Welsh Economy Research Unit
Yr Uned Ymchwil i Economi Cymru

CS Connected

Support for Strength in Places Bid: ACCELERATING THE GROWTH AND PERSISTENCE OF EUROPE'S FIFTH SEMICONDUCTOR CLUSTER **August 23rd 2019**

Welsh Economy Research Unit
Yr Uned Ymchwil i Economi Cymru

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Summary:

The Strength in Places (SIP) Fund is a new UK Research and Innovation (UKRI) scheme that takes a place-based approach to Research and Innovation investment. The fund aims to develop evolving and existing industrial clusters founded on a strong research base and research presence in Technology Readiness Levels (TRL) 1-3. A CS Connected proposal was shortlisted for full bid submission during Spring 2019.

This report was developed to support the full bid submission. The report examines the evolution of the compound semiconductor cluster 2015-2019, the challenges in strengthening the cluster, and the expected benefits for Wales of the further evolution of the cluster. The report examines how existing activity in the cluster, and then further activity supported by the Strength in Places bid, could work to meet place-based economic challenges.

The report has drawn on the findings from a series of interviews with a cross-section of key participants related to CS Connected, together with an analysis of a range of documents concerning CS Connected and the individual organisations associated with this entity. The quantitative analysis was supported by information provided by cluster firms which detailed their business activities in terms of employment, sales, purchases etc.

The report concludes that the future challenge for the Welsh economy, and relevant policymakers, is to identify and develop industries that potentially have competitive advantage. Although still embryonic, but growing, the activities in the compound semiconductor cluster represent a real source of such advantage, in an industry that is rapidly growing across the globe. Furthermore, the nature of the industry, especially skills requirements across the spectrum, means that the growth of the cluster would provide economic and social benefits to a broad range of individuals and their households.

Connecting expertise, capacities and capability within both the private sector, public sector and academia has already led to the establishment of a critical mass of activity – which is undoubtedly now the largest concentration of compound semiconductor activity in the UK.

The report finds a strong and distinct alignment between the proposed activities of CS Connected and the strategic priorities of Welsh Government and the Cardiff Capital Region. There has already been investments in the cluster by both of these stakeholders, and these have played an important role in illustrating the strategic direction of public sector economic and innovation/science policy in Wales.

The report finds that the place-based problem addressed through the development of the compound semiconductor industry embraces poor place-based productivity growth, pressure on local manufacturing output and related constraints on new inward investment and export growth. Alongside this, and a related issue, is a poor record of business expenditure on R&D in South Wales. Improved integration of the compound semiconductor activity provides an avenue for addressing these place-based problems.

In 2019 the principal CS Connected firms and organisations accounted for around 1,480 jobs, and private sector members accounted for £464m of sales, much of this (over 90%) relating to overseas exports, mostly destined for markets outside of the EU. The analysis reveals that the CS Connected members supported close to £125m of Welsh GVA.

In the context of the place-based economic issues the analysis reveals:

- Where economic activity is created and supported in compound semiconductor cluster activity that it provides relatively high levels of GVA per employee.

- That the sector already supports a regional supply chain but with scope to increase the regional supply of goods and services to the sector, and this being a core part of the SIP funding proposal.
- In part this high GVA per employee reflects relatively high earnings in the sector. The analysis reveals average earnings in parts of the sector in excess of £40,000 pa.
- The strengthening of this cluster of firms with their average productivity characteristics would provide an uplift to average regional productivity.

It is estimated that the SIP project would be associated with around an additional 1,160 FTE jobs divided between new employment in Computer, electronic and optical products (SIC 26) and Electrical equipment manufacture (SIC 27).

The report shows that the uplift associated with successful completion of the CS Connected SIP proposal would lead to direct cluster employment reaching close to 3,150 people by 2025, supporting £265m GVA directly, and once indirect supply chain and household effects are accounted, around £381m of total GVA.

1. Introduction

The Strength in Places Fund is a new UK Research and Innovation (UKRI) scheme that takes a place-based approach to Research and Innovation investment. The fund aims to develop evolving and existing industrial clusters founded on a strong research base and research presence in Technology Readiness Levels (TRL) 1-3.

A proposal from CS Connected was shortlisted for full bid submission during Spring 2019. The consortium consists of partners including: Cardiff University (lead), Swansea University, IQE, SPTS, Newport Wafer Fab, Microsemi, the Compound Semiconductor Centre, the Compound Semiconductor Applications Catapult, the Cardiff Capital Region (CCR) City Deal and Welsh Government.

This report by authors Professor Robert Huggins, Professor Max Munday and Dr Annette Roberts[1], was commissioned in May 2019 to assist in the preparation of the full Strength in Places (SIP) Bid (CS Connected) seeking funding to reinforce the compound semiconductor cluster in the Welsh economy. Critical here was to examine the evolution of the cluster since its genesis in 2015, and then to analyse how far the further development of the cluster, as supported by the CS Connected SIP funding application, would support activity in the regional economy, and meet the more persistent economic challenges facing the regional economy. The report is designed to be a source document for the full SIP bid, supporting different aspects of the application particularly surrounding challenges facing the local economy, the focus of the R&D surrounding the project, and an assessment of the economic impact of the project.

This report builds on research in 2014[2] which examined prospects for a cluster of economic activity around compound semiconductor manufacture. This work showed that employment growth connected with a compound semiconductor development project would be of value to Wales. The longer term vision of a Compound Semiconductor Foundry surrounded by collaborating enterprises could support new inward investment and be consistent with improving demands for higher level skills and providing graduates with more opportunity in the region. Improvements to the pattern of demand and supply side could work to improve regional productivity. Fundamentally development in compound semiconductors was shown to represent an opportunity to situate Wales at the epicentre of market-supply.

The reminder of this current report is structured as follows: Section 2: examines the evolution of the compound semiconductor cluster in the period 2015-2019, the challenges in strengthening the cluster, and the expected benefits for Wales of the further evolution of the cluster.

Section 3: focuses on the original and change policy context around the future development of the cluster, and then how far the further development of the cluster meets with different policy aims and objectives.

Section 4: focuses on specific place-based economic needs, and how existing activity in the cluster, and then further activity supported by the SIP bid, works to meet place-based economic challenges. Moreover, this section shows how cluster activity supports economic activity in Wales both directly and indirectly.

Section 5 of the report concludes.

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[1] See Appendix for information on the authors.

[2] *A Review of the Proposal to Establish a Foundation for Compound Semiconductor Technology: Creating Europe's Fifth Semiconductor Cluster in South Wales*, Robert Huggins, Max Munday, Annette Roberts and Richard Watermeyer., Feb 2014, Cardiff University Report.

2. Compound Semiconductor Cluster Evolution 2015-19

2.1. Introduction

The aim of this section of the report is to assess and examine the development and evolution of the compound semiconductor sector in South Wales. In particular, it seeks to focus on considering the extent to which the industry in the region is emerging as an identifiable business cluster that possesses an ecosystem of identifiable and interdependent companies and organisations. Such a clustered ecosystem business environment and culture should provide benefits to participants that leverage wider economic development benefits for the region. The principal objectives here are to map the emergence and evolution of the cluster, especially since 2015, as well as to consider the benefits it has generated, and how it can positively move forward in the future.

The case study represents a relatively bounded group of actors that have jointly branded themselves as 'CS Connected' representing organisations largely located in South Wales that are directly associated with research, development, innovation and manufacturing of compound semiconductor related technologies, as well as organisations along the supply chains whose products and services are enabled by compound semiconductors.

Methodologically, this part of the study draws on the findings from a series of interviews with a cross-section of key participants related to CS Connected and an analysis of a range of documents concerning CS Connected and individual organisations forming part of this entity. Before moving on to a mapping and analysis of the CS Connected concept, some context in terms of the broader compound semiconductor market is briefly outlined.

2.2. The Compound Semiconductor Market

Compound semiconductors are a Key Enabling Technology ("KET") for the economic growth drivers identified in the European Commission's "Horizon 2020" economic growth strategy, aimed at the reindustrialisation of the Europe. Compound semiconductors are at the heart of the high-tech devices used today, from smartphones and tablets to satellite communications and GPS, and the advent of the internet, fibre-optic communication and the smartphone revolution have been fundamentally dependent on compound semiconductor technologies. Compound semiconductors enable high speed processing in excess of 100 times that of silicon, as well as an array of other properties including the ability to emit and sense light, all the way from the infrared, through the visible and into the ultra-violet part of the spectrum. Compound semiconductors complement silicon in areas such as wireless communications, where chips made from material combinations such as gallium and arsenic (gallium arsenide, or GaAs) are found in virtually every smartphone where they enable high speed, high efficiency wireless communications in cellular and WiFi networks. The photonic and power efficiency properties offered by compound semiconductors that could not be achieved with silicon alone, enable technologies essential in areas such as safety and security systems, healthcare technologies, aerospace and automotive applications including electrically powered and autonomous vehicles.

