academic activity. We have significant infrastructure in the far South West (Wave Hub, Fab Test, COASTLab etc.). There is an important wider geographical linkage with Southampton, which is reflected in the development of a South Coast Marine Cluster. As recognition of the unique set of geographical and industrial assets, the South West was designated as the first Marine Energy Park in 2012,[40] while the Offshore Renewable Energy Catapult also has a dedicated presence in the area.

Hydrogen / fuel cells – running across the SWW is a corridor of technical expertise, specialism and capacity along the M4, from the Swindon Hydrogen Hub through to Cardiff, including the research centres at Baglan (University of South Wales) and Bath. Swindon saw the UK's first commercial hydrogen refuelling station open at Honda in 2011, with a second due to open at J16 of the M4 this year, growing the extent and potential of the M4 Hydrogen corridor. This 'corridor' needs to be better co-ordinated and networked to increase its potential for growth.

Nuclear – activity centred on the M5 corridor running from Gloucestershire (EDF Energy Generation at Barnwood, Magnox at Berkeley, and Horizon Nuclear in Gloucester), Bristol (EDF Energy NNB (HPC project)) and Somerset, with the nuclear skills centre at Bridgwater, EDF's national learning and development centre, plus the Hinkley C and Oldbury complexes.

There is also an emerging cluster of excellence and good practice in underpinning technologies relating to **distributed energy systems and smart grids**, which will have relevance across many new energy technologies.

The SWW is ideally placed to develop its science and innovation capacity further, and by so doing drive the development of new energy technologies where the UK has the potential to achieve competitive advantage.

Next Generation Microelectronics

The SWW has a long history of microelectronic, photonic and semiconductor companies, as well as world-leading system integrators such as GE and BAE systems. We are home to the largest silicon design cluster outside of the USA[41] and will shortly host the Compound Semiconductor Applications Catapult. SWW universities have a strong track record in relevant cutting edge research and have recently made significant investments in the areas of compound semiconductors and quantum technologies.

Next generation microelectronics represent key enabling technologies which underpin multiple industries such as aerospace, automotive and information technology. The European Semiconductor Industry Association has estimated that impact of micro- and nano-electronics on the whole economy is worth 10% of worldwide GDP and the European Commission has reported that photonics is essential to keeping >10% of the EU economy competitive.[42] Our ambition is to create the foundations for Europe's 5th Semiconductor Cluster, and the world's first cluster dedicated to compound semiconductors in the SWW.

Digital Living Innovation

As a recognised and well-evidenced powerhouse of electronics and computing both in industry and in academia, the SWW has taken a leading role in developing the digital technologies that will transform all aspects of future living with multiple capabilities based on strong established partnerships with corporates, SMEs and universities.

"Digital Living is the way in which our lives are affected by digital products and services. Digital means connectivity; digital means storage; digital means computation. But digital enables much more. Digital means applications become possible to offer new experiences for living, new ways of living and more convenient ways of living" – Michael Hill-King, Huawei Collaboration Director, UK R&D Centre

The strategic importance of the Digital Industries sector for the UK economy and the SWW regional strengths are well established, including in the 2016 Tech Nation report[43] with convergence around: Digital Health; Digital Creative Economy; and Smart Cities and Transport. These are underpinned by:

– Cloud computing (including communications, Internet of Things')
– Digital Media (including Virtual / Augmented Reality, Creative Media)
– Robotics / Autonomous Systems

These in turn build on capabilities within cloud computing, information assurance and cyber security / cryptography, quantum technologies, data analytics, machine learning, sensors, radio frequency, wireless / 5G, high performance computing, autonomous systems, digital media production, wired and photonic networks, and machine vision.

It should be noted that digital technology strengths and opportunities were also identified and mapped in the Resilience, Environment and Sustainability, and Aerospace and Advanced Engineering themes. These industries are underpinned by many of the same technologies but reported within the other themes, highlighting the need for investments the enable greater integration of existing expertise across the region.

Resilience, Environment and Sustainability

The SWW offers unparalleled, extensive and internationally excellent science capability and assets within sustainability and environmental science. Over a quarter of the UK's major environmental research organisations have a base in the SWW region.[44] There are almost 2,000[45] scientists (including more contributors to the 2014 UN IPCC report[46] than in any other area globally), and fast growing research activity in excess of £270m / year. In Devon, the concentration of environmental scientists is four times higher than the national average.[47]

The SWW has a broad-based and strong environmental goods and services sector, alongside LEP priority clusters in environmental futures, agri-food / agri-tech, energy, digital, water, low carbon and high value manufacturing. There are significant opportunities for the SWW region to enhance prosperity and resilience associated with climate and environmental change and sustainable development. Stakeholder and business communities have identified two areas, where we believe we have the potential to be globally competitive. These are Environmental Risk and Data Innovation, and Sustainable Technologies and Development, where future investment will enable the region's science capability to be fully exploited by business within the region and beyond.

This theme is closely aligned with global drivers, including the recent UN Sustainability Goals[48] and the Paris Climate Agreement in 2015.[49] There is an urgent need to utilise environmental data to tackle the risks from natural hazards and address the resilience of socio-economic systems. There is also a huge opportunity surrounding the technology and innovation that will be required to live sustainably. Quotes from business, captured through an independently commissioned survey, summarise the opportunities: *"new business models will be unlocked through future energy and environmental demands and concerns", "the mood and the climate is; Think differently, do things differently, look for different opportunities".*

Section 2: Regional science and innovation assets

The consortium area has 14 specialist research institutions, 15 higher education institutions and 27 Further Education Colleges.[50] (Annex B: Universities, Colleges and Research Organisations). In 2014/15, there were over 200,000 higher education students: 21% of which were postgraduates. 48.1% of undergraduate students were studying STEM subjects, compared to 45.7% in England and Wales.[51]

In terms of talent and the labour force, 60–75% of SWW graduates are retained in their home region. Progression from undergraduate subjects directly in to STEM employment (SOC21, 22, 24 and 31) however is low, with only 3.5% of graduates nationally, and 19.6% from providers with the SWW area moving directly into STEM occupations within the region.[52]

According to the BRES,[53] employment across the SWW area in 2014 in the five SIA themes, defined using SIC codes,[54] was:

- Aerospace and advanced engineering: 98,100 people
- New energy systems: 184,100
- Microelectronics: 18,500
- Digital Living Innovation: 93,800
- Resilience, environment and sustainability: 153,100

Our themes account for around 12.5% employee jobs across the SWW area, with particular concentrations in Gloucestershire (14.5%), Swindon and Wiltshire (13.9%) and the West of England (13.5%).

Location quotients (LQs) relate a sectors share of employee jobs in any one area to that sectors share of employee jobs nationally. An 'LQ'>1 indicates a higher concentration of employment in a particular sector than nationally. We have high shares of employment in:

- Aerospace and advanced engineering in Swindon and Wiltshire (LQ=1.71), West of England (1.53), Heart of the South West (1.27) and Gloucestershire (1.20).
- New energy systems in Gloucestershire (1.41)
- Microelectronics in Gloucestershire (5.48) and South East Wales (2.95)
- Digital Living Innovation in Gloucestershire (1.33)
- Resilience, environment and sustainability in Swindon and Wiltshire (1.25) and West of England (1.26)

Ranking the LQs of the 206 local authority areas across Great Britain reveals particularly high national rankings for:

- Aerospace and advanced engineering in South Gloucestershire (6th), Plymouth (9th), Swindon (12th)
- New energy systems in Gloucestershire (21st), Rhondda, Cynon, Taff (27th) and South Gloucestershire (30th)
- Microelectronics in Torfaen (1st), Caerphilly (2nd), Gloucestershire (3rd), Monmouthshire (5th), Rhondda, Cynon, Taff (7th), Newport (9th) and Blaenau Gwent (12th)
- Digital living innovation in South Gloucestershire (18th)
- Resilience, environment and sustainability in South Gloucestershire (19th) and Bath and North East Somerset (31st).

Aerospace and Advanced Engineering Assets

SWW strengths in Aerospace and Advanced Engineering have been built over decades and have resulted in the rich landscape of industrial primes; systems / structural suppliers; research centres and renowned academic institutions, all with related skills. This community has a long history of collaboration both within and outside of the region. This truly world class and world leading capability has delivered iconic products that the UK has taken great pride in being associated.

Key assets, detailed in Annex G, Appendix AAE1, include:

- National Composites Centre, owned by the University of Bristol, and part of the High Value Manufacturing Catapult.
- Centre for Additive Layer Manufacturing at the University of Exeter, developed in partnership with Airbus Group Innovations.
- Morgan-Botti Lightning Laboratory at Cardiff University, a collaboration between the Welsh Government, Cardiff University and Airbus Group Innovations.
- Bristol Robotics Laboratory, a collaboration between the Universities of Bristol and the West of England with strong industrial and international links.
- Electron Microscopy Centre at Plymouth University which undertakes analysis of materials defects and quality control.
- Powertrain and Vehicle Research Centre at the University of Bath, focused on improving the efficiency and emissions of diesel and petrol engines, and powertrain integration developed in partnership with Ford and JLR.

New business support capacity will be provided by Enterprise Zones at Aerohub[55] at Cornwall Airport Newquay and Goonhilly, including support for a spaceport and growing space cluster,[56] and at Plymouth Devonport (now named Oceansgate).[57]

There has already been considerable investment in developing high value manufacturing capability; the SIA considers that a broader strategy to protect and enhance capabilities elsewhere in the Industrial Value Chain is essential. Specifically, High Value Engineering Design and System Integration (e.g. whole structure, sub-structure and propulsion) are core to the SWW region and core to the protection of longer term manufacturing, recognised by the AGP, ATI, APC and the CEO of the HVM Catapults. Additionally, opportunities exist in developing Composite Capabilities and addressing life-long learning to manage the transition into Industry 4.0.

New Energy Systems Assets

The SWW has a wealth of research and innovation assets related to the New Energy theme, with academic research centres, major industrial R&D capacity and focused innovation support and skills infrastructure.

Key assets, detailed in Annex H, Appendix NES1, include:

- Major research centres and testing facilities relating to marine renewables, with significant synergies across institutions, but particularly in Plymouth (the largest marine institute in Europe at Plymouth University, and the home of Plymouth Marine Laboratory), and at the University of Exeter's Marine Energy Group, and in major collaborative projects such as PRIMARE and MARINET. The presence of the unique WaveHub facility off the Cornish coast has been the catalyst for much of this collaborative effort, while the creation of the Enterprise Zone at Oceansgate will be a key driver of innovation led business growth in the future.
- Academic and industrial capabilities in nuclear operation, new build and decommissioning, particularly centred on the South West Nuclear Hub and the Bristol-Oxford Nuclear Research

Centre, with a strong and complementary industrial R&D capability, as well as significant skills infrastructure (National College for nuclear at Bridgwater College and the Gloucestershire Science and Technology Park at the old Berkeley nuclear laboratories) and innovation support via the Somerset Energy Innovation Centre and Enterprise Zone near Bridgwater.

– Significant hydrogen production, storage and fuel cell research with its academic focus at the Sustainable Environment Research Centre (University of South Wales), the Cardiff Catalysis Institute and at Bath, as well as world leading industrial R&D and collaboration including Johnson Matthey Fuel Cells in Swindon.
– A number of leading research centres focused on underpinning technologies and energy systems including the Energy Systems Research Institute, the Centre for Integrated Renewable Energy Generation and Supply and the National Grid Centre (Cardiff) and the Institute for Sustainable Energy and Environment (Bath).

This rich R&D environment, in both research institutions and industry, provides a bedrock for further development that will add real value to the UK's energy systems innovation capacity.

Next Generation Microelectronics Assets

The SWW has a long history of microelectronics, photonics and semiconductor excellence that provides a wealth of science and innovation assets, and a highly trained workforce. We have the ambition to create the world's first cluster dedicated to compound semiconductors.

Key assets for growing, processing and characterising electronic devices, detailed in Annex I, Appendix NGM2, include:

– David Bullett Nanofabrication Laboratory which hosts the UK's Electron Beam Lithography Service at the University of Bath
– Institute of Compound Semiconductor (£80m capital investment ongoing) at Cardiff University
– Quantum Engineering Technology Labs at the University of Bristol
– Savchenko Centre for Nanoscience at the University of Exeter
– Institute for Bio-Sensing Technology with collaboration between the University of the West of England and University of Bristol
– Electronics and Photonics Innovation Centre in Torbay (under development)
– Compound Semiconductor Centre – a Cardiff University / IQE joint venture company

The UK Government recently announced £50m over five years[58] to establish the Compound Semiconductor Applications Catapult in South Wales. It will provide translational research facilities to accelerate the commercialisation of compound semiconductors in key applications such as: healthcare, the digital economy, energy, transport, defence and security, and space. It will be a cornerstone for establishing the compound semiconductor cluster, and there are well-developed plans to develop the cluster further with a low cost, high throughput, open access compound semiconductor epitaxy foundry pilot line.

Digital Living Innovation Assets

Our nationally recognised strengths are built upon a long history of academic and industry excellence and innovation in underpinning digital technologies and of innovative companies, large and small, delivering applications across many sectors. The SWW region has a large number of research and innovation assets related to this theme, including academic research centres and groups, industry innovation, development capacity and focused innovation support, which we are harnessing to maintain and grow the SWW's world leading position.

Given the nature of the theme, with applications areas underpinned by technologies, SWW assets are widely spread. Those of scale are described in Annex J, Appendix DL1, and include:

– Corsham Institute; Connecting for Care; Neuro-Cognitive Research; West of England Genomic Centre; The Diabetes Digital Coach Test Bed; MRC Integrated Epidemiology Unit; Biomedical Modelling and Analysis; Telecare and Telehealth; and part of the Precision Medicine Catapult.
– The Pervasive Media Studio, Creative Arts and Games; Playable City; Creative Cardiff; Connected Performance; and the REACT Hub.
– Games Hub; VR World Congress; motion entertainment research; immersive vision @i-DAT; and interactive systems.
– UK Collaboratorium for Research and Infrastructures in Cities; Centre for Transport and Society; SMART Islands; Exeter City Futures; Centre for Transport and Society and the Bristol Urban Area Diagnostics Pilot.
– Smart internet lab; Jean Golding Data Institute; Social Data Science Lab.; Cryptography and Security Institute; Heilbronn Institute; intelligent systems Group, HPC Wales, Bristol is Open; and the SW Centre in Satellite Applications Catapult.
– Bristol Robotics Laboratory Assisted Living Demonstrator; Plymouth Centre for Robotics and Neural Systems; Autonomous Marine Systems; Autonomous drone / unmanned aircraft systems and Autonomous Vehicles.
– GCHQ, with its expertise in cyber security and data, is a core digital asset underpinning the planned Cyber Innovation Centre and Cyber Park in Cheltenham, with the cluster of cyber-related businesses in Gloucestershire.

Resilience, Environment and Sustainability Assets

27% of the major public research organisations in the UK with relevance to resilience, environment and sustainability are based in the region.[59] *The SWW has an extensive network of eight universities, nine research organisations and other significant science and innovation assets relevant to Resilience, Environment and Sustainability.*[60] *Key industry sectors identified by LEPs include agri-food/tech, energy, water, low carbon and high value manufacturing building on a broad-based environmental goods and services sector.*

Key assets, detailed in Annex K, Appendix RES2, include:

– University Centres / Institutes in Sustainable Chemical Technologies; Sustainable Energy and Environment; Sustainable Places; Sustainable Building Design, Building Systems and Informatics; Innovative Construction Materials, Global Change, Food Security, Global Dynamic Environment, Glaciology, Environmental Risk; Catalysis; Water Research; Sustainable Planning and Environments; Water Systems; Environment and Sustainability; Climate Systems; Weather Forecast; Earth Systems Science; Land, Environment, Economics and Policy; Countryside and Community Research; Marine; and Sustainable Earth.
– Met Office: next generation supercomputer, Hadley Centre for Climate Science and Informatics Lab; Plymouth Marine Laboratory; Rothamsted North Wyke, a BBSRC National Capability; UK Hydrographic Office; Marine Biological Association; Sir Alister Hardy Foundation for Ocean Science.
– Goonhilly Earth Station; Satellite Applications Catapult Centre of Excellence; Flood Forecasting Centre; Environment Agency, HQ; Natural Resources Wales, HQ in Cardiff; three large water companies – South West Water (and wider Pennon Group), Welsh Water and Wessex Water; Future Farm, Duchy College; UK Catalysis Hub; WRc, Swindon; Brixham Blue Environmental Hub; Westcountry Rivers Trust; Exeter Science Park and Global Environmental Futures Campus; and Plymouth Science Park (established cluster of environmental technology companies).

The SWW is rich in natural capital assets, and the ecosystem services that derive from them. Regional policymakers have identified the natural environment as a key driver of prosperity and wellbeing, with Cornwall and Isles of Scilly, Heart of the South West, Gloucestershire and West of England LEPs all recognising the importance of their natural capital. Building on this, we have the potential to be globally competitive in Environmental Risk and Data Innovation, and Sustainable Technologies and Development.

Section 3: Excellence in science and research

Excellence in science and research can be found across the SWW region in all five SIA themes. Data from the 2014 Research Excellence Framework (REF) exercise show that the SWW area accounted for 16% of the UK's REF-submitted university researchers.[61] Highlights include:

– University of Bath's submission in Aeronautical, Mechanical, Chemical and Manufacturing Engineering represents 5.3% of the UK's REF-submitted staff.

– University of Bristol's submission in General Engineering which represents 5.0% of the UK's REF-submitted staff.

Our REF research income over the period 2010–15, has grown from £300.8m in 2010 to £344.7m in 2015, an increase of 14.6%. The highest growth has been in Engineering and Physical Sciences, where income increased by over £23.4m.

Over the same period, 2010–15, a total of 2,531 Research-Council funded projects have been undertaken in the SWW area, led by 1,073 organisations (Gateway to Research). 27% (691) were funded by EPSRC and 20% (510) were funded by NERC.[62]

A total of £1.04bn was received from the UK Research Councils in this period, with the largest proportion coming from the EPSRC (43%, £443m), followed by MRC (15%), NERC (12%), BBSRC (12%), ESRC (10%), AHRC (5%), and STFC (3%).[63]

Significant research excellence also resides in non-HE research organisations within the SWW, and this is detailed within the relevant themes below.

Aerospace and Advanced Engineering Excellence

Approximately 250 academic staff based at the region's Universities are involved in AAE research. Since 2008 the AAE academic community have trained over 750 PhD students with 90% of the research activity classified as world-leading or internationally excellent (REF 4 and 3*, respectively).*[64] *Research income totalled £210m during 2008-15.*[65]

Researchers are drawn from 10 REF Units of Assessment (UoA), with the majority associated in Aeronautical, Mechanical, Chemical and Manufacturing Engineering, and in General Engineering. 21 REF Impact Case Stories are directly associated with academics from this theme, pointing to excellence in:

– Design and manufacture processes: e.g. composite wing structures, light-weighting and performance enhancement of aerospace structures, and improving car production processes

– Decarbonisation through improvements in engine fuel efficiency

– Modelling, simulation and testing of new materials (composites, steel and alloys, concrete) and structures applicable across AAE

In the period 2008–15 the total research income in AAE across the consortium's universities was over £210m, with 2014/15 representing the academic year with the highest research income.[66] This is reinforced by the region's Universities being awarded eight further recent AAE projects worth over £1m each and all involving at least one commercial partner.

Publication analysis[67] for the period 2011–15 shows the combined publishing output of SWW Universities outperforms the UK, Europe and World in Aerospace: 23% of the University of Bristol's papers on this topic are highly cited (compared to 20% UK, 17% Europe, 10% World) and 84% of the University of Bath's articles are found in high impact journals (76% UK, 73% Europe, 53% World).

The SWW outperforms the UK, European and World averages for publication citations and impact

in Automotive Engineering with 63% of the University of Bristol's output being in highly cited papers, compared to UK (21%), Europe (16%) and the World (12%).

SWW Universities out-perform the Russell Group (which includes Bristol, Cardiff and Exeter Universities) and the UK as a whole on citation impact, publishing in high impact journals and co-publishing with industry in composites. We are world-leading in wing aerodynamics; composite materials, laminates and delamination, buckling, fibres and textiles.

Cardiff University is the leading UK institution for publishing on supply chains and is among the top 10 most active universities worldwide for this topic.

Over the period 2004–13 companies in the SWW area and associated with AAE filed over 1,500 patents (based on named inventors). Across the SWW area, eight of the ten most active companies in terms of protecting their intellectual property are associated with the theme, including Dyson, Airbus, Rolls-Royce, Renishaw, BAE Systems, Qinetiq, Vecto Gray Controls and Edwards. Furthermore, the Universities of Bath, Bristol and Cardiff all appear in the top 40 organisations in terms of number of patent filings.[68]

New Energy Systems Excellence

The SIA area has an extensive world class research community related to New Energy across a range of disciplines, with a track record of attracting research income worth nearly £150m in the past seven years.[69]

SIA analysis has shown that there are 232 academic staff undertaking research related to the New Energy theme, with 164 submitted to the REF from the SWW.[70] The theme covers a broad range of academic disciplines, across 17 REF UoAs, as outlined in Appendix NES2. This data, and an analysis of UoA environment statements and impact case studies[71] (see Appendix NES3) reveals that the main clusters of academic excellence within the New Energy theme are in the fields of:

- Earth Systems and Environmental Sciences: Marine renewable energy; Environmental impact; and Resource modelling and simulation.
- Chemistry: design and synthesis of materials for hydrogen storage, fuel cells and catalysts for the enhanced production of biofuels; developing a quantitative understanding of structures, mechanisms and interactions in organic chemistry, with applications in energy; and Energy storage.
- General Engineering: Coastal processes; Hydrodynamics of marine renewable energy; Physical and numerical modelling of marine renewable energy; Autonomous marine vehicles; Marine composite structures; Marine systems and interactions on energy generation; Performance and reliability of advanced structural materials in marine structures, offshore energy devices, and thermal power plant, including nuclear pressure vessels and steam turbine components; Combined network analysis and smart grids; grid infrastructure; hazard analysis; unconventional fuels; combustion diagnostics and control; emission characterisation; tidal energy; and Integration of renewables, energy networks and infrastructure.

Much of this research excellence cuts across a number of New Energy technologies, and indeed is relevant more broadly across the SIA themes. These synergies are important as much of the world class R&D being undertaken in the SWW region can be applied across a range of energy (and indeed other technologies). Modelling and simulation is a good example of this, with relevance to a range of engineering and manufacturing sectors.

An analysis of research income associated with New Energy shows that during 2008–15 the total research income across the consortium was £149m, with an upward trend over the period.[72] This upward trend has been confirmed more recently with major awards totalling £56m in 2014–16.

An analysis of publication data relating related to the New Energy theme has been undertaken,

based on the 230 academic staff identified by consortium institutions that are active in the field, and searching by a comprehensive list of keywords / phrases to focus the search on areas of particular relevance. There were over 1,400 relevant published articles during 2011–16, and a high level of citation impact.[73] A third of all papers were in publications in the top 10% most cited globally, and over 40% of papers involved international collaboration. Further data and analysis can be found in Appendix NES4.

Next Generation Microelectronics Excellence

There are 220 academics whose research interests align to the theme, with expertise in photonics, wireless, sensors, compound semiconductors and quantum engineering.[74] Research income has grown from £14.5 to £33m per annum during the period 2008–15.[75]

The science and engineering of next generation microelectronics and photonics spans a broad "stack" of activities that include theory, materials science, design and device architectures, manufacturing technologies and systems integration. The term microelectronics is a catch-all. The SWW has research activities that align with each component of the "stack" but has particular strength in materials science, semiconductor growth and fabrication, chip architecture and design, integration and the development of next generation technologies such as quantum sensors and computing.

SWW strengths include:

- **Photonics** – novel Photonic Crystal Fibre, Terahertz Plasmonics, Photonic Integrated Circuits, Metamaterials and Graphene technologies research that opens up the potential for unprecedented broadband speeds
- **Wireless** – pioneering wireless communications technologies with the underlying protocols for Wi-Fi being developed in region, advances in wireless spectrum analysis for the policing of critical national infrastructure and the first practical demonstrations of waveform engineering
- **Sensors** – development of magneto-resistive sensors and a specialist security thread in banknotes; development of bio-sensing and other new sensor technologies for health applications; one of two Internet of Things NHS test beds to evaluate sensor technology in the health sector, e.g. evaluation of glucose sensors
- **Compound Semiconductors** – GaN, III-V on Silicon and other photonic and electronic technologies, high performance facilities for compound semiconductor materials and device research.
- **Quantum** – Three consortium partners in the UK Quantum Technologies Hub network; leading approaches in Quantum Computing, Communications, Sensing and Measurement as well as the developments in the foundations of Quantum Information Science.

With the increased focus on design and application of novel materials, companies are increasingly looking towards universities to produce the next generation of highly skilled staff with the necessary technical and entrepreneurial expertise to drive the industry forward.

Physics, Electrical and Electronic Engineering (E&EE), General Engineering and Computer Science forms the core research activity relevant to the theme[76] – see Appendix NGM3 for REF data. Universities in the SWW area attracted £33m research income in 2014–15,[77] and have 220 academics whose research interests are directly aligned to the theme.

With the increased focused on design and novel materials, companies are increasingly looking towards universities to produce the next generation of highly skilled staff to drive the industry forward. In terms of supply, in 2014/15, the SWW region produced:[78]

- 335 physics graduates, 15 postgraduates and 65 PhDs

– 435 E&EE graduates, 175 postgraduates and 55 PhDs
– 840 computer science graduates, 300 postgraduates and 55 PhDs

The SWW hosts national EPSRC Centres for Doctoral Training in Condensed Matter Physics; Functional Nano-Materials and Quantum Engineering; and Metamaterials.

The shortage of suitable skills in this theme has been recognised as a regional priority.

Publication analysis[79] highlighted 2,029 papers in international peer reviewed journals for the period 2011–16 which were directly relevant to the theme. These represented 8–10% of UK total publications in this area and were of a particularly high quality, with a higher field-weighted citation impact (2.08 vs 1.69) and more citations per publication (10.7 vs 7.9) than the UK average. Of particular note, 591 of the region's publications fell within the top 10% most cited publications worldwide.

Digital Living Innovation Excellence

We have identified a total of 634 researchers working in fields directly related to the Digital Living theme in SWW Universities.[80] *Remarkably, the region contributes some 25% of the UK's research publications in the broad area of Digital Living, and 5% of the entire global output.*[81] *Total research income for the period 2008–15 totalled £261.7m.*[82]

Researchers active in the Digital Living theme were submitted to the 2014 REF across 29 different UoAs[83] of the 36 defined in the REF. The large number of UoAs is indicative of the very wide footprint that the Digital Living theme has across academic disciplines. Focussing on researchers directly identified within the theme, the 10 UoAs with most direct relevance were analysed and showed 79.2% of the overall REF quality profile was rated as world-leading (4*) or internationally excellent (3*). 86.5% of the related impact case studies were rated as having outstanding (4*) or very considerable (3*) impact.

Analysis of publications data[84] was undertaken to determine the proportion of SWW research outputs in the top 10% in the world based on Field Weighted Citations Index data. The region contributes some 25% of the UK's research publications in the broad area of Digital Living, and 5% of the entire global output (3899 publications from 2011–15). Furthermore regional publications outperform the UK as a whole, in terms of Field Weighted Citations (FWCI) a measure of the frequency that papers are cited in other publications (27% vs. 23%) and in publications in the top 10% of Journals (32% vs 29%). In addition using authorship as the measure 3% of papers have industry co-authors (UK=3%) and 52% have international co-authors (UK= 47%).

Research grants and awards income in fields related to the Digital Living theme totalled £52.6m in 2014/15, and showed a strong increase of 40% in real terms from £29.6m in 2008/9. Total research income for the period 2008–15 totalled £261.7m.[85]

The SWW research income in Digital Living shows a healthy balance of funders with Research Councils making long-term investments in strong underpinning alongside funders of more applied work. Annex J Appendix DL4 provides further details of research income by institution and funder type.

The University of Bristol hosts the EPSRC Centre for Doctoral Training in Communications. The University of Bath, together with Bournemouth University, hosts the Centre for Digital Entertainment, the EPSRC Centre for Doctoral Training in Games, Visual effects and Animation. The EPSRC Centre for Doctoral Training in Future Autonomous and Robotic Systems: FARSCOPE is delivered jointly by the University of Bristol and the University of the West of England through the Bristol Robotics Laboratory.