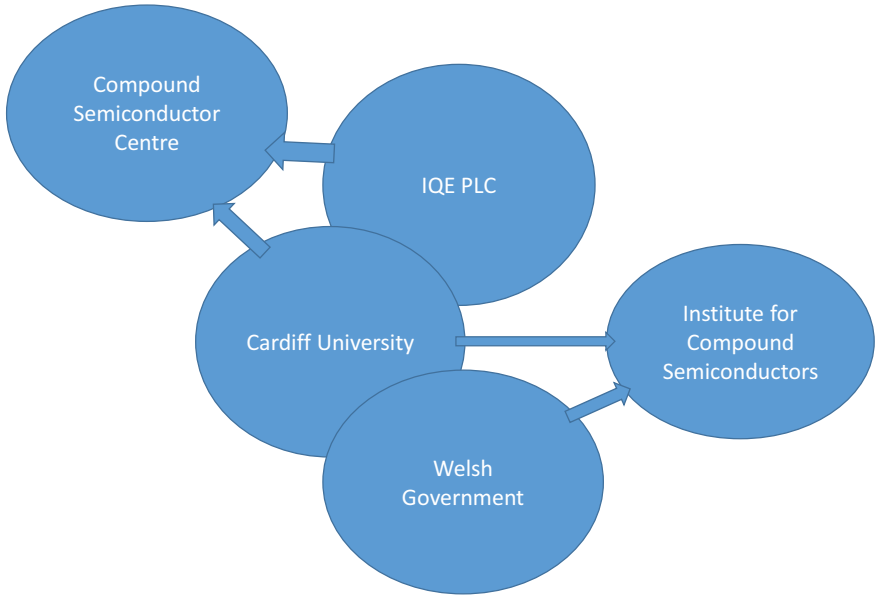
The total global semiconductor market (compound semiconductors and silicon) is worth around US$350bn a year and is growing at 10-15% per annum. The compound semiconductor market is around US$30bn, but market analysts consider there to be huge growth potential in new and emerging technologies such as driverless and autonomous vehicles and in healthcare technologies. According to analysts, global markets for compound semiconductors are projected to reach US$125 billion by 2025, with other analysts estimating the global market for compound semiconductors to grow from a 2016 figure of US$66 billion to more than $300 billion come 2030; three times the growth rate of silicon. In the UK, there are already more than 100 companies actively working with compound semiconductor devices. South Wales has been active in the research and development of compound semiconductors - i.e. the technology that enables devices like smartphones and sensors - for a significant amount of time. However to develop an ecosystem there is need for a critical mass of key actors and infrastructure to progress from concept right through to the commercial products, requiring substantial investment and impetus.

2.3. Assessing the Evolution of the Cluster

As shown by Figure 1, recent cluster evolution resulted from a three way agreement between IQE PLC, Cardiff University and Welsh Government. IQE (a leading global supplier of advanced compound semiconductor wafer products covering a diverse range of applications) and Welsh Government set up the Compound Semiconductor Centre and the University and Welsh Government set up the Institute for Compound Semiconductors (this being a translational facility to help researchers and industry work together). The Compound Semiconductor Centre founded in 2015, is a prototyping facility allowing businesses and academics to demonstrate new technologies based on compound semiconductor materials. It is beginning to position itself as a new European home for product, services and skills development in compound semiconductor technologies. The Centre is building on research undertaken at Cardiff University's Institute for Compound Semiconductors to develop innovative new materials technologies that will enable a wide range of new and emerging applications. The Compound Semiconductor Centre principally plays a role within the cluster that seeks to coordinate activities related to:

- The Skills and Jobs Agenda
- Facilitating Collaborative Projects
- Product and Process Development
- Prototyping
- Ensuring Effective Road Mapping.

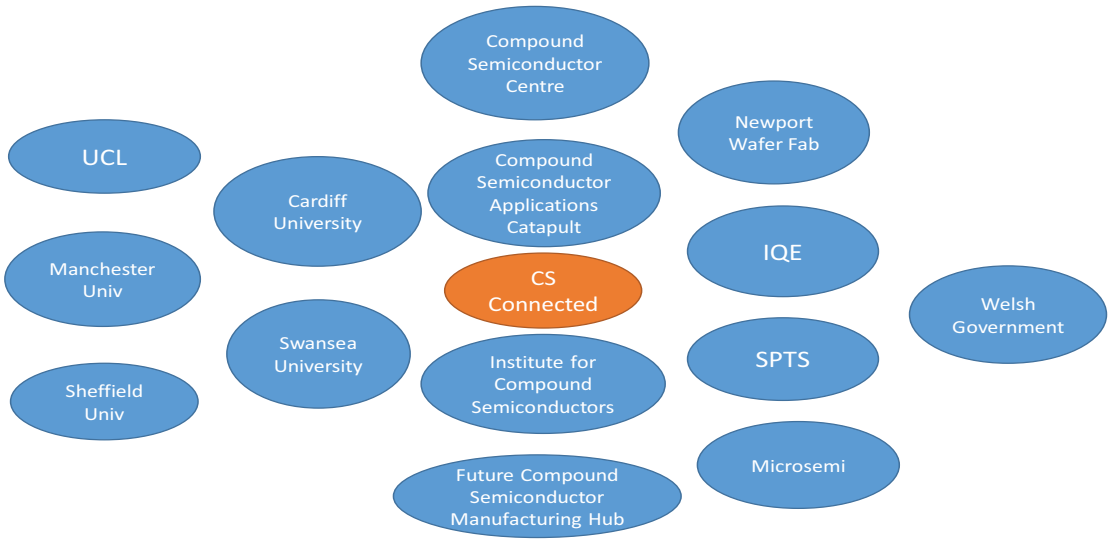
Figure 1: The Seeds of the Compound Semiconductor Cluster in South Wales



Since 2015, and as shown by Figure 2, the cluster has rapidly expanded to form an emergent regional ecosystem within significant interdependencies across a range of organisations across the private sector, public sector, and academic and research organisations. The most notable features of the cluster's development since 2015 are the investments in human capital and innovation. According to the Compound Semiconductor Centre, the cluster has secured investment in numerous forms of the order of £600m since 2015. As well as IQE, a number of South Wales-located companies – Newport Wafer Fab, SPTS and Microsemi – occupy important parts within the compound semiconductor value chain. In particular, Newport Wafer Fab is the UKs largest remaining silicon wafer fabrication plant employing 450 high value manufacturing jobs, with expansion plans to create a compound semiconductor fabrication capacity.

Essentially, the IQE wafer foundry and Newport Wafer Fab chip foundry are at the core of the cluster, with interviewees indicating that strategic investments into the core will generate high value supply chain opportunities. Furthermore, Newport Wafer Fab's strategic projects are designed to unlock the potential of the cluster creating significant economic vertical effects in the region by providing technologies for high speed communications, big data, LIDAR, healthcare, space, aerospace, EV engines, AI sensors, and RF for 5G. Other cluster members include SPTS Technologies, which designs, manufactures, sells, and supports capital equipment providing advanced wafer processing technologies and solutions for the semiconductor and microelectronics industry. Another core member of the cluster is Microsemi, which is an advanced packaging business delivering miniaturised electronic circuits, enabling wireless connectivity and developing novel energy sources for medical devices.

Figure 2: Activity in Compound Semiconductors in 2019



Alongside the Compound Semiconductor Centre, research and development is focused around Cardiff University's Institute for Compound Semiconductors and the Future Compound Semiconductor Manufacturing Hub.

The Institute for Compound Semiconductors aims to position itself as the European leader in compound semiconductor innovation. It offers cutting-edge facilities that help researchers and industry work together to generate economic impact through the commercial and academic exploitation of compound semiconductor technologies. The target is to become the UK facility of choice, with European recognition, for catalysing, facilitating and enabling world-class research, enabling high-impact compound semiconductor-based commercially relevant technology, company spin-offs and product development. The Institute is part of Cardiff University's £300 million Innovation Campus, combining research, technology transfer, business development and student enterprise. The Institute has received over £80 million investment for its new building and equipment including over £30 million of external investment.

The Future Compound Semiconductor Manufacturing Hub undertakes research into large scale compound semiconductor manufacturing and in manufacturing integrated compound semiconductors on silicon. It was established to be the UK's primary global research and manufacturing hub for compound semiconductor technologies. It aims to combine and connect the UK research excellence in compound semiconductors, with the translational facilities of the Compound Semiconductor Applications Catapult (see below) to support the UK compound semiconductor industry and UK industry users of compound semiconductors. The combined activity provides a path from enabling fundamental research through wafer, device and integrated chip manufacturing research into product prototyping, reliability testing and system qualification at the Compound Semiconductor Applications Catapult.

The original Hub consortium comprised 4 UK academic institutions, 24 industry collaborators, and a variety of other supporting entities. To date, over 30 industry collaborators have pledged their financial and in-kind support as partners. Its recent collaborations and partnerships include Airbus, Huawei (US), Lockheed Martin, Nokia, QinetiQ, Toshiba, as well as academic partners at the University of Manchester, University of Sheffield, and University College London.

A vital addition to the cluster is the establishment of the **Compound Semiconductor Applications Catapult**, which acts as business acceleration support organisation, fostering innovation and entrepreneurship. The Catapult was announced in 2016, backed by government funding of £50m (£10m per year up to 2020-21) and spearheaded by IQE. Its aim is to support industry's ability to access and exploit the advances made by UK researchers in compound semiconductor technologies over the past two decades, and to bridge the gap between companies developing novel semiconductor materials, topologies and devices, and those developing systems for end-user applications.