Resilience, Environment and Sustainability Excellence

The SWW region demonstrates a significant intensity of internationally excellent science in a breadth of relevant academic disciplines, with nearly 2,000 scientists[86] *currently working in relevant areas, £271m research activity*[87] *in 2014/15 and presence of 27% of the UK's major environmental*

research organisations.[88] *Devon in particular has four times more environmental scientists than the national average.*[89] *The SWW region's science strengths in comparison to the rest of the UK are in geography, chemistry, engineering, earth and environmental sciences. This science capability is vibrant and growing faster than national comparators.*

The theme covers a very broad range of academic disciplines, stretching across 35 REF UoAs, with 742 FTE academic staff submitted to REF 2014,[90] where 77% of science was judged to be internationally excellent (3* or 4*). Particular disciplines where there was a concentration of high quality outputs and significant volumes of staff submitted (>40) include: Biological Sciences, Agriculture, Veterinary and Food, Earth Systems and Environmental Science, Chemistry, General Engineering, Architecture, Built Environment and Planning, and Geography.

When the REF 2014 Research Power[91] for these UoAs was analysed against the leading UK HEIs, a particular strength of the consortium was identified in Geography. There were also 32% more scientists working in these UoAs in the consortium (27.5%) compared to the average for the UK (20.9%), showing an intensity of relevant academic expertise.[92] Analysis of REF data 2008-12 indicates, 2,403 doctorates were awarded by the SWW consortium in relevant UoAs.[93]

There are nearly 2,000 theme-related scientists currently active in the SWW region,[94] 1,119 from the universities and 858 at SWW major Research Organisations (representing 27% of all UK major environmental Research Organisations): MBA (8); Met Office (639); PML (98); Rothamsted North Wyke (25); SAHFOS (35); and UKHO (53). We have also undertaken some analysis that has identified a particular hot spot of relevant scientific activity in Devon,[95] indicating that approximately 3.4% of people employed in professional science roles are working in areas relevant to the theme, this compares to a UK average of 0.8% (i.e. four times higher than the national average).

Total university research income relevant to the theme during 2008-15 was in excess of £430m, growing 55% from £49m in 2008/09 to £76m in 2014/15.[96] By way of a comparison the growth in research income over the same period for the Russell Group (all disciplines) was 36%.[97] A further £195m of research income in 2014/15 came to SWW research organisations, making the combined total research income of £271m in 2014/15.[98]

Publication analysis in theme related journal categories[99] showed a greater proportion of outputs in the top 10% of the world compared to the rest of the UK and world, and also comparing favourably to the Russell Group. Categories showing the greatest differentiator from the rest of the UK are Process Chemistry and Technology, General Earth and Planetary Sciences, Civil and Structural Engineering, and Environmental Science. In the CWTS 2016 Leiden Rankings[100] for 'Life and Earth Sciences' two of SWW institutions are in the World top 35, Europe top nine, and UK top six (based on proportion of publications in top 10% of field). The consortium has a combined total of nine academics named in the Thompson Reuters Highly Cited list, representing the world's most influential scientists: the University of Exeter and the Met office each have three scientists listed in Environmental Sciences, the University of Bristol has two listed in Agricultural Sciences while Cardiff University has one in Chemistry.

The Met Office has an international reputation for world-class environmental science: its climate research centre, the Hadley Centre, has been ranked as the world's leading geophysical institution, ahead of Harvard and Princeton, in terms of the influence of its peer reviewed publications.[101] The Met Office represents the UK at EUMETSAT[102] (European organisation for the exploitation of meteorological satellites – an intergovernmental organisation which supplies weather and climate-related satellite data, images and products from seven satellites to its member states, including the UK), in relation to scientific advice regarding the use of satellite data, ocean observations, instruments and missions, international relation and data policy.

Section 4: Innovation strengths and growth points

The SWW has key business clusters within each of the five SIA themes, and in this section we will detail where the high-growth businesses are concentrated and the rich infrastructure of business support and economic development assets to promote innovation and growth.

Analysis of businesses in English LEP areas within the SWW shows that 16% of firms are fast-growing, creating on average almost 3% of all new jobs. Almost 6% of businesses with turnover of £1m in 2011 grew to have turnover of at least £3m in 2014. On average, 60% of all new businesses in the consortium area survive for three years.[103]

There were 37,870 enterprises[104] operating within the SIA themes across the SWW region in 2015:

- Aerospace and advanced engineering: 7,775
- New energy systems: 22,815
- Microelectronics: 505
- Digital living innovation: 14,870
- Resilience, environment and sustainability: 25,295

SWW themes account for around one in six enterprises in the area (16.5%), rising to one in five in the West of England (20.9%) and Swindon and Wiltshire (19.5%).

Location quotient analysis suggests particular concentrations of specialised activity in the following:

- Aerospace and advanced engineering in West of England (LQ=1.17)
- New energy systems in West of England (1.10)
- Microelectronics in Swindon and Wiltshire (1.30) and West of England (1.18)
- Digital Living in West of England (1.20) and Swindon and Wiltshire (1.19)
- Resilience, environment and sustainability in West of England (1.16) and Swindon and Wiltshire (1.10)

The SWW accounts for:[105]

- 9% of the amount claimed nationally under the SME R&D tax credit scheme (HMRC).
- 6% of the amount claimed nationally through all R&D Tax schemes. (HMRC).
- An average, per person Business Expenditure on R&D of £797 (BIS and ONS).
- 7% of the UK's FDI successes (97) in 2013, though this is based on a combination of South West England and the whole of Wales, due to data limitations (BIS).
- A total of £965m in Private Equity and Venture Capital was invested in South West England and Wales (all) over the period 2012–14. On average, 0.3 companies per 1,000 VAT registered local units have received investment from these sources over 2012–14 (BVCA).

The SWW received a total of £849m in grants from InnovateUK during 2004–16,[106] with:

- £52m (6%) in Low Impact Buildings.
- £41m (5%) in High Value Manufacturing.
- Innovate UK invested £15.20 per person in South West England and £2.30 per person in Wales (all) in 2013/14 (BIS).

One in five firms in the SWW business base (18%) reported being active in product and service innovation during 2010–12, with 15% of innovating firms undertaking R&D. Two in five innovating firms (41%) introduced new to the market (high risk) innovation, and one in ten (11%) innovating firms innovate their own processes in order to increase capability and capacity.[107]

The SWW has developed an extensive distributed network of science and technology parks, growth hubs and university / business partnerships. These support both technology-led innovation and technology transfer in the SIA themes, but also wider innovation and business growth capacity across the region. Key assets include the Bristol and Bath, Exeter, and Plymouth Science Parks, and the Science and Technology Park at Berkeley and the proposed Cheltenham Cyber Park, all of which have investment potential to support future innovation. See Annex D for a list of Science Parks and Innovation Centres.

Aerospace and Advanced Engineering Innovation

In 2015, across the SWW area there were 7,775 enterprises operating within Aerospace and Advanced Engineering.[108] *This represented an increase of 29% over the past five years, with much of this growth occurring after 2012. This is more than twice the average rate of growth in number of enterprises across industries in the SWW region (13%).*[109] *We host the largest aerospace cluster in the UK, and 2nd in Europe, with 20% of the UK aerospace workforce.*[110]

Approximately 475 companies are associated with the aerospace sector with a value to the economy of £3.2bn and Gross Value Added (GVA) of £2.3bn,[111] 190 are associated with the automotive sector, 150 with the marine sector and 140 with steel. Furthermore, 14 of the 15 largest aerospace companies in the world have a presence in the South West[112] and sector exports from the region are estimated to account for between 50 – 65% of sales.[113] 1015, 1385, and 3805 companies were classified under Engineering Design for Production and Process, Technical Consulting in Engineering and Other Engineering codes, respectively. However, over 90% of these companies employed fewer than 10 people.[114]

Between October 2013 and May 2016 the SWW region's SME population had the highest uptake of NATEP projects (35) and highest predicted growth in jobs.[115] Moreover, a significant number of these projects undertaken in the region were in innovative materials for aero-structures and components, particularly composites. This links directly to the ATI pillars and themes and support the national AGP strategy.

According to the Business Register and Employment Survey 98,100 people are employed in AAE in the SWW, representing over 12% of all those in employed in this sector in Great Britain (812,600).[116] Employment in AAE has been rising locally and in 2014, was 9,800 (10.9%) higher than it was in 2009. This is a much larger percentage increase than employment across all industries in the SWW region (0.6%) and is higher than the industry average across Great Britain (6.6%).[117]

Jobs in AAE are high value: productivity throughout the aerospace sector is estimated at £54,000 per FTE, rising to £73,000 amongst the major aerospace companies, compared to a regional average of £43,000 per FTE. More than 30% of UK aerospace employees are educated to degree level or above, compared to a national average of 21% for the total working age population.[118] Despite a projected decrease in the total number of people employed in AAE in the region between 2010 and 2020, the replacement demand, will be roughly twice the scale of the employment decline; a net requirement for 2,500 additional employees in advanced engineering over the next ten years.[119]

These sectors are underpinned by technical engineering services, materials and component supply chains and research and experimental development in the region, with over 42,000 jobs classified under general engineering activities, engineering design activities for industrial process as well as

engineering related scientific and technical consulting activities.[120] Approximately 65% of workers engaged in these industries are qualified to at least NVQ Level 3 or above.[121] Strengths by LEP area are in Annex G.

New Energy Systems Innovation

Across New Energy the SWW has potential to deliver significant growth and high value jobs, driven by innovative businesses and collaborative R&D, with positive impact across the whole geography.

Marine renewables

The number of people directly employed in the South West England renewables industry overall has grown to 12,800 people. Based on current growth rates, it is predicted there will be 16,000 in 2020.[122] The South West Renewable Energy Manifesto sets out how meeting the 15% target in the south west could deliver £10bn of investment and up to 34,000 jobs.

The majority of this employment is related to onshore wind, PV, and renewable heat. The marine renewables sector currently makes up only a small part of the total. However, in the past seven years the South West has invested over £100m to provide world leading research and demonstration marine renewables facilities.[123] The new Demonstration Zones off the north coast of Devon and Cornwall provide the next development step to these facilities. Reflecting these assets and investment, the South West was designated as the first Marine Energy Park in 2012, bringing together research and assets from the Isles of Scilly to the Severn. Bristol has become a centre for tidal technology development, and Plymouth and Cornwall research and demonstration facilities have attracted UK and international wave and tidal developers such as Wello, Carnegie, Seabased, Simply Blue, Seatricity, Searaser, OWEL and Tocardo. See Annex H Appendix NES5 for further details.

The SWW also has an important underpinning and enabling capability in manufacturing for the marine environment with significant expertise and capability in the design and manufacture of complex composite structures, e.g. wind and tidal turbine blades. Engineering companies include: Babcock, BMT, LICenergy, Ocean Fabrication, MSubs, Sub Marine Services, Viper Subsea, Teignbridge Propellors Apex Fluid Engineering and Thales Underwater Systems. There are also significant numbers of consultancy companies covering renewable energy, technical and engineering, oceanographic, naval architects and environmental consultancies – including: Arup, GoBe, ClearLead, Hayes McKenzie Partnership, Johns Associates, BSW Consulting, Clarehill Associates, Parsons Brinckerhoff and Royal Haskoning.[124]

As the marine renewables sector expands it is expected that the number of long term jobs will increase, with an ambition to reach over 3,000 permanent and long term jobs by 2030, plus a potential average of 1,900 jobs (2018–30) involved in the construction of major tidal lagoons and offshore wind projects.[125] With regard to tidal lagoons, the current Independent Review, led by industry expert Charles Hendry, will be influential and may provide fresh impetus following previous reviews of the Cardiff Western barrage, to capitalise on the tidal range expertise: academic, developer (Tidal Lagoon Power) and supply chain, that exists in the SWW area.

Hydrogen Storage / Fuel Cells

According to the UK Hydrogen and Fuel Cell Association[126] there are currently over 100 UK companies, as well as over 35 academic and contract research groups highly active in fuel cells and hydrogen. Within the SWW area, and stretching along the M4 corridor is a cluster of businesses with significant R&D activity in the field including Johnson Matthey, Fuel Cell Systems, Cella and Auriga Energy as well as large global players such as Air Products, MMI and BOC / Linde. The UK fuel cell industry is characterised by a number of world class system developers, active across a range of application areas.

Nuclear new build, operation and decommissioning

While considerable focus has been given to the development of Hinkley Point C as a driver of supply chain development and investment (including that in the Somerset Energy Innovation Centre and the approved Enterprise Zone at Huntspill near Bridgwater), there is an existing cluster of R&D activity particularly around Bristol, Bridgwater / Taunton and Gloucester / Cheltenham.[127]

The Berkeley site in South Gloucestershire is a potentially significant asset and is being developed as the Gloucestershire Science and Technology Park. Magnox and Cavendish Nuclear have a presence there, and Growth Deal funding is supporting the development. If Oldbury is confirmed as the site of a new nuclear power station, the Berkeley site will take on additional significance as a centre for training, innovation and support.

The SWW also hosts the two key nuclear regulators: the Office for Nuclear Regulation and the Environment Agency and with the headquarters of EDF Energy Existing Generation, Magnox Ltd, Horizon Nuclear Power and NNB Genco there is an emerging centre of excellence for nuclear power station development, licensing, operation and decommissioning in the SWW.[128]

The Nuclear Industry Association lists 103 individual business units within the consortium area, employing 6,600 people.[129]

Distributed / smart systems

The UK is uniquely placed to be a market leader in smart systems and energy storage, creating a major new supply chain with opportunities to develop high value jobs, innovation and inward investment. The UK already has an established position as a world leader in data analytics and software development.[130] The sector can be broken down into key categories: smart grid infrastructure; advance meter infrastructure; smart distributed generation integration; energy storage; demand side response; and consultancy services.

There are clear linkages with these capabilities and other themes within the SIA, particularly around Digital Living. Regen SW's national directory for the Smart energy and storage supply chain reveals particular clusters of activity in the SWW area around battery and inverter manufacturing, and electric vehicles. Other projects include:

- Western Power Distribution managing the grid network in real time: Active Network Management connections within the SIA area in Bridgwater, submitted under Regen SW's Renewable Energy Grid Collaboration Service.
- Smart Cornwall, and the Smart Islands programme which will be a first project to demonstrate a replicable, scalable model of how an individual community can transition from a carbon intensive to a low carbon community.
- Distributed / localised / decentralised energy systems in communities such as Wadebridge (WREN) and Exeter (Cranbrook and Science Park as well as city wide ongoing developments).
- Energy Systems Catapult Smart Systems and Heat demonstrator programme large scale demonstrators, one of which is adjacent to the SIA area in Bridgend, South Wales, using the expertise from South Wales universities.