The Catapult focuses on helping the compound semiconductor industry to exploit the significant advances made by UK researchers over the past two decades. The Catapult provides translational research facilities to accelerate the commercialisation of compound semiconductors in key application areas including: healthcare, the digital economy, energy, transport, defence and security, and space. The Catapult is developing an innovation centre that offers the capabilities and laboratory facilities required by industry to accelerate the development of new products. Furthermore, it develops, offers and collaborates on evaluation modules for companies to rapidly explore new compound semiconductor technologies, enabling them to enhance their product range and target new markets stimulating demand across the UK supply chain through challenge-led programmes. This supports a number of prioritised industry sectors apply compound semiconductor technologies in their roadmaps.

Since 2015, research expertise at Swansea University has also become a significant component of the cluster's R&D activities through its involvement in numerous collaborative projects. In particular, the **Centre for Integrative Semiconductor Materials** at Swansea University (CISM) brings together semiconductor and advanced materials platforms and processes to deliver new technologies while seeking to develop industry skills. It provides services including new research, prototyping and process development, specialist services, incubation, engagement, training and access to the UK and EU innovation grants portfolio. Key here as an objective is to integrate state-of-the-art semiconductor platforms with over-the-horizon materials and processes to deliver next generation technologies for optoelectronics, energy, power systems and healthcare applications.

Finally, the public sector in the form of the **Welsh Government** through its Innovation Strategy, is committed to making strategic interventions in industrial sectors where there are three pre-conditions: (1) where Wales already has internationally recognised expertise; (2) where there are businesses capable of exploiting this knowledge; and (3) where there is a significant global market potential to address. Given this, the Welsh Government has recognised the potential of the compound semiconductor industry in Wales and has supported it in numerous ways.

While not part of the production and research cluster, Cardiff Capital Region (CCR) has acted as a champion for the development of the industry through both financial support and international exposure. The CCR City Deal is a programme of activity agreed in 2016 between the UK Government, Welsh Government and ten local authorities in South East Wales to bring significant new economic growth opportunities. The local authorities that comprise the CCR have a stake in the recently established Compound Semiconductor Foundry Limited, with the investment not being a grant or a loan but a commercial investment. The business plan is for the original investment plus interest to be returned to the councils over the lifetime of the project. Specifically, the Regional Cabinet agreed to contribute £38.5 million from the CCR City Deal's Wider Investment Fund towards the establishment by IQE plc of a major, cutting-edge facility, acting as an anchor in the region for the high-end production of compound semiconductors (see also section 3.3).

According to the Compound Semiconductor Centre, the cluster in South Wales has total current employment estimated to be close to 1,480 in 2019 and with this expected to grow through further development of the downstream supply chain. It is clear that these aims could be further accelerated through the attraction of external investment, and the cluster is actively seeking to attract new foreign direct investment, particularly with regard to creating value down the supply chain. A key target for the cluster is to improve the diversity of the verticals utilising compound semiconductor technology, as well as to improve the R&D capacity to meet the needs of the world class manufacturing that is already a feature of the cluster. The automotive industry is a significant customer, along with mobile communications technology. Compound semiconductors are potentially also a key enabling technology related to:

- Robotics
- Energy Efficiency
- Healthcare
- Aerospace
- Security
- Internet of Things
- Energy Efficiency.

In essence, the ingredients for fast growth across CS Connected is in place, but this can be significantly accelerated through additional investment aimed at improving hard and soft infrastructure in a number of key areas. The cluster has already achieved some significant success through the creation and attraction of three new high-technology companies, with current discussions indicating the potential attraction of a unicorn company in the area of Artificial Intelligence. From the perspective of entrepreneurship and indigenous business development, the introduction of the Compound Semiconductor Applications Catapult acts as a focal point for stimulating new local businesses, and the introduction of a number of incubation spaces are set to house locally developed firms, especially spinouts from the universities of Cardiff and Swansea. Interviewees suggested that the Catapult is now becoming more embedded within the cluster and is helping to foster new collaborative innovation projects with a focus on:

- Transport
- Healthcare
- Digital economy
- Energy
- Defence and security.

Within the compound semiconductor industry the spatial proximity of companies, universities, research organisations and other entities plays an important role in knowledge sharing and allowing good practice to flow. This is often the case with respect to the emergence of key enabling technologies – with Silicon Valley being the archetypal example - and once embedded these tend to offer an evolutionary and enduring advantage for those locations that are the recipients from the initial emerging developments. Similarly, companies in the sector are required to make significant heavy sunk investment in their chosen location. Therefore, the advantages of, and necessity for, locational stickiness indicate that capital flight from the cluster to other locations is unlikely to occur unless there are significant changes in macroeconomic conditions. Furthermore, the cluster members appear to have developed a common business culture with significant levels of trust and interdependences being established across the cluster.

The Compound Semiconductor Centre has played a vital part in developing this culture and creating positive behavioural change through the promotion of an open innovation attitude, as well as the promotion of solutions to common issues such as skill shortages (see below). Undoubtedly, the compound semiconductor industry has a degree of risk given the availability of alternative technologies, but the global growth of the industry indicates that it is likely to represent a disruptive and high value technology, and the cluster has already positioned itself to capture a significant proportion of this value. As one interviewee stated ‘every smartphone has a bit of Wales’. The cluster’s own estimate suggests that it could create an initial 3,000 new jobs by 2025, and global projections for the growth of the sector indicate this to be a reasonable projection. A major feature of the potential to secure these jobs is the establishment of the Compound Semiconductor Cluster Foundry Ltd, which represents a dedicated compound semiconductor technology and manufacturing facility, with the first phase being completed in 2018.

It is also important, however, to consider the nature and the quality of these jobs, which in this case will consist of a balanced mix of high-end knowledge-intensive and R&D focused occupations through to managerial positions and more technical employment opportunities. From the perspective of the South Wales region, this broad range of skill requirements represents a good fit with the overall composition of local labour markets in terms of its capacity and capabilities. This will allow the benefits of the cluster to be spread quite broadly across the region, with workers (particularly in the supply chain) being attracted from numerous locations, including a number of the more deprived towns and localities.

2.4. Moving Forward

The CS Connected ecosystem has been a major catalyst of relationship building both within South Wales and more broadly, and it has successfully acted as a brand for the cluster. However, much of these efforts have been undertaken on a goodwill and voluntary basis, and the common view of cluster members is that increased investment to formalise and cement the CS Connected ecosystem will result in the cluster as whole growing more rapidly and sustainably. South Wales has already become the premier UK site for compound semiconductor production, and the forging of a growing cluster initially from the joint venture between Cardiff University and IQE, as well as its continued growth in line with the apparent projections, means that this growth needs to be more strategically managed. Critical issues here include strengthening the value chain between IQE, Newport Wafer Fab and Microsemi, using equipment from SPTS, and supporting material/product development in conjunction with the Institute for Compound Semiconductors, the Compound Semiconductor Applications Catapult and the Future Compound Semiconductor Manufacturing Hub. The Compound Semiconductor Centre is obviously well positioned to undertake this role, but in order to achieve this effectively more resource and investment is necessary if it is to be operated on a less piecemeal and more joined-up approach. Alongside this, the CS Connected ecosystem brand has helped develop new markets with large multinationals across the world.

A primary economic development factor for continuing to build the cluster is that the value and benefits stemming from the sale of compound semiconductors will remain almost entirely within the UK, without the need to outsource parts of the production process to locations such as China. Ensuring, therefore, the value at all points along the supply chain within British shores represents a clear UK national competitive advantage within a globally leading high-technology industry. Without a stronger core dedicated team, activities related to brand building, network and collaboration coordination, and the capability to leverage a wider pool of actors may be compromised during the next round of development. At a European level the traditional hotspots for semiconductor production consist of Leuven, Eindhoven, Dresden and Grenoble, which comprise of more than 800 companies and 150,000 employees. These clusters are major drivers of the European economy, and with enhanced coordination of activity in South Wales there is a clear opportunity to both compete and collaborate with these leading technology-based centres due to compound semiconductor technology having a rapidly increasing application footprint, especially in traditional markets whereby many new disruptive applications are emerging. According to some interviewees, the expectation is to grow the cluster to around 30 private sector companies through a mix of both inward investment attraction and indigenous development.

With the number of cluster members growing, a vibrant labour market and open innovation network is emerging, and there is significant evidence of this through the collaborative projects that have been undertaken in recent years. Another indication of this is the fact that in 2019 key members of the cluster won the ‘Best Collaboration’ award at the prestigious Insider Media’s ‘Made in the UK’ Awards, which adds to a host of similar awards in previous years. Similarly, the establishment of the Innovation Village is creating a private sector-led hub for R&D, with Cardiff University investing in 60 PhD scholarships researching compound semiconductor technology.

These investments do not exist in isolation and strong university-industry interaction occurs, with universities leveraging the intellectual capital of the private sector. The scholarships are supported by 23 industrial partners, which are complemented by taught MSc courses in Compound Semiconductor Physics and Compound Semiconductor Electronics. The cluster has also hosted a conference dedicated to open innovation that has helped position the cluster at the centre of these debates and practices. Interestingly, a number of interviewees suggested that the nature of the Welsh business culture, especially the close ties and communities that exist, have helped to aid a culture within the cluster that possesses the required agility and flexibility to react effectively to ever changing circumstances, opportunities and threats within the global economic environment. Building on this, current and future areas for innovative products and solutions include:

- Semiconductors for Healthcare,
- Photonics & Sensor Technologies
- Power Electronics
- Next Generation Semiconductors & Dielectrics
- Functional Coatings.