Next Generation Microelectronics Innovation

There has been considerable consolidation within the microelectronics industry in the past 15 years as volume production has shifted to Asia. This has led to a much more fragmented industry and enabled companies and clusters to emerge which focus on a particular specialisation within the value chain such as chip design, device packaging and integration.

The SWW is home to around 685 microelectronics companies[131] with particular concentrations around Bath, Bristol, Cardiff, Exeter, Plymouth and Torbay. These companies have a combined turnover in

excess of £1.6bn and employ 8,400 people in the SWW region.[132] Such employment is particularly important as the wages within the sector are substantially higher than the regional average.

The SWW has a number of next generation microelectronics companies across the entire value chain. The industry is highly international with many regional companies fully integrated into global supply chains with high levels of export. The SWW is also home to a number of world-leading prime system integrators such as General Dynamics, Airbus, Rolls-Royce, Boeing Defence UK and BAE Systems. These systems integrators bring together various components and sub-systems to provide the technological solutions that drive advances in defence, aerospace, healthcare, Internet of Things, robotics etc.

SWW expertise can be clustered into three distinct but overlapping sectors:

– Microprocessor and Communications Chip Design: Microprocessor and signal processing chips, software, design tools and associated technologies.
– Semiconductors: Design, fabrication, test / qualification and packaging of devices.
– Photonics: Design, prototyping, fabrication, test / qualification and packaging of devices.

Key companies include: Plessey, Microsemi, Intel Design Centre, CICO, Imagination Technologies, XMOS, Blu Wireless, IXYS, Infineon, IQE, Dialog Semiconductors, Gooch and Housego, Oclaro, II-VI Laser Enterprise, EFFECT Photonics, Bay Photonics, and Venture Photonics.

With the change of emphasis in sector away from fabrication towards fab-less design (due to the extreme high cost of building new deep-sub-micron foundries) the UK has become a centre for advanced design of electronic and optical circuits and systems, with the SWW area being a particular hot-bed of this type of activity with significant numbers of smaller, design-oriented companies, with applications from microprocessors, ASIC design to photonics, wireless and sensor integrated circuits.

This provides a major opportunity to extract more value from the supply chain, maximising the market advantages realised by exploiting novel component technology within locally clustered system integrators.

Digital Living Innovation

Using standard measures of economic activity, employment data and counts of active enterprises is challenging in this field. As digital technologies are seen as nationally critical this has led to experimentation by a range of bodies such as NESTA in new ways of capturing data about the broad sector. These methods and the associated reports identify that the SWW region has a number of well-established and nationally significant high tech / digital clusters. The 2016 Tech Nation report[133] highlights digital technology clusters in Bristol and Bath, Cardiff, Exeter and Truro and Redruth.

Digital Health

Tech Sparks Cluster map[134] identifies that the regional Digital Health sector is made of 70 companies. The UK digital health sector is estimated to be worth £2bn, forecast to rise to £2.9bn by 2018, with a 2015 turnover of £886m and 7,400 employees.[135] The global market value is estimated to be €17.6bn in 2017.[136] SWW's stable and ageing population presents a significant opportunity to develop digital health and life science industries in the region. A number of innovation support mechanisms are in place, including: South West Interactive Healthcare Programme; Assisted Living Action Network; and a Health Tech Hub has been proposed by UWE with the West of England AHSN focusing on innovation for independent living and citizen-centric health.

Digital Creative Economy

Employment in the SWW creative industries grew 21.5% in 2013–14, overtaking the North West.

Bristol and Edinburgh are the only UK cities outside the London / SE to appear in the top 20 for their concentration of both creative industries and technology, defined by location quotient. Tech Sparks Cluster map[137] shows a Digital Creative economy which is made of 500 companies in the SWW region, totalling revenues of £660m with 15,900 employees.

The Geography of the UK's Creative and High Tech Clusters Report[138] demonstrates that Bristol is one of only five clusters that demonstrate high concentrations of employment in both the creative economy and in high tech, making it well positioned to lead in creative digital applications and technologies. According to research[139] published in 2015 by the Creative Industries Council, Bristol is one of three UK cities outside London identified as having the best prospects for future growth in the creative industries. The Cardiff and South East of Wales area has been increasingly recognised as a significant cluster in this thematic area and in particular the subset of activities around the film industry.

Key employers include: Aardman Animations, BBC in Cardiff and Bristol including the Natural History Unit, Pinewood Studios and TwoFour Group.

Smart Cities / Regions and Smart Transport

In the May 2016 Huawei sponsored UK Smart City Index[140] Report Bristol was identified as one of two UK leader cities, alongside London. This is reflected in an emerging group of companies specialising in smart cities or transport related products and services in the SWW region. Corporates such as ARUP, Atkins, Buro Happold Engineering and Altran are developing regional high level expertise in smart cities, transport systems and connected autonomous vehicles, and Bristol is Open (BIO) is attracting international corporate partners including NEC and Nokia. Demonstrator programmes, such as BIO, and Smart Islands (Isles of Scilly), offer companies already active in digital applications opportunities to enter this emergent market area.

Underpinning Technologies: Cloud computing, Communications and Internet of Things (IoT)

Cloud computing, communications and IoT is dominated by number of key corporates with assets, together with a network of SMEs and start-ups. Toshiba, Cray, Google, Huawei, ORACLE, IBM UK, Hewlett Packard Enterprise, Amazon, PCS, Intel and Amdocs all have a digital R&D and innovation oriented presence in the SWW region. SWW specialist areas include communications, cloud computing and storage, human computer interaction / immersion, chip design and cyber security.

The support infrastructure for growth oriented tech companies is well developed, examples include: SETsquared, TechSpark, Digital Plymouth, Tech Exeter Software Cornwall, and Innovation Point, Newport. New capacity is coming on-stream at Gloucestershire Science and Technology Park at Berkeley, Cheltenham Cyber Business Park and at Exeter Science Park.

Underpinning Technologies: Digital Media, Virtual and Augmented Reality

Virtual and Augmented Reality are emerging technology areas, with significant economic development potential. As a set of creative design practices and skills this area draws heavily on CGI, vision technologies, immersive digital media (such as Data / Fulldomes) and a history of simulation and 3D modelling.

VR and VR related digital media content is a major opportunity for the UK's world leading creative industries. Aerospace, high tech digital and nuclear clusters all have on their agenda the use of virtual or augmented reality to improve their operations and lower the cost of maintenance. Airbus, GKN and EDF Energy have a strong interest in virtual and augmented reality applications to their businesses. Intel Swindon hosts the Intel Wearable IP Lab which focuses developing the building blocks for a range of applications areas including Virtual and Augmented Reality.

The ecosystem is primarily based within the Bristol and Bath High Tech cluster and in Cardiff with further clusters of computer games related activity and innovation support in Cheltenham and in Devon and Cornwall, e.g. the Games Academy in Falmouth. The Bristol Games Hub organises the annual VR world congress conference,[141] attended in 2016 by 750 delegates. Six companies make

up the driving force behind this industry in the West of England: Opposable games, Auroch Digital, Big Robots Games, Evil Twin Artworks, Force of Habit, Esportsify and Yogscast. Notable Cardiff companies include On Par, Atticus, 4Pi Production and Orchard.

Plans are developing for a Bristol-based VR Hub to support this emergent area.[142]

Underpinning Technologies: Robotics and autonomous systems

A strong concentration of activity around the West of England area with notable Plymouth based activity in marine autonomous systems research and innovation (e.g. Applied Automation and MSubs), is underpinned by the regional presence of major corporates within the aerospace and advanced engineering sector (Airbus, GKN, Rolls-Royce, EDF) with an interest in robotics and autonomous systems; Renishaw in medical robotics; and other large specialist engineering services companies with robotics domain expertise, such as Altran.

A range of organisations provide innovation assets to support organisations developing or using robotics and autonomous systems: the Bristol Robotics Laboratory runs a business incubator, and support offered will expand with the opening of the adjacent University Enterprise Zone in August 2016 providing start-up and grow-on space for technology and knowledge based businesses in robotics and autonomous systems and other related fields. The National Composites Centre is a centre of excellence in industrial robotics and digital design as applied to composites manufacture.

Resilience, Environment and Sustainability Innovation

The environmental goods and services sector in the region comprises 25,000 enterprises[143] *providing 153,000 jobs.*[144] *This sector has grown 16 times faster than other sectors in the region.*[145] *The stakeholder and business communities have identified two areas where our region has the potential to be globally competitive: Environmental Risk and Data Innovation, and Sustainable Technologies and Development. This is reinforced by existing and planned regional and LEP strategies and investments, as well as extensive innovation initiatives and activities.*

Environmental Risk and Data Innovation, including areas such as: smart grids / metering and intelligent mobility; satellite communications and access / provision of data; understanding extreme weather; climate change resilience and adaptation strategies; asset management; resilient buildings and structures; flood modelling and monitoring.

Sustainable Technologies and Development – potential opportunities are linked to changes in legislation regarding the low carbon economy; energy storage and electric vehicles; sustainable buildings; trends in distributed energy generation and developing new materials.

These themes were explored through a workshop of 30 partners[146] followed by an independently commissioned survey of 37 companies (Appendix RES1) who either have their headquarters, or other significant presence / interests, in our region.[147] Of those interviewed, 31 described their business activities as being world-class, and nearly all indicated that their R&D expenditure would either increase, or stay the same, over the next five years, and that collaboration with universities is important. Nearly all interviewees anticipated introducing a new product, or service, process and / or entering a new market over the next three to five years.

Most of the interviewees confirmed that Environmental Risk and Data Innovation, and Sustainable Technologies and Development are important areas for our region, where developments could add commercial value to their business over the next five to 10 years.

This theme has a number of identified growth points that can be maximised for economic gain, including the Global Environmental Futures campus at Exeter Science Park, catalysed in-part by the presence of the Met Office; the South West Satellite Applications Catapult Centre of Excellence, based at Goonhilly Earth Station in Cornwall; the Rural Innovation Centre and Berkeley Science and Technology Park in Gloucestershire; and the Porton Science Campus in Wiltshire.

Section 5: National and international engagement

The SWW is well connected locally, nationally and internationally across the five SIA themes. This inter-connected landscape drives innovation. As an indicator of engagement we now look at EU funding, and then at each theme in detail.

Over 2007–15, the lifetime of the Seventh European Framework Programme (FP7) for Research and Technology Development, the consortium area accounted for 9% of all UK participations.[148] In line with other areas, the majority of these participations were undertaken by higher education institutions (42%, 676), followed by research organisations (32%, 505). Private commercial organisations made up 19% (305) of the SWW area's FP7 participation. The SWW area accounts for almost 9% (£605m) of all funding drawn down from FP7 by the UK.

In the successor to FP7, Horizon 2020, the SWW so far accounts for almost 11% (1,279) of the UK's participations in the programme and just over 11% (£596m) of all funding competitively won by the UK.[149]

Aerospace and Advanced Engineering Engagement

Aerospace and Advanced Engineering industries are global, and SWW consortium partners are fundamental to that global endeavour. SWW primes and OEMs are international businesses, and SWW Universities all undertake significant collaborative research in AAE[150] with companies of various sizes (SME to Multinational) and universities across the UK, Europe and world-wide.

The SWW links nationally, for example through the National Composites Centre which is part of the UK's HVM Catapult, and via links through bodies such as the Advanced Propulsion Centre (APC) UK. This inter-connectedness is crucial for future developments.

As well as being connected nationally and internationally, organisations in the SWW region can boast strong local networks involving industry, academia and government, e.g. Aerospace Wales and the West of England Aerospace Forum (WEAF) are membership trade organisations representing Wales and South West England respectively. WEAF is the regional coordinator for National Aerospace Technology Exploitation Programme.

The Wales Space Academic Partnership is supported by Welsh Government and operates under the umbrella of the Aerospace Wales. It is pan-Wales and SE Wales has strengths represented by both major blue chip companies such as Airbus and SMEs such as QMC Instruments Ltd., which has laboratory and office space within Cardiff University.

Along with WEAF and Aerospace Wales, other regional aerospace alliances represent clusters in different parts of the UK, including Farnborough Aerospace Consortium, Midlands Aerospace Alliance and North West Aerospace Alliance. These alliances work closely with the national aerospace sector body, ADS, and are a recognised Federation.

Collaboration between industry and academia can be evidenced through publications data[151] with the percentage of highly cited articles by SWW universities that are co-authored with industry partners being over twice that of similar publications from the Russell Group and the UK as a whole. Highlights include:

– Airbus's top UK academic publishing partner is the University of Bristol, with the Universities of Bath, Exeter and Cardiff also in their UK top 10.
– Lotus's second most frequent publishing partner is the University of Bath.

– Jaguar Land Rover's academic publishing partners include the Universities of Bath and Bristol in their UK top 10.
– Rolls Royce's 7th most frequent UK academic publishing partner is the University of Bristol.

The data also indicates the desire for companies outside the SWW region to participate in the world class research being carried out by academics at universities in the SWW.

New Energy Systems Engagement

Consortium partners have been involved in a number of large-scale national and international research consortia, in particular various SUPERGEN projects.

SWW partners are involved in six of seven SUPERGEN consortia (Bioenergy, Energy Storage, HubNet, Hydrogen and Storage, Marine, and Solar.[152] These consortia provide expertise, knowledge exchange and facilities which attract business locally and internationally to work with them.

PRIMARE – the Partnership for Research In Marine Renewable Energy – a 'network of excellence' centred in the south of the UK involving the Universities of Plymouth, Exeter, Southampton, Bristol and Bath, along with the Marine Biological Association of the UK and Plymouth Marine Laboratory, work together on research projects across the spectrum of marine renewables. The South West Marine Energy Park (SW MEP) and the Wave Hub facility act as conduits between the research community and industry.

The Offshore Renewable Energy Catapult has a dedicated and supportive presence in both South West England and in Wales, an important factor in forging collaborations with other parts of the UK, particularly Scotland.

South West England is home to a number of national-level collaborative initiatives in Nuclear aimed at meeting strategic challenges by bringing together academia, government and industry, such as: Nuclear South West; South West Nuclear Hub; Bristol-Oxford Nuclear Research Centre; National College for Nuclear (Bridgwater); and Somerset Energy and Innovation Centre (Bridgwater).

Wales has an extensive research and development base in renewable energy and smart energy solutions, e.g. SPECIFIC (an EPSRC Innovation and Knowledge Centre), the Low Carbon Research Institute, and Cardiff University's £24m FLEXIS project which involves worldwide collaborations.

With a track record of international, national and regional collaboration, the SWW area is ideally placed to lead further R&D and innovation activity in the New Energy field, ensuring activities complement and enhance efforts elsewhere to maximise return on investment.

Next Generation Microelectronics Engagement

The next generation microelectronics industry is highly international with supply chains spanning many different countries and companies. UK photonics companies, for example, will typically export >75% of their output.[153]

Publication analysis[154] showed that SWW academics are well connected, because 59% of papers included at least one international author. The countries that the SWW region's scientists most frequently collaborate with are the US followed by Germany, France, China and Italy. The SWW region also collaborates with leading universities such as Cornell University, CERN, and Massachusetts Institute of Technology.

In addition to academic collaboration, SWW universities also have a higher than average level of engagement with industrial partners (4.3% vs 2.9%). This includes joint publications with companies as diverse as Toshiba, IBM, Airbus and General Electric.

SWW universities are engaged with major UK science initiatives and are involved in three of four of the EPSRC's recent £120m Quantum Hubs.[155] They are also involved in two of the three Quantum Technologies Training Hubs and host the UK's only dedicated quantum training centre for Post-Doctoral researchers – the Quantum Technologies Enterprise Centre. The University of Bristol also hosts the UK centre for Quantum Photonic Integrated Circuit Fabrication.

SWW universities are also very engaged with the skills agenda, with four of the 18 UK Electronic Skills Foundation partner universities being based in the SWW region.[156]

Digital Living Innovation Engagement

Digital technologies and applications are highly international with academic expertise and leading companies spanning many countries. Many of the world's leading digital technology companies have innovation related operations in the SWW.[157]

Publication analysis[158] indicates that SWW researchers collaborated most frequently with researchers from the USA, followed by Australia, Canada, Germany and France.

Academic research income data for the theme highlights that 22% is received from EU research programmes and a further 3.3% from other international funders.[159] The majority of this income is related to collaborative multinational research, and demonstrates significant levels of international collaboration and, given the competitive nature of this funding, regional excellence for researchers in the theme.

Resilience, Environment and Sustainability Engagement

The SWW shows excellent connectedness and capacity to work collaboratively regionally, nationally and internationally. In particular we had more contributors to the 2014 UN IPCC report[160] *than any other area in the world, and the presence of the Met Office and other world-leading research organisations also delivers significant national and international reach and influence.*

SWW–SIA consortium members are involved in global engagement and full details of relevant alliances are provided in Annex K: Appendix RES16. Highlights include: Defra Sustainable Intensification Platform, Met Office Academic Partnership, Natural Hazard Partnership, UK Catalysis Hub and the Intergovernmental Panel on Climate Change (IPCC) 5th Assessment Report.[161]

The Met Office[162] has significant international influence through its unified weather and climate model (UM), which is now relied on by some 1,000 scientists in the UK, as well as several hundred internationally. It is used in Australia, New Zealand, South Korea, India, South Africa and several other countries for the delivery of their weather services. The United States Air Force also chooses to use the Met Office model as the basis for its weather operations. Since 1981, the Met Office has co-authored papers with scientists from 163 different countries and over 1,900 institutions worldwide. The Met Office also makes significant contributions to the UN Framework Convention on Climate Change (UNFCCC) and the UN World Food Program. The Met Office's scientific capability supports a number of UK Government ODA programmes such as the Newton Fund, and the Met Office is one of DFID's partners on the WISER programme (Weather and climate information services for Africa). The Met Office represents the UK at EUMETSAT[163] (European organisation for the exploitation of meteorological satellites). PML[164] has also worked with 500 partners in more than 60 countries since 2010, including formal partnerships such as the Partnership for Observation of the Global Oceans.

Publication analysis assessing international collaboration showed two key areas where the consortium demonstrates a significantly higher proportion of their publications being co-authored with international partners compared to the rest of the UK during 2011–15.[165] These are Process Chemistry and Technology (60.9% of publications with international co-author for consortium, 50.7% for UK) and General Earth and Planetary Sciences (62.3% for the consortium, 57.2% for UK).

Section 6: Developments in national / international markets and science and technology

In each of the SIA themes we now consider the anticipated developments in national and international markets and in science and innovation by drawing upon secondary sources.

Aerospace and Advanced Engineering Markets

AAE companies face a crossroads of immense importance over the coming years. The extended design, build, test, implement cycles in advanced engineering industries require technologies to meet future policy demands to be developed today.

One of the most important issues currently shaping the aerospace, automotive and advanced engineering industries globally is fuel economies and emissions standards required under Government legislation. The Climate Change Act (2008)[166] set a long-term legally binding framework for greenhouse gas reduction in the UK.

Strong growth in the short to medium term will be driven by the production of composite components for the new civil and military aircraft and adoption of composites in the automotive and marine sectors with a major driver being the need to reduce weight for fuel efficiency. Aerospace, Automotive, Construction, Oil and Gas and Renewables all have a potential market size of over £1bn each by 2030.[167] Consultation with the UK composites supply chain has shown that the UK has the opportunity to grow its current £2.3bn composite product market to £12bn by 2030.[168]

Studies[169] have shown that "product design" has the greatest influence on productivity improvement and downstream costs. Correcting the effects of "poor design" can be prohibitively expensive and have tangible impact on market share and / or business performance. Global excellence in "high value design" capability will ensure that the UK is able to deliver world-leading technologies and product solutions, delivering maximum competitiveness to customers. Leadership in design quality and productivity will ensure that the UK is an attractive supplier for product solutions and analysis / validation services.

Other crucial technology developments include:

- **Automation, Smart Factories and Industry 4.0** – a report by McKinsey[170] estimated that the application of advanced robotics could generate a potential economic impact of $1.9tn to $6.4tn per year by 2025.
- **Propulsion** – the challenge for the UK economy is to be ahead of any emerging market preferences, across sectors and technologies, in order to secure the long-term future of propulsion in this country.[171]
- **Additive Layer Manufacturing**[172] – which involves the production of three-dimensional parts directly from computer aided design data, is likely to have wide-ranging uses across advanced engineering.
- **Testing, Certification and Metrology** – industrial testing, certification and metrology is integral to advanced engineering manufacturing processes, and will be crucial to the development of new technologies.

Aerospace

The UK aerospace sector is expected to grow at a rate (CAGR) of 5% over the coming years.[173]

To 2031 there is an estimated global requirement for over 27,000 new passenger aircraft worth circa $3.7tn. Over the same time period, the global market demand for new commercial helicopters is expected to be in excess of 40,000 units, worth circa $165bn.[174] *The Maintenance, Repair and Overhaul market is growing rapidly and represents a significant opportunity for the future.*[175] *The commercial space market is forecast to be worth a trillion dollars globally by 2020 and the global market for Unmanned Air Vehicles (UAVs) was worth ~$5bn in 2010 and is projected to increase to more than $11.5bn per annum over the next decade.*[176] *Cornwall Airport Newquay is well placed to be the UK's first spaceport.*[177]

Competition is spread globally. For example in Europe, the Toulouse Aerospace Valley (TAV),[178] created in 2005 has 859 members from industry and academia. It employs 124,000 staff and 8,500 researchers representing one third of the French aerospace workforce. To 2015 its 450 R&D projects had a value of €1.1bn. By 2025 TAV aims to create 35–40,000 new jobs. The model has been replicated on a smaller scale at locations such as Andalucia Aeropolis[179], Italian Aerospace Research Centre[180] and Poland's Aviation Valley.[181] Beyond Europe, competitors include the Asia Aerospace City[182] and Korea Aerospace Research Institute.[183]

Automotive

Britain is the fourth largest vehicle producer in Europe, making 1.6m vehicles in 2014. 78% of cars produced in the UK are exported to more than 100 countries. It is expected that the global light vehicle sales will hit 100m units by 2017 and 111m by 2020.[184]

Automotive research facilities include the National Automotive Innovation Centre (NAIC), a £150m investment between Jaguar Land Rover, Tata Motors European Technical Centre, Warwick Manufacturing Group (WMG) and the University of Warwick. Ford's Dunton Technical Centre in Essex houses one of the largest automotive technical centres in the UK, employing approximately 5000 staff.

UK competitors include advanced automotive research centres located in Germany including The BMW Group Research and Innovation Centre,[185] the International Centre for Turbomachinery Manufacturing[186] which constitutes the Fraunhofer Institute and RWTH Aachen University.

Marine

The global marine market is estimated at £3tn, especially with high value opportunities across emerging economies.[187] As well as marine renewables manufacturing (see New Energy Systems Theme), naval export of high tech systems and class leading capability in leisure craft can capture the rapid growth of middle classes in other countries, building on the UK's reputation for quality.

Marine clusters within the UK include Belfast Harbour, Lowestoft / East of England and the Southampton / Portsmouth region, which is part of the South Coast Marine Cluster that incorporates much of the SIA area. International competition includes Brest commercial port, located on the northern coast of France in the Brittany region and is an important gateway to France and continental Europe. The Port of Brest is the leading French port for military fleet maintenance and for civil naval repair.[188]

New Energy Systems Markets

Analysis shows that the SWW is ideally placed to both benefit from, and drive, new and rapid developments in marine renewables, nuclear and hydrogen technologies, where the opportunity exists to create global leadership in the UK

The Paris Climate Change Summit in November 2015[189] has given new impetus to the move towards a lower-carbon and more efficient energy system, but does not alter the picture of rising global needs for energy. Energy use worldwide is set to grow by one-third to 2040,[190] driven primarily by India, China, Africa, the Middle East and Southeast Asia.

Marine renewables

Europe is currently at the forefront of the exploitation and development of Marine Renewable Energy, hosting more than 50% of tidal energy and about 45% of wave energy developers.[191] The UK is the leader in both wave energy (with 29 developers) and tidal energy (with 32% of the global technology developers). Across both wave and tidal energy eleven UK developers have reached an advanced technology readiness level. These technologies are at a crucial stage as they are at the forefront and are going through the critical "valley of death", where support is critical to reach full commercialisation.

Increasing competition is being seen from emerging markets – France and Canada for tidal, and the US and Australia for wave. Across both, China is engaged in heavily funded catch up research and development.

In Europe, R&D activities have been mainly funded with governmental support. The main financial support mechanism at a European level is the 'NER 300 programme'.[192] Of two wave and two tidal energy projects selected for NER300 funding, three are located in the UK and Ireland. The implications of 'Brexit' on future support for UK based device developers are uncertain, but uncertainty is in itself one of the primary barriers to future development.

Hydrogen / fuel cell

The sector is already generating billions of dollars in revenues every year, with annual growth (from a low base) of over 50%.[193] This trend is expected to continue for some time. In Asia, car manufacturers will produce around 3,000 fuel cell cars in 2016 and around 50,000 fuel cell combined heat and power devices. Detailed projections by all OEMs for the Californian Air Resources Board suggest that more than 30,000 cars will be on the roads in California by 2021. However, most hydrogen and fuel cell technologies are still in the early stages of commercialisation within the UK and Government support can help accelerate their development and deployment.[194]

The UK lags badly behind, however, the UK's hydrogen infrastructure is growing rapidly, following the lead set by Germany, Japan, and California with regard to the kind of large scale demonstration projects required to capitalise on the UK knowledge base and develop native commercial expertise. With an increasing number of hydrogen and fuel cell technologies now close to commercial application, small but coherent and coordinated actions could open pathways to large benefits.

The Roadmap commissioned by Innovate UK "Hydrogen and Fuel Cells: Opportunities for Growth, A Roadmap for the UK" (August 2016) highlights the opportunities for hydrogen and fuel cells to form a "major component of a future low carbon energy system" and equally importantly to be integrated synergistically into the overall energy system enabling the system as a whole to achieve better performance. Understanding such interactions is at an early stage and research and development and support deployed now would give the UK significant future opportunities.

The value of such support is clear. With 20 public hydrogen refuelling stations, Germany is the trailblazer in Europe in terms of hydrogen infrastructure. Further development of the infrastructure in Germany has now taken shape with the establishment of H2 MOBILITY, a company which will establish and operate the first 100 hydrogen refuelling stations by 2018/19. Unconditionally and irrespective of vehicle numbers Hydrogen could cover up to 40% of the demand for energy in Germany's transport sector by 2050.

Nuclear Energy

The production of nuclear energy around the world is growing as countries look for secure, reliable and affordable energy sources that do not contribute to climate change. In the UK, the nuclear energy sector is undertaking a huge science and engineering effort to extend the lives of its unique fleet of Advanced Gas-Cooled Reactors (AGRs), planning and building a new generation of light-water reactors, decommissioning the legacy of the world's earliest nuclear power programme, while facing a workforce of highly experienced experts rapidly approaching retirement. The scale of the

effort to train the scientists and engineers and then to deliver this programme is unprecedented.

The SWW is recognised as a cluster for nuclear expertise,[195] similar to that around Sellafield in the North West, and is thus well positioned to play a significant role in this renewal.

Both current and future nuclear energy technologies also have the significant potential to deliver a step change in value by being applied in new ways, such as exploiting the radiation environment for the production of high-value materials, production of hydrogen for the hydrogen economy and the large-scale desalination of sea-water to provide freshwater for human populations around the world.

Importantly, SWW regional excellence is of truly global relevance. It is not predicated on the construction of any one nuclear power station in the UK, and as such the potential developments at Hinkley and Oldbury are further elements of this expertise, not the central components.

Next Generation Microelectronics Markets

Microelectronics are enabling technologies which drive innovation across a number of key market sectors such as automotive, aerospace, and ICT. Within the microelectronics industry itself there are a number of key technological and commercial developments which present a major opportunity for the SWW.