2.5. Coordination: Skills development and recruitment

The value of the Compound Semiconductor Centre as a coordinating body for the cluster cannot be underestimated. Throughout this review it became apparent that the establishment of the Compound Semiconductor Centre was at least partly responsible for the development of a number of the incumbent members of CS Connected as well as supporting the attraction of companies from elsewhere. Also, CS Connected has facilitated the acceleration of the capability to access and capitalise on new and emerging business opportunities as well as to coordinate responses and solutions in relation to issues such as accessing talent and skills. Indeed, the areas of skills and talent development and retention in the South Wales area is recognised as one that will require particular attention if the potential of the cluster is to be fulfilled. There is also a need here to coordinate the activities of the existing CS Connected Skills Group. Fundamentally, unless these issues are addressed, the growth of the cluster is likely to lead to acute skill shortages. Key areas that the cluster will need to address in the future regarding the skills economy and agenda are:

- The pipeline of talent suitable for the compound semiconductor sector needs further nurturing.
- There is a need for the primary and secondary education sector in South Wales to be made more aware of the opportunities available in the compound semiconductor industry, as well as more generally the opportunities in the ‘new electronics’ industries.
- The need to recruit new employees with experience, and the need to improve training to those already employed.
- To further stimulate the uptake of STEM related courses, especially among females.
- To develop more outreach, including educating the parents of school pupils of the availability of high quality employment opportunities.

- And to engage more closely with the further and higher education sector in South Wales to ensure the suitability and applicability of vocational and more academic educational routes.

With regard to the final point above, more work is likely to be required to engage with the further education sector, given that a high proportion of the forecast jobs to be created will require vocational and technical skills. Relationships with the higher education sector are more fully evolved given that the universities are already key and primary members of CS Connected, and the private sector are often working with the higher education sector to establish tailored courses. To some extent this has led to a focus on high-end R&D activity, which is positive but should not be at the expense of developing some of the more fundamental technologies. A recent Skills Survey[3] covering CS Connected stakeholders found:

- There is a lot of positivity surrounding the potential for growth within the cluster, but there is significant concerns about sourcing sufficient additional, skilled, staff at all levels to meet the future demand.
- It is widely acknowledged that there are few, if any, 'ready-made' potential employees for the cluster; upskilling and re-training are required for all new recruits.
- The likely retirement of older staff over the next decade means that sustainability is a genuine and immediate concern for companies; recruitment has to increase over the next five years just to maintain capability, let alone meet future growth plans.
- There is a need to take a more strategic approach, across the cluster, in order to create a 10-12 year pipeline of 'talent' to address both skills shortages and skills gaps.
- Employers are positive about apprenticeship schemes but they would encourage providers to offer a whole range of more flexible and modular-based training courses, not just for apprenticeships.
- Employers have some specific skills gaps; these include wafer level testing, characterisation and software.
- Employers saw the future demand for engineering staff educated to Level 8 (PhD) as high; plans for the Centre for Doctoral Training are welcomed, particularly the collaboration with industry. However, some doubts remain that demand at both Level 7 and Level 8 may still exceed supply.

2.6. Assessing the Impacts

South Wales clearly already has a degree of advanced semiconductor expertise in the form of IQE, SPTS Technologies, Newport Wafer Fab and Microsemi, along with academic partners and the UK Government's £50million Compound Semiconductor Applications Catapult, forming the world's first compound semiconductor cluster, CS Connected. This review reveals that a sustainable innovation ecosystem and cluster is emerging due to the strong and enduring ties and connections being developed across the relevant organisations. The ties and networks involve both market and supply-chain connections, through to knowledge sharing and a more general pooling of information and expertise.

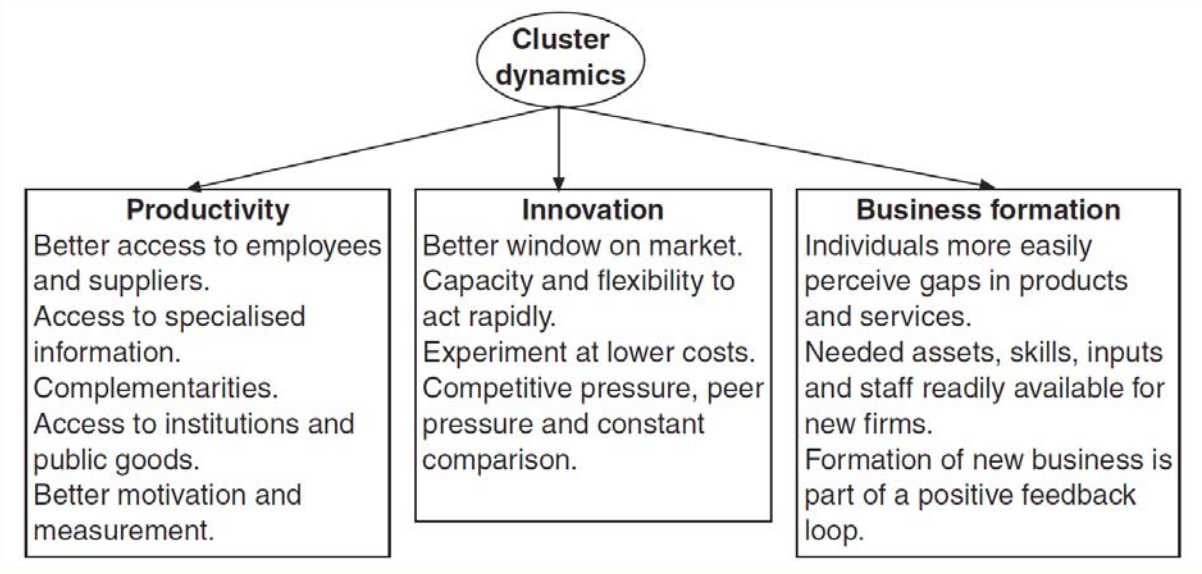
[3] See https://www.ukesf.org/wp-content/uploads/2018/12/Survey-Report-final.pdf

Furthermore, the plethora of project funding awards announced since 2015 is testimony to success in creating an environment steeped in innovation and entrepreneurial endeavour, resulting in South Wales emerging as a hotbed for the development, innovation and manufacture of advanced compound semiconductor related products. Therefore, it can be concluded that a clustered ecosystem based on interdependency, trust and common goals and obligations has rapidly emerged since 2015.

In order to consider more systematically the benefits that have emerged from the establishment of the cluster it useful refer to proposed impacts in relation to improvements in productivity, innovation, and business formation (see Figure 3 – but also see Section 4 on this issue):

- **Productivity** – the cluster has developed a number of the key components that are likely to drive productivity gains. Improved connections across the supply-chain and access to key industry information have advanced considerably. Access to suitable employees is an issue, which represents part of the necessary growing pains, and is being addressed. The close involvement of both regional and local government and the academic sector is real and concrete, rather than rhetorical, and provides a strong fundamental base to improve productivity at all levels. The Compound Semiconductor Centre has provided a major motivating agent, and the next steps include a more detailed focus on cluster measurement metrics.
- **Innovation** – innovation has been a hallmark of the cluster's evolution, especially through the adoption of a culture of open innovation. Cluster members, from the private sector and academia, have successfully bid and undertaken a wide range of collaborative projects in the field of compound semiconductor research and development. The involvement of the private sector actors has maintained a commercial focus to these projects that has placed the cluster at the forefront of developments in the sector. In particular the Future Compound Semiconductor Manufacturing Hub at Cardiff University and the emerging Innovation Village located at Newport Wafer Fab provide a means for coordinating an innovation strategy for the cluster that facilitates leading innovation across the technology readiness level spectrum.
- **Business formation** – entrepreneurship and new business formation is a central feature the cluster's strategy, and through the activities of the universities – with a focus on spinout generation – and the Compound Semiconductor Applications Catapult – with its focus on business acceleration – the necessary components are successfully being put in place. Tangible benefits in this area require patience, and although the cluster has yet to witness a cadre of new entrants, it is probable that these will be forthcoming as the commercialisation potential of the innovations mentioned above is harnessed.

Figure 3: The Economic Benefits of Clusters



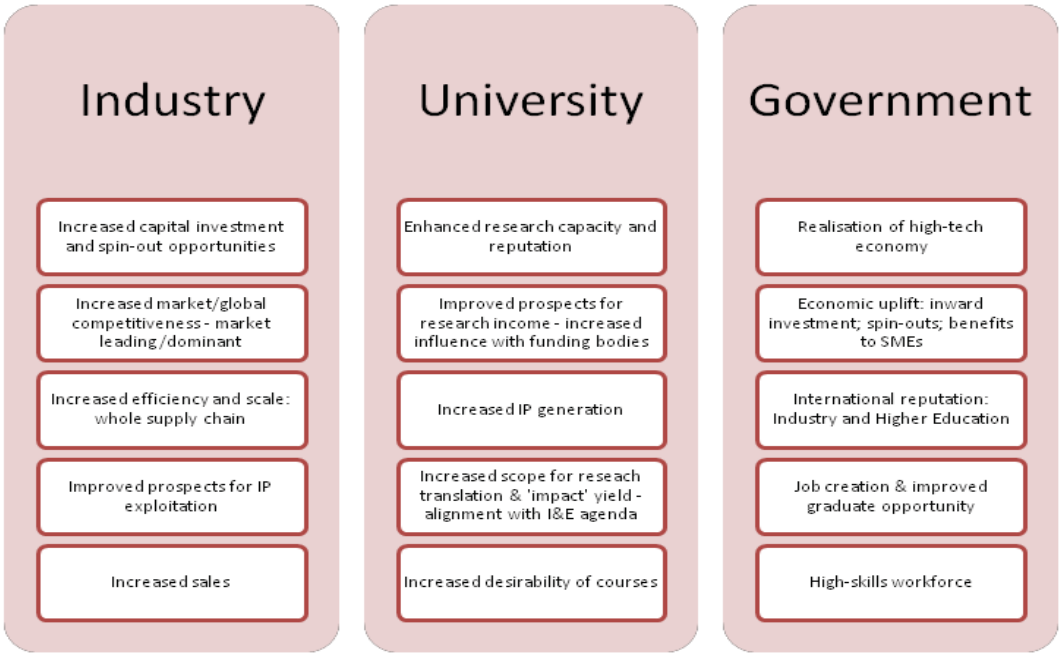
Source: Huggins and Izushi (2007) based on Porter (1998)

As a further means for considering the benefits of the cluster it is instructive to look back at the views of key stakeholders on the potential advantages when they were surveyed in 2014 as part of the initial feasibility work (Huggins et al., 2014)[4]. In this case, the analysis was presented according to three forms of stakeholder type: industry; university; and government. As shown by Figure 4, each type suggested that the development of the cluster should yield a range of potential advantages. In the case of industry stakeholders the focus was on increasing and improving: investment; new firms; market share; efficiency and scale; IP commercialisation; and revenue. In overall terms, the cluster has made significant strides with regard to each of these, and although measurable benefits have not yet emerged, the building blocks to enhance these over the long-term are being constructed. In particular, sustained capital investment and new business formation will be primary factors in ensuring that the cluster will continue to grow and flourish.

From the perspective of the university sector, as expected the benefits of the cluster were very much geared toward improvements in research income, capacity and reputation, coupled with new knowledge and IP generation, the expansion of relevant translational research and learning opportunities. In many ways, for universities – Cardiff and Swansea University – these proposed impacts have become self-fulfilling prophecies, as their own efforts – through the coordination of the Compound Semiconductor Centre, the development of the Institute for Compound Semiconductors (Cardiff), and Centre for Integrative Semiconductor Materials and Centre for Nanohealth (Swansea)– have led to considerable and significant benefits across each of these themes.

[4] See footnote 1.

Figure 4: Stakeholder Perceptions in 2014 of the Development of the South Wales Compound Semiconductor Industry



Source: Huggins, R., Munday, M., Roberts, A. and Watermeyer, R. (2014) 'A Review of the Proposal to Create Europe's Fifth Semiconductor Cluster in South Wales'. Cardiff: Cardiff University.

As indicated above, these efforts have led to the cluster developing a culture steeped in open and collaborative innovation. For the government sector, the potential impacts concern a more general upgrading of the economic structure and capacity of the knowledge economy in Wales, led by improvements in human capital, entrepreneurship, innovation and investment. As shown in this review, the fact that government at both local and regional level have shown a significant and long-term commitment to the development of the compound semiconductor cluster in South Wales, indicates the current value they perceive has already been generated, and which will do so in the future. Given some of the policy issues alluded to in the 'policy context' considered in the next section, it would appear manifest that the evolution of the CS Connected is one of the shining lights of the Welsh economy.

2.7. Conclusions

The future challenge for the Welsh economy, and relevant policymakers, is to identify and develop industries that potentially have real competitive advantage. The long-term decline of the region's economy has meant that these have become virtually non-existent, resulting in a continual erosion of economic competitiveness. Although still embryonic, but growing, the activities in the compound semiconductor cluster in the region represent a real source of such advantage in an industry that is rapidly growing across the globe. Furthermore, the nature of the industry, especially skills requirements across the spectrum, means that the growth of CS Connected will provide economic and social benefits to a broad range of individuals and their households in terms of their education levels and backgrounds (see Section 4 of the report). Indeed, the nurturing of the cluster represents a model means for progressing the types of economic strategy planning that have been established by the Welsh Government (see Section 3 of the report).

The marrying of expertise, capacities and capability within both the private sector and academia has already led to the establishment of a critical mass of activity – which is undoubtedly now the largest concentration of compound semiconductor activity in the UK – and the proposals to enhance the local supply chain will create further value and economic opportunity. Although Wales continues to experience many economic challenges, it is not totally bereft of the types of technology-based economic activity that is at the heart of development in the most economic advanced regions, not only in the UK but across the globe. A fledgling information and communications technology sector is emerging, and the expansion of the compound semiconductor industry in the region will have multiple benefits contributing to this broader sector becoming larger and more sustained and embedded.

3. Policy context

3.1. Introduction

The parlous state of the economy of Wales is well documented, and it persistently performs below UK-wide gross value added (GVA) per capita levels, whilst low average GVA per job (labour productivity) and low-wage employment have been associated with industrial restructuring (as low-value services replaced traditional resource and manufacturing jobs). The general business culture is seen to be weak, and across the Welsh small and medium-sized enterprise (SME) base there is a lack of a culture of entrepreneurship and innovation. An overemphasis on branch plants and foreign direct investment (FDI) in the past, rather than building up the capabilities of indigenous firms, is pointed to by some as a contributing factor. A fundamental issue in Wales has been lack of an innovation system that provides entrepreneurs with the nurturing environment they require. Whilst leading locations can create a virtuous cycle of entrepreneurship and innovation, regions such as Wales have become trapped in a more vicious downward cycle.

This section of the report examines the innovation policy context prior to reviewing selected regional strategy documents to establish how well the proposed aims and objectives of CS Connected align with those of Welsh Government and others, as this has important implications for the likely support and sustainability of CS Connected in the future. Critical here is that the aims of CS Connected link closely with regional place-based policy.

While this section of the report focuses on the Welsh policy context, CS Connected, due to its scale and sectoral scope, has important wider significance for the UK economy. The UK policy context, in particular *The Industrial Strategy*[5], is then an important reference for CS Connected activities and outcomes. Of specific relevance within the *Industrial Strategy* is a key policy to 'Raise total research and development (R&D) investment to 2.4 per cent of GDP by 2027' (p.11)[6] and a vision for 'the world's most innovative economy' (p.13). CS Connected then has a further opportunity to help address the UK wide innovation and productivity challenge.

3.2. Innovation policy

In general, the location context plays an important role in shaping the nature of innovation and entrepreneurship pursued. Supporting increased levels of innovation and entrepreneurship is of central importance to economic development in Wales. However, previous initiatives such as the Technium incubator programme have found it difficult to generate success. A multifaceted and arguably somewhat chaotic innovation policy backcloth is in place in Wales, reflecting, in part, an innovation agenda that has waxed and waned.

[5] https://www.gov.uk/government/publications/industrial-strategy-building-a-britain-fit-for-the-future

[6] The Industrial Strategy Challenge Fund, is 'a core pillar in the government's commitment to increase funding in research and development by £4.7 billion over 4 years to strengthen UK science and business'. See https://www.ukri.org/innovation/industrial-strategy-challenge-fund/

However, there has been a resurgent interest in innovation since 2010, with it featuring centrally in economic strategies, and with an innovation strategy, *Innovation Wales*,[7] in place, which seeks to attach itself to 'smart specialisation' principles. Improving collaboration, promoting a culture of innovation, providing flexible support and finance for innovation, innovation in government, and prioritising and creating critical mass are key threads of the strategy. Poor representation in some key innovation-led areas; a weak external perception of Wales as a base for knowledge based companies; improvement in the quality of engagement between academia and industry; and poor graduate retention arising from lack of suitable employment opportunities are seen as key priorities for improving the Welsh innovation landscape.

3.3. Alignment with current policy in Wales

The report commissioned by Welsh Government (2014)[8] identified alignment between the vision of the cluster and the Welsh Government's economic and strategy documents at that time. The report also recognised alignment with strategies relating to science and innovation in Wales. Since that report, there have been significant changes to the relevant strategy documents in Wales, as well as the establishment of CCR City Deal in 2016, with publication of a Strategic Business Plan in 2018[9]. The broader economic context within Wales has also changed following the EU referendum and the ongoing Brexit negotiations.

Prosperity for All: the national strategy

The Welsh Government published *Prosperity for All: the national strategy* in September 2017[10] and later that year the related *Action Plan*[11]. A critical observation of relevance to CS Connected is that the *Action Plan* in its Foreword (p.1) notes that it is: '.. grounded on the principle that places matter and seeks to make real our ambition to deliver better jobs closer to home'.

A key difference with this latest Welsh Government strategy and *Action Plan* compared with its predecessor documents is that they have been developed in line with the obligations of the **Well-being of Future Generations (Wales) Act (2015)**[12]. The *Action Plan* directly supports the delivery of seven of the twelve well-being objectives (while indirectly contributing to the others). Of these seven well-being objectives addressed by the *Action Plan*, the activities of CS Connected will contribute most explicitly to the following:

- Support people and business to drive prosperity (see later on connections between employment creation and regional prosperity).
- Build ambition and encourage learning for life.
- Equip everyone with the right skills for a changing world.
- Promote and protect Wales' place in the world.