Photonics technologies are increasingly being used in smartphones, laptops, lighting and medical devices. They also underpin communications infrastructure as low-cost high efficiency interconnects which support the exponential growth in data transfer due to growth in video consumption, cloud storage, and network virtualisation. The overall global market is ~£250bn and is expected to continue to grow at an annual growth rate of 8–10%.[196] The economic importance of photonics has been recognised by the EU which has identified them as one of their six key enabling technologies. The market for LED lighting technologies is continuing to grow and is expected to reach £55bn by 2020.[197]

The wireless market covers electronic devices that communicate wirelessly such as mobile phones, smartphones, mobile networks, Wi-Fi, smart metering, satellite navigation, and a plethora of other connected devices. The wireless communications market has recently grown rapidly reflecting the increased adoption of wireless technology, coupled with the need for an increased compound semiconductor content to support greater sophistication of mobile devices.

The global market for sensors is expected to reach $154.4bn by 2020, and is demonstrating a compound annual growth rate of 10.1% over the five-year period from 2015 through 2020.[198] Smaller more energy efficient sensors which can monitor external factors (such as temperature, air flow, speed, exhaust gas content) are enabling electronic systems to interact with the real world. The development of such “smart” systems are becoming increasingly important for IoT, Smart Building, Smart City wide area applications and manufacturing. One of the fastest growing applications for sensors are as medical diagnostics and this market is expected to reach $22.68bn by 2020. In particular, photonic and sensor technologies are increasingly being used to provide low cost point of care screening methods.

The overall global market for semiconductors is £230bn and expected to grow by 4% over the next two years. Within this, the market for compound semiconductors is currently worth around £23bn but has an anticipated growth rate of 17.3%.[199]

Digital Living Innovation Markets

The UK digital economy contributes 7% of national output, 5% of jobs and 9% of businesses. This is similar to the US, but behind South Korea which leads the world at 11% of national output.[200]

The UK Digital Catapult has recently refreshed its strategy to focus on technology layers offering UK

businesses significant global opportunities. The SWW region's research and innovation strengths map well onto this revised strategy. These layers are: Data – including cyber security and privacy; Connected – Internet of Things and 5G; Intelligent – machine learning and artificial intelligence; and Immersive – virtual and augmented reality and new forms of human machine interfaces. It highlights Creative industries and Health as sectors to target, alongside Digital Manufacturing which is addressed under the Aerospace and Advanced Engineering theme in this SIA.

Clear market and technology opportunities have been identified across the main Digital Living themes and underpinning technologies.

Digital Health

In 2015, NESTA published "The NHS in 2030".[201] It offers a vision for the NHS that clearly identifies that the digital sector can play an important part in addressing the issues the NHS faces. For example, virtual and augmented reality will play a role in diagnostics and other interventions, including robotic and remote surgery.

Digital Creative Economy

A significant overlap and convergence exists between two significant UK sectors, 'digital / high tech' and 'creative industries' giving rise to the term 'Digital Creative Economy'. The Digital Sector accounted for 7.3% of the UK Economy in 2014, providing 2m jobs, and exports worth £15.9bn. In 2009, GVA of the Digital Sector was £93.7bn, and accounted for 6.9% of the UK economy. Between 2009 and 2014 it increased by 26.3%. The GVA of the Creative Industries was £84.1bn and accounted for 5.2% of the UK economy. IT, software and computer services continued to be the largest constituent part of the Creative Industries, accounting for 43.5% of Creative Industries GVA.[202]

Smart cities / region and transport

In a 2013 report for BIS, ARUP identified the market for Smart Cities products and services at greater than $400bn in 2020 with Smart Transport valued at $150bn and with a growth rate of greater than 20%.[203]

IoT and Smart Cities are a clear linked opportunity. The integration of data analytics with the cloud, sensors, software development, data storage, security and cryptography and resilience is ready to happen, and the convergence of different strands of technologies coming together will underpin future services and products.

Bristol is Open (BIO) is now at the stage of proving the concept of a truly smart city, where citizens can be empowered. The SWW region, from BIO, to the Isles of Scilly through the Smart Islands programme is deploying test beds and running demonstrator projects (such as in connected autonomous vehicles) and is ready for the next revolution.

Underpinning Technologies

Cloud computing, communications and IoT trends in mobile video, cloud computing and storage have driven an exponential growth in data transfer. The trend for all devices to be connected (IoT) and the emergence of new services and digital media content are driving communications and cloud computing research to achieve the required performance, scalability and agility. The 2016 Ericsson Mobility Report predicts that Internet of Things is expected to surpass mobile phones as the largest category of connected devices in 2018.

Quantum engineering represents a promising emergent technology. From the development of a quantum computer to improved cryptography using quantum key (QKD) methods.

Virtual and Augmented Reality has a predicted market value of $150bn by 2020 (compared to a film industry market of $104bn).[204]

A 2013 McKinsey study[205] into disruptive technologies estimates that by 2025 Robotics / Autonomous Systems (RAS) technologies will have an impact on global markets of $1.9 – $6.4tn per annum. Current estimates from Europe and Japan indicate that the market for RAS products

and technology, for non-military sectors, will be in the order of £70bn by 2020–25. Examples include nuclear decommissioning, where the SWW region has leading research and commercial strengths in the use of UAVs and robotic manipulators and vehicles. RAS is projected to make up 20% of the £50bn per annum global decommissioning costs by 2020. In offshore energy and oil recovery autonomous underwater vehicles (a regional strength) are poised to revolutionise the sector.

The economic benefit in terms of national costs avoided thanks to the use of RAS as part of the intelligent mobility solutions in transportation over the next 20 years is estimated to be in the order of £1tn for the UK. The world connected autonomous vehicles (CAV) market alone has been valued at $30bn by 2030 by Frost and Sullivan, dominated by vehicle sales. Whilst the SWW region will not address the majority of this market, systems, communications and control form a significant part of the value add and science and innovation challenges in these areas are being addressed in the SWW region.

Resilience, Environment and Sustainability Markets

This theme is driven globally via climate change and sustainable development agendas, challenges and opportunities. There is an urgent need to utilise environmental data to tackle the risks from natural hazards and protect the resilience of socio-economic systems. There is also a huge opportunity surrounding the technology and innovation that will be required to live sustainably.

In the UK the impacts of severe weather and natural hazards have been significant:

– The Bank of England reports weather related insurance losses have increased from an annual average of around $10bn in the 1980's to around $50bn in the last decade.[206]
– The 2007 floods generated £3.2bn in insured losses and killed 13 people.[207]
– Flooding in winter 2013–14 cost the UK £1.1bn.[208]
– The 2015 windstorms resulted in a total UK economic loss of £3bn.[209]

The UK Climate Change Risk Assessment 2017 synthesis report[210] specifically sets out where the UK is at greatest risk, and where action is needed, include flooding and coastal change, high temperatures and health, water shortage, risks to natural capital and food production and new and emerging pests and diseases.

The global market for commercial weather and climate services has been identified as being worth £35.3bn in 2015, having grown by a third during 2010–15.[211]

Environmental pressures are having a growing impact on global and national economy and on key issues such as food, energy security, population movements, international diplomacy, conflict, agriculture and civil contingency. Estimates from Munich Re suggest natural hazards caused 23,000 fatalities globally in 2015, with 24% of these being due to climatological events.[212] Between 2010 and 2050 the costs of adapting to climate change globally have been estimated to be in the range of $70bn to $100bn a year by 2050.[213]

The UN Sustainable Development Goals were defined in 2015 – Transforming our World: the 2030 Agenda for Sustainable Development.[214] 17 key goals were identified, including: sustainable agriculture, sustainable management of water, access to energy, sustainable economic growth, resilient infrastructure, sustainable consumption, tackling climate change, sustainable use of the oceans and terrestrial ecosystems.

The majority of the world's nations have also recently signed up to a very challenging climate target to limit global warming to below 2°C, at the UN Paris Climate 2015[215] conference. It is recognised that, if this target is to be reached before 2050 we have to largely decarbonise the global economy. According to the MIT Technology Review 2016[216] 'technology innovation stands to reap billions from a warming planet'.

Sustainable technologies and development innovations open the way for significant increases in economic value, e.g. there is potential to grow the GVA of the chemical and chemistry-using sector from £195bn to £300bn by 2030 in the UK[217] catalyst businesses that support manufacturing and refining have an annual turnover of $15bn globally, and the full value of the goods and products produced by those catalysts is in the region of $15,000bn;[218] and by adopting circular economy principles, Europe can take advantage of the impending technologies revolution to create a net benefit of €1.8tr by 2030.[219]

Section 7: Conclusions

The SWW–SIA was structured around five themes. It has revealed, however, that core science and innovation capabilities cut across these themes, and greater value will be gained by investing in closer collaboration and cross-theme skills development to unlock the true potential of the region. Large-scale investment is needed in advanced engineering and digital innovation, as well as further integration, co-ordination and sustained investment in underling capabilities, if they are to realise their full potential.

Figure 4. Underpinning high level skills and core science and innovation capabilities to support industries in two priority areas: Advanced Engineering and Digital Innovation.

There are a small number of existing projects with identified industrial need that should be funded where they will have immediate impact, but this should be coupled with the development of a medium term programme of investments to build new capacity and greater integration of Advanced Engineering and Digital Innovation.

Advanced Engineering

Conclusion 1. SWW innovation in advanced engineering is essential to its world-renowned aerospace sector and associated manufacturing industries. Selective investments are necessary to maintain and enhance global competitiveness. The SIA recommends a series of short-term investments, coupled to a long-term plan linked to the Government's Industrial Strategy, that integrates current activities and focuses on new skills development.

Conclusion 2. SIA highlighted the importance of new capabilities afforded by the *Compound Semiconductor Applications Catapult,* and the proposed *Institute for Advanced Automotive Propulsion Systems (IAAPS)* and *Composites Excellence – with National Composites Materials Centre.* These selective investments will have an immediate impact on the research and innovation infrastructure as identified in the SIA and are driven by existing industrial need.

Conclusion 3. The SIA recommends investment in High Value Engineering Design and Systems Integration capabilities, initially focused on the aerospace sector, but also designed to support the automotive, nuclear, space, marine engineering / energy and microelectronics sectors. Systems integration of whole structures, sub-structures and propulsion systems are key to long-term growth. This has very strong industry support and significant commercial leadership.

Conclusion 4. The transition to Industry 4.0 is fundamental to all sectors identified in the SIA. Industry 4.0 will result in fusion of technologies and blurring of boundaries between physical, digital and biological spheres, requiring new, integrated interdisciplinary training. The SWW is well-equipped to provide training through multi-institutional training capacity, from technical skills development to post-doctoral training. This is necessary to fuel innovation across the SWW advanced engineering sectors and their supply chains.

Conclusion 5. The natural environment of the SWW provides a well-equipped marine renewables test-bed for wave and tidal energy. We identify a need for collaborative R&D to better utilise academic strengths, in simulation, modelling and visualisation, with existing industrial capacity and real-world testing expertise.

Conclusion 6. In the energy industries, integrating the energy capabilities of the SWW provides unparalleled potential to create a large-scale distributed energy demonstrator from cities to peripheral rural areas, incorporating nuclear, marine renewables and hydrogen fuel cells. We also identify an urgent need to integrate academic nuclear energy expertise to industrial innovation, skills and technology development and supply chain evolution to ensure success of major new nuclear power generation in the region.

Conclusion 7. Building on the low carbon agenda, SWW strength in developing technologies that deliver a circular economy can be enhanced through investment in facilities where innovative sustainable manufacturing and chemical production processes, as well as improvements to our built environment, can be iterated and integrated.

Digital Innovation

Conclusion 8. The SIA identifies world-leading expertise in smart cities, digital creativity, autonomous systems and digital health in which we are the national exemplar. Integrating digital innovation investments so they drive forward the development of smart cities, towns and rural environments is a clear opportunity for the SWW region.

Conclusion 9. The SIA region's world-leading environmental science and data analytics expertise, capability and assets, such as the Met Office and Marine Institutes, as important centres to tackle the risks from natural hazards that are of increasing severity in light of environmental change. Better integration of the Marine research sector is necessary, with much activity still too fragmented and separate. Specific investment to integrate diverse expertise that exists across SWW universities and research institutes, with expertise and innovation in the private sector, will provide significant added value.

Conclusion 10. The SWW has clear strengths in microelectronics, wireless technologies, data analytics, autonomous systems, vision, remote sensing, high performance computing, cloud computing, quantum engineering, cyber security and virtual reality. These capabilities form the basis of high growth digital industries, which coupled to world-leading research and local assets such as GCHQ in cyber security, will be key to underpinning advanced engineering, but also for success of new industries in digital innovation, in which we excel.

Conclusion 11. A major finding of the SIA is the identification of investment in a network of Digital Innovation Hubs (DIH) as key to driving new industry creation. Investment in DIHs will integrate researchers, entrepreneurs, students, industry and users to create the technologies, policies, practices, business models, and businesses for the digitalised society.

Phase One will establish a Bristol-based Hub bringing together academic and industry expertise in underpinning technologies (e.g. cloud computing, communications etc.) and with a focus on SWW's specialisms in Smart Cities, Digital Media, Autonomous Systems and Digital Health; and a specialist Hub, the Institute for Environmental Risk and Innovation at the Met Office's Global Environmental Futures Campus in Exeter. This should be followed by a series of further DIH to co-ordinate and integrate digital innovation across the region.

Underpinning Skills

Conclusion 12. Underpinning the SIA findings is a clear and urgent need to upskill the current and future workforce in SWW so that we have the right people in place to fill the high-end, advanced engineering and high tech digital jobs these industries require. We identify the means by which HE providers and businesses will work together to deliver new training environments that both nurture research leaders of the future and upskill the current workforce.

Whilst the propositions begin to address skills, this was not a detailed skills audit, and so further work will need to be undertaken looking at higher-level provision, including degree apprenticeships and different entry points that will grow the workforce and skills base. This is a particular challenge within SMEs.

Opportunities for Development

The SWW–SIA makes a clear recommendation that existing projects identified through industrial need, should be funded where they will have immediate impact, but this should be coupled with development of a medium term programme of investments to build new capacity and greater integration of Advanced Engineering and Digital Innovation.

To deliver the SIA hypothesis in Advanced Engineering we recommend the development of a programme that focuses on delivering High Value Engineering Design and Integration Capabilities along with enhancing Systems Integration expertise into the region. We envisage this to be centred in Bristol and Oceansgate, Plymouth. Any investment would need to be linked to the existing assets and industrial base in the SWW region and act as an effective means to collaborate with complementary UK Advanced Engineering programmes and initiatives that are targeted on enhancing engineering design capability in the UK – see Figure 5.

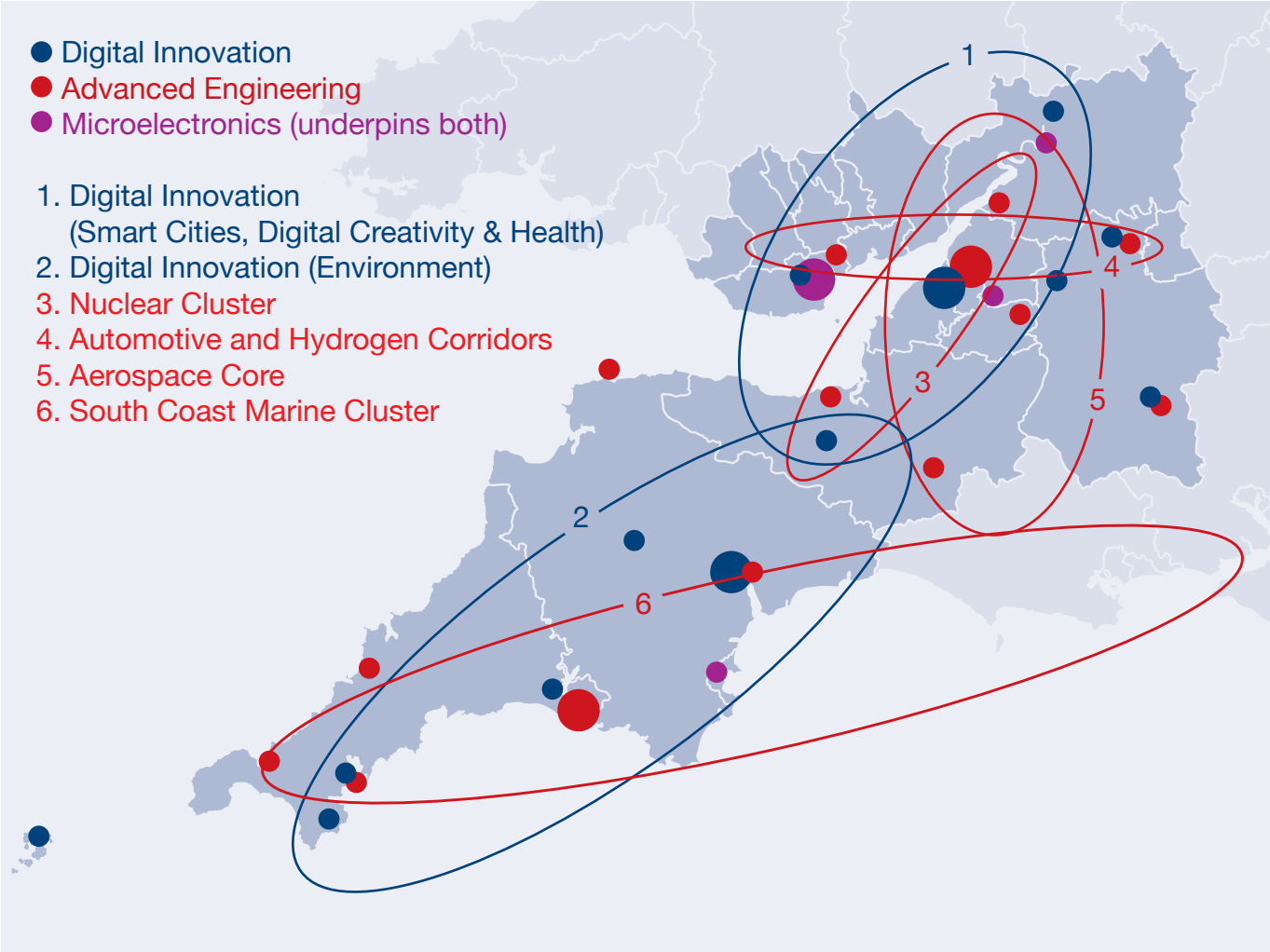

Figure 5. Advanced Engineering and Digital Innovation inter-connected hubs ◯ and linked assets o (Note: schematic – size does not reflect scale.)

In Digital Innovation, the focus will centre on creating a network of Digital Innovation Hubs (DIH), starting with the new Institute for Environmental Risk and Innovation at the Global Environmental Futures Campus in Exeter and a Digital Innovation Hub in Bristol. This will bring environmental, autonomous systems, digital health and smart cities agendas together because the underlying capabilities are highly complementary. Again, these Hubs would reach into the SWW region via links to specific assets and further afield to integrate with UK assets – see Figure 5.

Our planned investments cover a timeline of projects currently in a bidding process, those that are under development, and opportunities emerging from the SIA that are the new opportunities. They are summarised in Table 1, and further details (for those marked *) are provided in Annex N.

	Advanced Engineering	Digital Innovation
Significant New Opportunities Those in bold are at Outline Business Case stage	**– High Value Engineering Design and Systems Integration Capabilities*** Other concepts developing within this agenda: – Aerospace Substructure Wing Integration Centre – Wind simulation for MRE devices – Energy Demonstrator – Marine autonomy test range	**– Digital Innovation Hub*** **– Digital Innovation Specialist Centre: Institute for Environmental Risk and Innovation***
Significant projects under development	– Composites Excellence – with National Composites Materials Centre* – Oceansgate Marine Industries Production Campus* – Compound semiconductor epitaxy foundry pilot line* – Institute for Sustainable Technology Innovation*	– VR Lab – Berkeley Science and Technology Park*
Bids in progress Examples of bids to Growth Deal Three, ESIF and other funds relating to the SIA themes	Growth Deal Three (see Annex F): – Institute for Advanced Automotive Propulsion Systems (GD3 & RPIF)* – Innovation Aero (iAero) – Cornwall Airport Newquay – Future Flight and Spaceport – NUCLEATE And others: – National College for Advanced Manufacturing	Growth Deal Three (see Annex F): – Quantum Innovation Factory – Cheltenham Cyber Park, (GCHQ/GD3) And others: – Environmental Futures and Big Data Impact Lab (ESIF) – National Arts and Technology Innovation Centre (Arts Council England) – Launchpad expansion (ESIF)

Table 1. Pipeline of Investments

Next Steps

1. An industry-led business case to support **'High Value Engineering Design Capabilities and Systems Integration'** is being developed, initially focused on aerospace and with intent to support the automotive, marine, nuclear and microelectronics sectors. This has strong industry support.

The UK aerospace sector is the second largest in the world, with proven experience in the design and manufacture of complex major components and systems, and the SWW region hosts the UK's largest aerospace cluster. However, a number of factors have contributed to a situation where the UK aircraft design capability has suffered decline for a number of years and this now threatens the

future of the SWW, and the UK's Aerospace Industry. Notably, the extended period between new aircraft development programmes, combined with retirement of experienced Engineers, is leading to a growing "capability gap".

The aerospace industry's continued success depends on retaining excellence in design and competitiveness in the face of growing international competition. "High Value Design" is the intellectually-intensive activity associated with the architectural definition and integration of a complex product, its major components and its systems. It has been shown that the Engineers and designers involved in the conceptual / architectural design phase have the greatest influence on the overall product specification and thus the subsequent selection and optimisation of technologies and systems. Other industrial sectors face similar challenges, and opportunities to provide cross-sector support and benefits have already been identified. Urgent action is needed to ensure the future competitiveness of HVD in the SWW and the UK, and to demonstrate this to the global market. Crucially, a means to provide developing Engineers with the opportunity to gain relevant experience within a realistic programme environment must be provided. Investment in improving the "design productivity" of UK-based Engineering teams is essential.

Proposals include the formation of a "High Value Design Institute" (HVDI), an organisation dedicated to delivering the next generation of Engineering design capability in the region as part of a national HVD capability development initiative. This project is at a formative stage but has support from some of the UK's largest aerospace companies. A number of OEM's and first tier suppliers have independently identified the need for urgent action to support the UK's vital HVD capability. This was confirmed when aerospace stakeholders met to discuss this SIA.

2. As a recognised and well-evidenced powerhouse of electronics and computing both in industry and in academia, the SWW region has taken a leading role in developing the digital technologies and underpinning capabilities that are transforming all aspects of the lives of individuals and the competitiveness of businesses worldwide. These strengths are built upon a long history of academic and industry excellence and means the SWW region has developed a large number of research and innovation assets.

To maintain and grow the SWW's world leading position we now need to put in place mechanisms and facilities that will accelerate the innovation process, promote increased collaboration, co-creation of new knowledge, develop the highly skilled workforce required and better integrate the existing SWW academic and industrial capabilities and assets. This will include the wide range of regional resources that support digital innovation based in small and medium sized companies such as innovation centres, incubation support, demonstrator platforms and development funds. These all need to be better tied to SWW research and innovation capabilities.

This will help deliver a transformation in the partnership between academia and industry to deliver business growth, productivity and global comparative advantage for the SWW region and for the UK. We plan to do this through an investment in integrated facilities in which researchers, entrepreneurs, students, industry and users help create the technologies, policies, practices, business models, and businesses for the digitalised society we are building.

We are developing linked full business cases for investment in a network of Digital Innovation facilities focused on regional strengths. Phase One will establish a Bristol-based **Digital Innovation Hub** bringing together academic and industry expertise in underpinning technologies (e.g. cloud computing, communications etc.) and with a focus on SWW's specialisms in Smart Cities, Autonomous Systems and Digital Health. The first specialist Hub would be in Exeter, the **Institute for Environmental Risk and Innovation**, focused on the modelling and simulation of future risks, utilising academic expertise and the capabilities of the Met Office. Further business cases could be developed for specialist capabilities supporting other regional strengths, including Digital Manufacturing (Industry 4.0) and simulation for the energy sector, all linked back to the Digital Innovation Hub.

Society's exposure to extreme weather and climate events threatens to derail the sustainability of economic development and social welfare across the globe, and to threaten the securities on which we rely for our health and wellbeing. As the world's population grows, with more and more people living within large cities and dependent on globally interconnected supply systems for their everyday needs, so the need for resilience to environmental risks becomes more and more pressing.

Solutions will require the continued development of essential technical infrastructure such as high speed, high capacity wireless networks, high performance computing for complex simulations, advanced data storage and manipulation capabilities, and associated skills. These developments, alongside entrepreneurship and innovation facilities, will be used as leverage in driving growth in other environmentally related sectors and in achieving a common vision for a smarter city.

By investing in 'digital innovation' we can drive this revolution in the SWW region and the UK and build world beating specialised capability.

3. We propose to undertake further work looking at higher-level skills provision, including degree apprenticeships and different entry points that will grow the workforce and skills base.

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References

Detailed references are available within in the Annexes.

[1] Annex G: Full Theme Report

[2] Annex H: Full Theme Report

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[5] www.techcityuk.com/wp-content/uploads/2016/02/Tech-Nation-2016_FINAL-ONLINE-1.pdf

[6] www.centreforcities.org/wp-content/uploads/2014/07/FINAL_Centre-for-cities-report2014.pdf

[7] Annex K: Full Theme Report

[8] Annex K: Appendix RES7 REF 2014 https://www.britishcouncil.org/sites/default/files/eligible_uk_research_organisations_v.8.pdf

[9] Annex K: Appendix RES8

[10] Annex M: Tables 33 and 37 – BRES via NOMIS

[11] https://sustainabledevelopment.un.org/?menu=1300

[12] http://www.cop21.gouv.fr/en/

[13] Annex A: Lists the full consortium membership

[14] Annex M: Section 2.1 2011 Census of Population

[15] Aged between 16 and 64

[16] Annex M: Table 2 ONS Population Estimates

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[19] Annex M: Tables 5 – 9 Annual Population Survey via NOMIS

[20] Annex M: Section 4.1 Fig. 2 England: Department for Education SFR 01/2016, Wales: StatsWales

[21] Annex M: Table 10 Department for Education SFR 01/2016. Wales: StatsWales.

[22] Annex M: Table 11 South West – FE Data Library (Skills Funding Agency)

[23] Annex M: Tables 13-18 HESA Student Returns 2012/13, 2013/14 and 2014/15

[24] Annex M: Table 20a-b HESA 2014/15 Student and DLHE Returns

[25] Annex M: Table 24 Annual Population Survey ONS

[26] Annex M: Table 26 Annual Population Survey via NOMIS

[27] Annex M: Section 4.9 UK Employer Skills Survey

[28] Working Futures is the government's detailed model of the UK labour market, compiled by the Institute of Employment Research at the University of Warwick

[29] Annex M: Table 30 Working Futures

[30] Annex L: Table 11 Building Local Advantage. Review of LEP area economies 2014. LEP Network and Athley Consulting (2014)

[31] Annex L: Table 12 Mapping local comparative advantages in innovation. BIS (2015)

[32] Technopolis Summary data (unpublished) – SIA0003 overview paragraphs

[33] Annex L: Table 13 Mapping local comparative advantages in innovation. BIS (2015)

[34] Annex L: Table 36-37 UK Growth Dashboard 2015. Enterprise Research Centre (ERC) in partnership with Business Growth Service (2015)

[35] E.g. http://www.westofenglandlep.co.uk/assets/files/Transport%20and%20Infrastructure/Unlocking%20our%20potential_Low%20res%20web%20version%20Dec%202012.pdf

[36] E.g. https://peninsularailtaskforce.co.uk/, http://heartofswlep.co.uk/wp-content/uploads/2016/09/Heart-of-the-South-West-Devolution-Prospectus.pdf and http://www.westofenglandlep.co.uk/place/transport-investment

[37] Fixed Broadband: Policy and Speeds – Briefing Paper Number CBP06643 (House of Commons Library, 2016, p.28)

[38] Annex E: Theme Rationale

[39] http://www.pwc.co.uk/industries/aerospace-defence/top-100-aerospace-companies-2014.html

[40] SW Marine Energy Park – Outlook and statement of ambition to 2030, Regen SW, 2015

[41] Silicon Southwest http://ubic.org.uk/siliconsouthwest/

[42] The Leverage Effect of Photonics Technologies: The European Perspective, 2011, DG Information Society and Media SMART 2009/0066

[43] http://www.techcityuk.com/wp-content/uploads/2016/02/Tech-Nation-2016_FINAL-ONLINE-1.pdf

[44] Annex K: Appendix RES7 REF 2014

[45] Annex K: Appendix RES8 Scientists and employment in Theme

[46] https://www.ipcc.ch/report/ar5/

[47] Annex K: Appendix RES8 Scientists and employment in Theme

[48] https://sustainabledevelopment.un.org/?menu=1300

[49] http://www.cop21.gouv.fr/en/

[50] Annex B: Universities, Colleges and Research Organisations

[51] Annex M: Tables 13-18 HESA Student Returns 2012/13, 2013/14 and 2014/15

[52] Annex M: Tables 19-20 HESA 2014/15 Student and DLHE Returns

[53] Annex M: Tables 33-36 BRES via NOMIS

[54] Annex M: SIC codes for each Theme are listed in: Tables 47, 62, 77, 90 and 103.