[7] https://gov.wales/sites/default/files/publications/2019-04/innovation-wales-strategy.pdf
[8] Huggins, R., Munday, M., Roberts, A. and Watermeyer, R. (2014) A review of the proposal to establish a Foundation for Compound Semiconductor Technology: creating Europe's fifth semiconductor cluster in south Wales.
[9] https://www.cardiffcapitalregion.wales/wp-content/uploads/2018/06/ccr-strategic-business-plan.pdf
[10] https://gov.wales/sites/default/files/publications/2017-10/prosperity-for-all-the-national-strategy.pdf
[11] https://gov.wales/sites/default/files/publications/2019-02/prosperity-for-all-economic-action-plan.pdf
[12] https://futuregenerations.wales/about-us/future-generations-act/

In the case of the first point above, supporting people and business to drive prosperity, there is another difference in this document compared with *Economic Renewal*, in that there is a move away from 'priority sectors' in terms of targeting business support. The *Action Plan* instead identifies three 'national thematic sectors' for Welsh Government focus. These sectors are Tradable services, High value manufacturing, and Enablers. The *Action Plan* defines High value manufacturing as 'Enterprises applying leading-edge technical knowledge and expertise to the creation of products, production processes and associated services that have the strong potential to bring sustainable growth and high economic value' (p.14). The activities of CS Connected closely link to this definition, and this is shown later in this report.

To help build ambition and learning for life, *Prosperity for All* notes the importance of the higher education system as a 'crucial partner in building the Welsh economy, equipping individuals with the highest levels of skills required as well as building the public service workforce of the future. Welsh universities undertake cutting edge research every day, and this needs to be increasingly geared to commercialisation and economic growth, supporting the development of our key sectors, as well as the future social cultural and environmental needs of Wales' (p.17). The collaborations already within the CS Connected between two higher education institutions in Wales and the private sector companies provides an example of the benefits of close and integrated working between academia and business, which would be further enhanced and strengthened through future development.

In terms of the contribution toward equipping everyone with the right skills for a changing world, The *Action Plan* specifically mentions the 'Compound Semi-Conductor Cluster', as an example of 'selective investments in key research and innovation facilities to support new technologies and business development in all parts of Wales.' (p.34). The plan within CS Connected is to focus on skills provision through a Compound Semiconductor Skills Academy collaboration between further and higher education, which will further contribute towards this well-being objectives.

As part of promoting and protecting Wales' place in the world, the *Action Plan* has prioritised exports and trade. The document notes that exports will be promoted through new marketing campaigns, using successful exporters as exemplars (p.42). Indeed the firms involved within CS Connected would be such exemplars (and see Section 4).

Cardiff Capital Region: Strategic Business Plan

In 2018, the CCR published a five year Strategic Business Plan[13]. 'The Compound Semi-Conductor Project' features prominently within the Business Plan, being the first project to gain investment through the CCR Wider Investment Fund (see also Section 2.3). The four strategic themes of the Business Plan are: skills and employment, innovation, connecting the region, and regeneration and infrastructure. The planned future development of CS Connected is particularly relevant to the first two themes, but also links to the other themes in the future through supply chain developments to connect the CCR and the wider Welsh economy, as well as helping contribute to economic regeneration in the region, through high quality employment and income opportunities.

[13] https://www.cardiffcapitalregion.wales/wp-content/uploads/2018/06/ccr-strategic-business-plan.pdf

The CCR Cabinet are planning further investment opportunities which will help to meet the aspirations of the Business Plan. Those opportunities identified for the next 5 years include 'skills for the future' which aims 'to develop the social and economic potential of the Cardiff Capital Region, supporting people and businesses to deliver a high performing and prosperous region that stimulates and supports inward investment' (p.20). This is aligned with the CS Connected vision, particularly relating to the Compound Semiconductor Skills Academy, and also in the explicit mentioning of supporting inward investment.

The other investment opportunity identified in the Business Plan is a regional innovation portfolio. This aims at 'developing industry clusters, new space for innovative start-ups, and incentives to attracting high-tech firms to the region'. As noted above, the 'Compound Semi-Conductor Project' project is included within this portfolio, with the CCR seeking to 'optimise this investment and explore other opportunities' (p.8).

Review of government funded research and innovation in Wales

The Welsh Government commissioned a review into government funded research and innovation in Wales. The review was undertaken by Professor Graeme Reid of University College London during 2017, with publication of the report in 2018[14]. Whilst this was a review of government-funded activity, the content and recommendations have relevance for CS Connected as they cover the broader research and innovation landscape in Wales.

Whilst the review noted 'strikingly successful examples of university-business collaboration and research impact' it also identified weaknesses, which could limit the extent to which the priorities identified in *Prosperity for All 2017*, and the requirements of the *Well-being of Future Generations (Wales) Act (2015)* can be met, as well as the capabilities in Wales to adapt to the new UK funding environment.

Funding will move away from its previous focus on EU Welsh European Funding Office (WEFO) provision to competitively awarded funding within the UK. The review therefore proposes that the research and innovation landscape undergoes major changes. These include closer working of the research and innovation community in Wales to strengthen its ability and influence in pursuing competitive funding. The Review identifies an important role for Welsh Government in 'driving through this change' (p.3). The report suggests that the gap between Wales and the rest of the UK in un-hypothecated research and innovation funding should be addressed as this limits Wales' potential in accessing competitive funding sources. In addition the review considered that 'the level of skills and knowledge within the Welsh workforce will need to increase significantly to deliver Welsh Government ambitions on enhanced productivity, competitiveness and prosperity' (p.3). The review suggested this could be aided through funding which would further enable innovation stakeholders to work together in new innovation hubs across Wales.

[14] https://gov.wales/sites/default/files/publications/2019-04/review-of-government-funded-research-and-innovation-reid-review.pdf

As a result of the review, three recommendations were made. Firstly that Welsh Government increases visibility of research in Wales through the creation of a new Welsh research and innovation London office. The second recommendation is that Welsh Government strengthen the research base and 'enables Welsh researchers to attract a greater share of UK-wide funding by implementing Diamond's recommendation for QR [*quality-related*] funding and creating an additional Future of Wales Fund specifically to incentivise Welsh researchers to win funding from outside Wales'. Incentivising and rewarding collaboration is an important element of this recommendation. The Review suggests that funding could be used to 'further increases to the scale of business collaboration with universities in Wales, further increases in university collaboration with public sector bodies in Wales, and the attraction to Wales of collaborators from business, charities and public sector bodies elsewhere' (p.5). CS Connected could help in the achievement of these enhanced and extended collaborations which will then extend the capabilities of Wales in achieving funding and developing capabilities and skills in the pursuit of productivity improvements.

The final recommendation is that Welsh Government increase 'the visibility, coherence and impact of research and innovation in Wales by creating a single overarching brand for its innovation activities: the St David's Investment Fund. ….'(p.5). The Review suggests that part of this fund should be to create three innovation-led innovation hubs, which, while having some long term support from Welsh Government, would be in a position, through partnerships and collaborations with others, to seize other funding and growth opportunities.

This vision proposed by CS Connected are therefore consistent with the recommendations of the Review, and would help most significantly in achieving critical mass and agglomeration of activities that could create a virtuous circle of additional funding, cluster growth and productivity. In addition, the university stakeholders within CS Connected have shared visions within their strategic plans, in relation to innovation and world class research with local and global impact[15]. The issues covered in the Review align closely with those of **Science for Wales 2017**[16], and also strongly suggest a way forward in collaborative working between government, academia and industry. The *Science for Wales* strategic document notes the success of the Sêr Cymru, and the significant research income generated so far as a result of the research teams which have been established in both Cardiff and Swansea universities.

Trade Policy: the issues for Wales

The strategy documents and reviews discussed above have been published at a time of increasing uncertainty within the UK economy due to the ongoing Brexit negotiations as well as issues in the wider global trading environment. The mission of economic development policy is therefore particularly important at this time in helping strengthen the economy and minimise the potential negative impacts of Brexit, while maximising any benefits that may arise from new trade deals.

[15] Swansea University: https://www.swansea.ac.uk/media/strategic-plan-2020-english.pdf
Cardiff University: https://www.cardiff.ac.uk/__data/assets/pdf_file/0015/10347/TheWayForward2018EngWeb.pdf
[16] https://gov.wales/sites/default/files/publications/2019-05/science-for-wales-2017-report.pdf

In 2018, the Welsh Government published its proposals for trade post-Brexit: *Trade Policy: the issues for Wales*.[17] This document aimed to address the key issues for consideration as the UK prepares to leave the European Union and develops future trading relationships. This policy document notes the importance of international trade (imports and exports) to the Welsh economy, and the overall reliance in Wales on the EU as an export market. The document contains various sectoral information in order to support the trade policy, including an assessment of sector risk, based on an analysis of large firms within selected sectors of the economy. One of these sectors was electrical engineering components and semiconductors. This broad sector would include (most of) the activities/products of the CS Connected firms. This sector was rated high in terms of tariff risk (on both exports and inputs), with some of the other risk factors also considered to be medium-high (see Figure 7 later). These conclusions do, however, apply to a fairly broad sectoral group, which includes diverse range of firms and products. An investigation of the CS Connected firm's trading relationships reveals them to be highly export intensive (Section 4 of this report), especially to non-EU markets. **This would therefore give these firms a particular importance in future in providing a shield the broader sector from the worst of the economic impacts of Brexit.**

The trade policy document also notes the importance of inward investment for the Welsh economy, and reports on 'a new approach to targeted trade and inward investment activity focussing on strategic sectors in the current markets where we have an overseas presence, while also examining new market opportunities' (p.22). This is of relevance to the CS Connected firms, and the potential new inward investments that are being targeted in the future.