[55] http://www.aerohub.co.uk/

[56] http://www.sacatapultcoe.org/centre/south-west/

[57] Oceansgate – http://www.oceansgateplymouth.com/

[58] https://www.gov.uk/government/news/chancellor-pledges-50m-for-ground-breaking-new-innovation-centre-in-wales

[59] Annex K: Appendix RES7 UK not for profit research organisations

[60] Annex K: Appendix RES2 List of Assets

[61] Technopolis SIA0003 data (unpublished): REF, HEFCE (2015)

[62] Technopolis SIA0003 data (unpublished): Gateway to Research, RCUK (2016)

[63] Technopolis SIA0003 data (unpublished): Gateway to Research, RCUK (2016)

[64] Annex G: Appendix AAE3 REF 2014 data

[65] Annex G: Appendix AAE5 Theme Income data HESA

[66] Annex G: Appendix AAE5 Theme Income Data – HESA

[67] Annex G: Appendix AAE4 SciVal Analysis for 2011-15

[68] Annex L: World Intellectual Property Organization 2004–13

[69] Annex H: Figure NES1 Research Income – HESA

[70] Annex H: Appendix NES2 REF 2014

[71] Annex H: Appendix NES3 REF 2014 Impact and Environment Statements

[72] Annex H: Figure NES1 Research Income – HESA

[73] Annex H: Appendix NES4 Publication Analysis – SciVal

[74] Annex I: Appendix NGM3 REF 2014

[75] Annex I: Appendix NGM5 Income data – HESA

[76] Annex I: Appendix NGM3 REF 2014 data

[77] Annex I: Appendix NGM5 Income data – HESA

[78] Annex I: HESA data

[79] Annex I: Appendix NGM4 Publication data – SciVal

[80] Annex J: Appendix DL2 REF 2014 data

[81] Annex J: Appendix DL3 Publication Data – SciVal

[82] Annex J: Appendix DL4 Research income data – HESA

[83] Annex J: Appendix DL2 REF 2014 data

[84] Annex J: Appendix DL3 Publication Data – SciVal

[85] Annex J: Appendix DL4 Research income data – HESA

[86] Annex K: Appendix RES8 Scientists and employment in Theme

[87] Annex K: Appendix RES12 – Research Income data – HESA

[88] Annex K: Appendix RES7 UK not for profit research organisations

[89] Annex K: Appendix RES8 Scientists and employment in Theme

[90] Annex K: Appendix RES4 REF 2014 data

[91] Annex K: Appendix RES5 REF 2014 data – Research Power

[92] Annex K: Appendix RES6 REF 2014 data – UK comparison

[93] Annex K: Appendix RES9 REF 2014 data – Doctoral Awards 2008-12

[94] Annex K: Appendix RES8 Scientists and employment in Theme

[95] Annex K: Appendix RES8 Scientists and employment in Theme

[96] Annex K: Appendix RES12 – Research Income data – HESA

[97] Annex K: Appendix RES13 Russell Group Research income – HESA

[98] Annex K: Section3 – Research Organisation research funding (unpublished)

[99] Annex K: Appendix RES11 Publication Analysis – SciVal

[100] http://www.leidenranking.com/ranking/2016/list

[101] http://www.publications.parliament.uk/pa/cm201012/cmselect/cmsctech/1538/1538we02.htm, section 4.9 c.

[102] http://www.eumetsat.int/website/home/index.html

[103] Annex L: Table 36-37: UK Growth Dashboard 2015. Enterprise Research Centre (ERC) in partnership with Business Growth Service (2015)

[104] Annex M: Table 37: BRES via NOMIS

[105] Annex L: Tables 26-30, 32: Mapping local comparative advantages in innovation. BIS(2015); HMRC; Building Local Advantage. Review of LEP area economies 2014. LEP Network and Athley Consulting (2014); Private Equity and Venture Capital Report on Investment Activity 2014; and Public Research And Innovation Expenditure (BIS)

[106] Annex L: Tables 31 and 33 Innovate UK

[107] Annex L: Table 34 Benchmarking Local Innovation – The innovation geography of the UK. Enterprise Research Centre (2015)

[108] Annex M: Table 37 BRES via NOMIS

[109] BRES 2014, NOMIS Official Labour Market Statistics

[110] Annex M: Table 47 – BRES via NOMIS

[111] ADS Group UK Aerospace Outlook 2011

[112] South West and Wales, Spotlight, Autumn 2015 – http://sites.southglos.gov.uk/wp-content/uploads/sites/241/2015/09/2015-bristol-spotlight-autumn.pdf and http://www.pwc.co.uk/industries/aerospace-defence/top-100-aerospace-companies-2014.html

[113] South West and Wales, Spotlight, Autumn 2015 – http://sites.southglos.gov.uk/wp-content/uploads/sites/241/2015/09/2015-bristol-spotlight-autumn.pdf and http://www.pwc.co.uk/industries/aerospace-defence/top-100-aerospace-companies-2014.html

[114] Annex M Table 50 – ONS Business Counts – NOMIS

[115] NATEP Analysis and Statistics May 2016 – issue 005

[116] Annex M: Table 33 – BRES via NOMIS

[117] Annex M: Figure 3 – BRES, ONS via NOMIS

[118] Aerospace and Advanced Engineering Sectors – South West Region's Inward Investment Strategy

[119] West of England Strategic Economic Plan 2015-2030

[120] BRES 2014, NOMIS Official Labour Market Statistics

[121] Aerospace and Advanced Engineering Sectors – South West Region's Inward Investment Strategy

[122] South West Renewable Energy Progress Report, 2015, Regen SW

[123] Annex H: Appendix NES1 – List of Assets

[124] Annex H: Appendix NES5 – Marine Renewables Supply Chain

[125] South West Renewable Energy Progress Report, 2015, Regen SW

[126] http://www.ukhfca.co.uk/

[127] South West Nuclear Cluster Inward Investment Opportunities Evaluation and Initial Engagement Report, DNA Ltd, June 2015

[128] Annex H: Appendix NES6 Regulated Nuclear Sites in the UK (ONR)

[129] Annex H: Appendix NES7 Industrial capacity in the nuclear sector (NIA)

[130] National Infrastructure Commission report on Smart Power

[131] Evidence based on iNET list of 425 companies + EstNet 260 companies

[132] http://techspark.co/cluster-map/

[133] www.techcityuk.com/wp-content/uploads/2016/02/Tech-Nation-2016_FINAL-ONLINE-1.pdf

[134] Annex J: Appendix DL8 Tables and Figures

[135] http://www.sehta.co.uk/wp-content/uploads/2016/06/Stephanie-Parker-Office-for-Life-Sciences.pdf

[136] https://ec.europa.eu/digital-single-market/news/mhealth-what-it-infographic

[137] Annex J: Appendix DL8 Tables and Figures

[138] http://www.nesta.org.uk/publications/geography-uks-creative-and-high-tech-economies

[139] https://www.gov.uk/government/groups/creative-industries-council

[140] http://www.huawei.com/en/news/2016/5/UKs-leading-smart-cities

[141] http://vrworldcongress.com/

[142] Annex J: Appendix DL6 Project Portfolio

[143] Annex M: Table 37 – BRES via NOMIS

[144] Annex M: Table 33 – BRES via NOMIS

[145] Annex M: Figure 7 – BRES, ONS via NOMIS

[146] Annex A: Consultation – Stakeholder workshop attendees

[147] Annex K: Appendix RES1 – Industry survey, July 2016

[148] Annex L: Tables 43-45 Mapping local comparative advantages in innovation. BIS (2015)

[149] Annex L: Tables 45-46 Mapping local comparative advantages in innovation. BIS (2015)

[150] Annex G: Appendix AAE2 Collaborative Projects

[151] Annex G: Appendix AAE4 Publications data – SciVal

[152] Annex H: Appendix NES1List of Assets

[153] https://photonicsuk.org/category/press-releases/

[154] Annex I: Appendix NGM4 Publication Data – SciVal

[155] https://www.epsrc.ac.uk/newsevents/news/quantumtechhubs/

[156] http://www.ukesf.org/universities/

[157] Annex J: Appendix DL5 Major Companies in Theme

[158] Annex J: Appendix DL3 Publication data – SciVal

[159] Annex J: Appendix DL4 Income data – HESA

[160] https://www.ipcc.ch/report/ar5/

[161] https://www.ipcc.ch/report/ar5/

[162] Data from Met Office (unpublished)

[163] http://www.eumetsat.int/website/home/index.html

[164] Data from PML (unpublished)

[165] Annex J: Appendix RES17 Publication data – SciVal

[166] The Climate Change Act 2008 (c 27)

[167] Aerospace and Advanced Engineering Sectors – South West Region's Inward Investment Strategy

[168] Composites Leadership Forum, UK Composites Strategy 2016

[169] Sandy Monro (Ford Motor Company) – Lean Design Philosophy 1988

[170] McKinsey & Co: Disruptive technologies: Advances that will transform life, business, and the global economy

[171] Warwick Economics and Development Report – University of Bath IAAPS

[172] http://emps.exeter.ac.uk/engineering/research/calm/

[173] ADS UK Aerospace Outlook 2015

[174] Lifting Off – Implementing the Strategic Vision for UK Aerospace

[175] Commercial Aircraft Maintenance, Repair and Overhaul (MRO) Market Forecast 2015-25

[176] Aerospace and Advanced Engineering Sectors – South West Region's Inward Investment Strategy

[177] http://www.cioslep.com/assets/uploads/documents/1463644707_AH_spaceport_v3.pdf

[178] Toulouse Aerospace Valley – http://www.aerospace-valley.com/en

[179] Andalucia Aeropolis – http://aeropolis.es/en/

[180] Italian Aerospace Research Centre – http://www.cira.it/en?set_language=en

[181] Poland Aviation Valley – http://www.dolinalotnicza.pl/en/

[182] Asia Aerospace City – http://www.asiaaerospacecity.com/

[183] Korea Aerospace Research Institute – http://www.kari.re.kr/eng.do

[184] Statista – Worldwide light vehicle sales – outlook 2011-2020

[185] BMW Group R&I Centre – www.bmwgroup.com/forschung_entwicklung

[186] International Centre for Turbomachinery Manufacturing – http://www.ictm-aachen.com/

[187] UK Marine Industry Alliance: A strategy for growth for the UK Marine Industries

[188] Plymouth Marine Industries Demand Study – Regen SW

[189] http://www.cop21.gouv.fr/en/

[190] World Energy Outlook, 2015, International Energy Agency / OECD, 2015

[191] Magagna, D., and Uihlein, A.: 'Ocean energy development in Europe: Current status and future perspectives', International Journal of Marine Energy, 2015, 11, pp. 84-104

[192] 'NER 300 programme' is a joint initiative of the European Commission, the European Investment Bank and Member States

[193] E4tech "The Fuel Cell Industry Review 2015" http://www.fuelcellindustryreview.com/

[194] Technology Roadmap – Hydrogen and Fuel Cells, International Energy Agency / OECD, 2015

[195] Annex H: Appendices NES6&7 – Regulated Nuclear Sites in the UK and Industrial capacity in the nuclear sector

[196] Photonics: A Key Enabling Technology for Europe, http://tinyurl.com/hyctqbb

[197] Towards 2020 – Photonics driving economic growth in Europe Multiannual Strategic Roadmap 2014-2020

[198] http://www.bccresearch.com/market-research/instrumentation-and-sensors/sensors-ias006f.html

[199] http://www.bccresearch.com/

[200] The Economist , 11 June 2016

[201] www.nesta.org.uk/sites/default/files/the-nhs-in-2030.pdf

[202] www.nesta.org.uk/publications/geography-uks-creative-and-high-tech-economies

[203] www.gov.uk/government/uploads/system/uploads/attachment_data/file/249423/bis-13-1217-smart-city-market-opportunties-uk.pdf

[204] www.fastcompany.com/3052209/tech-forecast/vr-and-augmented-reality-will-soon-be-worth-150-billion-here-are-the-major-pla

[205] Disruptive Technologies – advances that will transform life, business and the global economy, McKinsey Global Institute, May 2013

[206] http://www.bankofengland.co.uk/pra/Documents/supervision/activities/pradefra0915.pdf

[207] Pitt Review section 9.2 – http://webarchive.nationalarchives.gov.uk/20100807034701/http:/archive.cabinetoffice.gov.uk/pittreview/thepittreview/final_report.html

[208] http://www.newstatesman.com/staggers/2014/06/counting-1bn-cost-winter-floods

[209] http://www.cityam.com/231565/economic-impact-of-storms-eva-desmond-and-frank-could-hit-3bn

[210] https://documents.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Synthesis-Report-Committee-on-Climate-Change.pdf

[211] Space Innovation Strategy report on Leadership in Climate Technologies and Services, http://www.the-iea.org/wp-content/uploads/2016/03/IGS-Climate-Services-report.pdf

[212] https://www.munichre.com/site/corporate/get/documents_E-397017904/mr/assetpool.shared/Documents/5_Touch/Natural%20Hazards/NatCatService/Annual%20Statistics/2015/2015_Torten_Ereignis_e.pdf

[213] Economics of Adaptation to Climate Change, the World Bank, 2011 – http://www.worldbank.org/en/news/feature/2011/06/06/economics-adaptation-climate-change

[214] https://sustainabledevelopment.un.org/?menu=1300

[215] http://www.cop21.gouv.fr/en/

[216] https://www.technologyreview.com/s/602001/the-business-of-climate-change/

[217] Strategy for delivering chemistry-fuelled growth of the UK economy http://www.cia.org.uk/Portals/0/Documents/Growth%20Strategy%20FINAL.PDF'

[218] Adams C., Topics in Catalysis, 2009, 52, 924–934.

[219] "Growth Within: a circular economy vision for a competitive Europe", Ellen MacArthur Foundation, SUN, McKinsey & Co. (June 2015): https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Growth-Within_July15.pdf