3.4. Conclusions

The review of documents in this section shows a distinct alignment between the proposed activities of CS Connected and the strategic priorities of the UK Government, Welsh Government and the CCR, within the context of Brexit and other trade factors. There has already been investments in the cluster by Welsh Government and CCR stakeholders, and these have played an important role in illustrating the strategic direction of public sector economic and innovation/science policy in Wales. The documents reviewed therefore suggest the likely high levels of support which will continue into the future, as CS Connected helps in the achievement of research and innovation-led economic development in Wales and the wider UK economy.

[17] https://gov.wales/sites/default/files/2018-01/180202-trade-policy-the-issues-for-wales.PDF

4. Local economic impact

4.1. Introduction

This section builds on the material in Section 2 of the report and identifies how current CS Connected activity supports the Welsh economy. Moreover, this section provides evidence on how activity works to meet the economic needs of the region, and then how a deepening of CS Connected resulting from a successful SIP bid could provide important additional economic dividends in the longer term.

4.2. Recent sector performance in Wales and trade activity

Much of the compound semiconductor manufacturing activity in South Wales is within standard industrial classifications (SIC) 26 and 27. There were around 10,500 employees in the Electrical engineering and equipment sector in Wales in 2017 (defined as SIC 26 - Manufacture of computer, electronic and optical products (around 6,000 employees), and SIC 27 - Manufacture of electrical equipment (around 4,500 employees)). The elements of SIC 26 in which firms such as Newport Wafer Fab, IQE and Microsemi operate (i.e. SIC 261 Manufacture of electronic components and 262 - Manufacture of loaded electronic boards) account for around a third of Welsh employment in SIC 26. It is important to recognise that the SIC codes above are not always a perfect fit to the different commodities produced by the semiconductor industry in South Wales.

Further analyses of economic activity in SIC 26-27 reveals that:

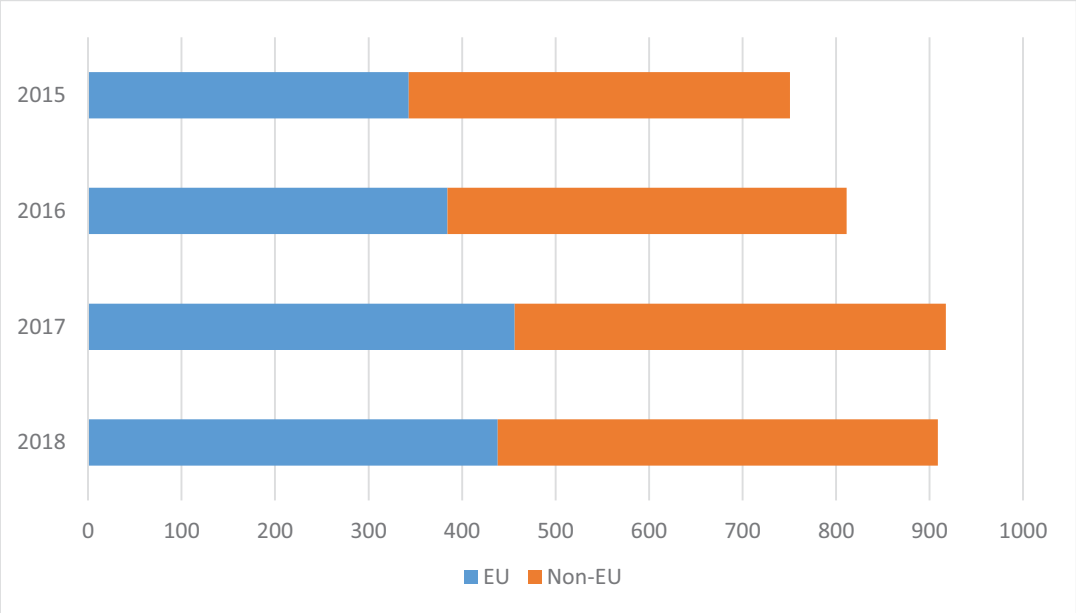
- GVA for the sector (SIC 26-27) as a whole in Wales was around £948m in 2017. Economic activity appears to have grown faster in Computer, electronic and optical products (SIC 26) in the period 2013-2017 with GVA growing by 67% (£360m to £601m – in current prices). In Manufacture of electrical equipment (SIC 27) GVA has varied in current prices between just £291m and £347m for the whole of the period 2013-17, and with growth of 14% over this period. The index of production for the broadly defined computer and electronic products sector shows an increase in output since 2012, with the latest information showing that output increased by around 12% in the three year period ending in the first quarter of 2019.[18]
- In parts of this sector there is strong Welsh specialisation. For example, with respect to SIC 26 employment-based location quotients exceed 1.5[19] in sectors including electronic components, communication equipment, electro-medical equipment, wiring devices, batteries and optical instruments.

[18] See Stats Wales https://statswales.gov.wales/Catalogue/Business-Economy-and-Labour-Market/Economic-Indices/Indices-of-Production-and-Construction/welshindicesofproductionandconstruction-by-section-year

[19] A location quotient (LQ) equal to one indicates that the regional employment share matches the proportion of national employment in that industry. An LQ less than one indicates that the regional employment in a particular industry is lower than the national average, while a figure greater than 1 reveals the regional employment share to be higher than the national average.

- The Electrical machinery, apparatus etc. sector[20] (that includes IQE and Newport Wafer Fab) exported goods to the value of over £900m in 2018, and with the value of exports in this sector up on 2015, although there was a fall in trade volumes in Electrical machinery etc. between 2015-18.

Figure 5 Welsh exports, Electrical engineering (SITC 76 & 77), 2015-2018, £m



Source: Derived from Regional Trade System, HMRC. See https://www.uktradeinfo.com/Statistics/RTS/Pages/default.aspx

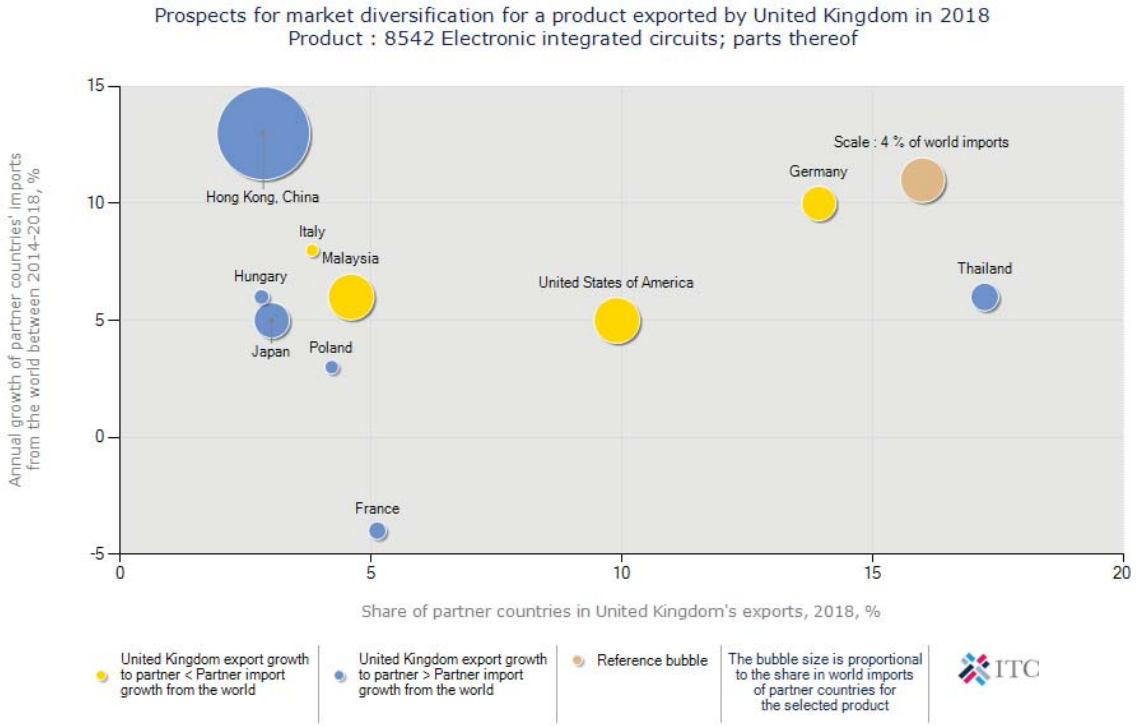
- For the faster growing part of the sector i.e. SIC 26 Computer, electronic and optical products, direct greenhouse gas emissions were 98 ktCO2e in 2016, and with this growing to 459 ktCO2e once account was taken of indirect emissions in other parts of the economy that support operations in the sector – this latter figure equated to a total of 0.92 tCO2e greenhouse gas emissions per £1m GVA generated in the sector in 2016. This is a low carbon sector, and with production point emissions from Welsh industry a key issue is sustainable development targets.

UK trade prospects in integrated circuits and parts thereof (SITC 8542) are summarised in Figure 6. More generally analysis of ITC Trademap data revealed that:

- 49% of UK exports of $1.6bn in 2018 were destined for the EU, but with 12% destined for markets in the North America Free Trade Association area.
- The overall sector is less dependent on EU markets, compared to other elements of UK manufacturing. Elements of SIC 261 and 262 in Wales, in particular, exemplify this conclusions with stronger links to USA markets. Figure 6 reveals that in the case of 'integrated circuits and parts thereof' that selected non-EU markets have a strong demand for imports of these goods.
- Hong Kong, China accounts for a large share of the growth of world imports (c.12%) and a large share of world imports in 2018 (see Figure 6), but with just 2-3% of UK exports destined for this market in 2018.

[20] Here defined as Standard Industrial Trade Classification (SITC) 76-77.

Figure 6 UK Trade Prospects in Electronic Integrated Circuits and parts thereof



Source: Derived from analysis of ITC Trademap

4.3. Place-based economic needs

The problem addressed through the development of compound semiconductor activity is poor place-based productivity growth, pressure on local manufacturing output and related constraints on new inward investment and export growth. Alongside this, and a related issue is a poor record of business expenditure on R&D in South Wales and leakage of highly qualified graduates with the skills to contribute to the development of the compound semiconductor cluster. Much of the regional manufacturing sector exists in the context of an evolving low skills equilibrium, where poor demand for skills has implications for the supply side availability of local skills. However, improved integration of compound semiconductor manufacturing and related activity provides an avenue for treating with these place-based problems.

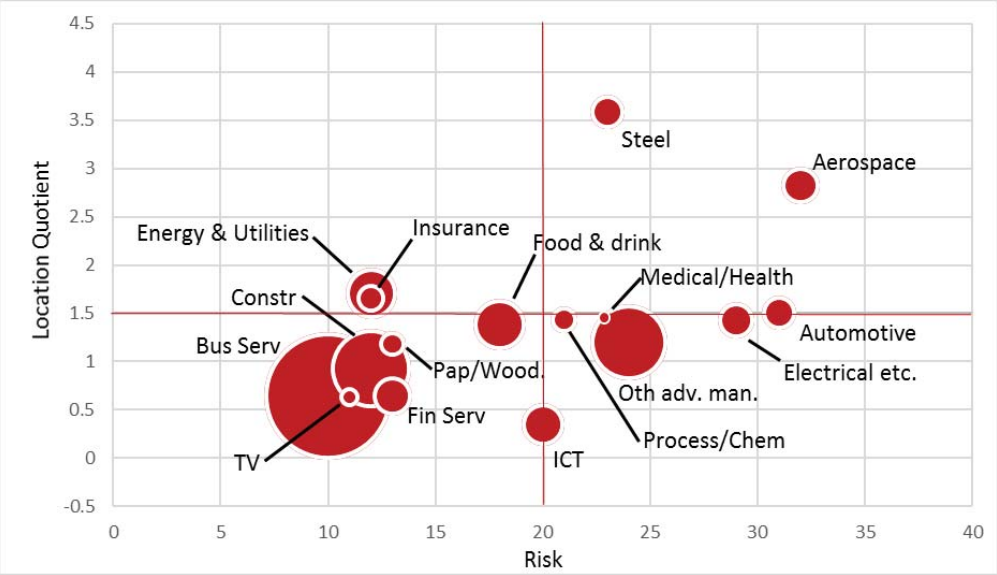
The following sections expand on selected of these place-based economic issues:

- **Pressure on manufacturing employment.** Manufacturing employment in Wales has displayed a falling long-term trend. Of particular concern in more recent periods has been losses of employment in relatively more productive sectors of regional manufacturing and a reduction in employment in key local industries. Manufacturing employment in Wales fell by a further 4% between 2015-17 to around 132,000. Earnings in Welsh manufacturing tend to be higher than the Welsh average earnings for both men and women.
- **Poor productivity growth**. Wales is identified as having a persistent productivity growth problem. Price (2018) in the Chief Economist's report for Wales reveals that: "Over the

period since devolution, Wales has demonstrated a relatively strong performance on employment, unemployment and inactivity, but less so on productivity and pay (which are closely related)..... Wales ranks bottom out of the 12 UK countries and regions on productivity and pay."[21] While the causes of the Welsh productivity problem are complex the loss of activity in relatively productive manufacturing sectors in Wales is expected to further harm the regional standing on productivity, and widen the divergence between Wales and other parts of the UK on indicators such as gross value added (GVA) per head.

- **Poor record on business R&D spending.** The UK Government target is for R&D spending to be 2.4% of GDP by 2027.[22] The Welsh economy accounts for around 5% of UK economic activity, but just 1.9% of the UK share of business expenditure on R&D. This reflects a number of factors including relatively few large firms being headquartered in Wales, and undertaking research in the region; and a historical model of inward investment attraction that has focused on employment creation from firms primarily focused on EU market access as opposed to collaborating on local knowledge creation and the development of new competitive advantage for the region. Total business R&D spend in Wales in 2017 was just £457m.

Figure 7 Summary of Cardiff Business School (2017) report examining Risks facing Welsh Anchor Firms and Regionally Important Companies (RICS)



Source: See Trade Policy the Issues for Wales. https://beta.gov.wales/sites/default/files/2018-01/180202-trade-policy-the-issues-for-wales.PDF

- **EU transition pressures.** Selected elements of manufacturing in South Wales have been shown to be at high risk from a disorderly Brexit. Figure 7 shows findings from Cardiff Business School (2017) which summarised Brexit risks facing Wales' largest firms, and compared this with the amount of sector specialisation, and revealing high risks facing selected of Wales' most productive manufacturing sectors. Compound semiconductors is

[21] See https://gov.wales/sites/default/files/publications/2018-10/chief-economists-report-2018.pdf

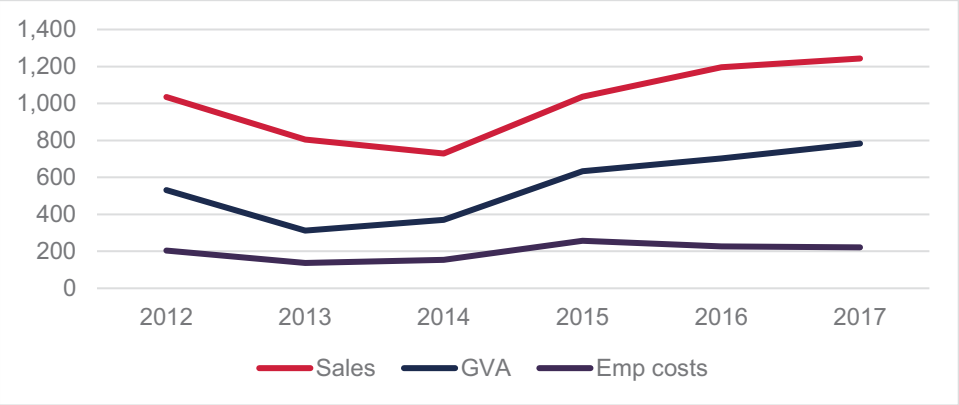
[22] See https://www.ukri.org/about-us/increasing-investment-in-r-d-to-2-4-of-gdp/

within ‘Electrical etc’ in Fig 7 i.e. Electrical engineering, electronic components and semiconductors. However, this is a broad sector which overall shows higher risks linked to Brexit, a conclusion which might be less relevant to compound semiconductors where much of sector output is not destined for the EU (see later).

- In part linked to the above, Wales is operating in a much **tougher inward investment environment** and with strong competition from EU regions to attract investment that otherwise might have come to UK regions. A key determinant for previous Welsh success in attracting foreign capital was ease of access to EU markets coupled with competitive factors costs. This type of advantage has been seriously eroded.
- Electronic engineering **as a whole** in South Wales is particularly exposed to **EU market threats** with few opportunities to displace imports into the UK with regional production. For example, Asia Pacific Trade Agreement (APTA) and Association of South East Asian Nations (ASEAN) states already account for significant UK imports in the sector, and these are more likely to displace any EU imports in the future. While the sector is vulnerable to EU transition processes, there are limited opportunities in non-EU markets because of strong competition from these same APTA and ASEAN states.

In respect of the above points it is important to recognise that firms in the evolving compound semiconductor cluster are export intensive (and with future export potential), less dependent on EU markets (than other parts of electronic engineering, optical sectors) and with stronger links to North American markets, and with strong growth potential. For example cluster firms such as Microsemi, IQE, SPTS and Newport Wafer Fab export well over 90% of their output. The recent performance of firms in the compound semiconductor cluster is one factor contributing to the stronger growth showing of electronic, optical and electrical products as a whole in South Wales in recent periods. For example, growth of GVA in Welsh manufacturing as a whole was around 19% 2013-17, whereas GVA growth in the computer, electronic and optical products sectors was close to 67% in the same period. Employment in the sector has been maintained at around 6,000 people 2015-17, and with employment costs in the Welsh sector growing more slowly than sales and gross value added, this providing some evidence of strong productivity growth in this sector of manufacturing (see Figure 8).

Figure 8 Recent trends in Sales, GVA and employment costs in SIC 26 Electronics, Computing and Optical Products in Wales (£m)



Source: Derived from ONS see https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/nominalandrealregionalgrossvalueaddedbalancedbyindustry

Figure 9: Summary of Place-Based Economic Challenges

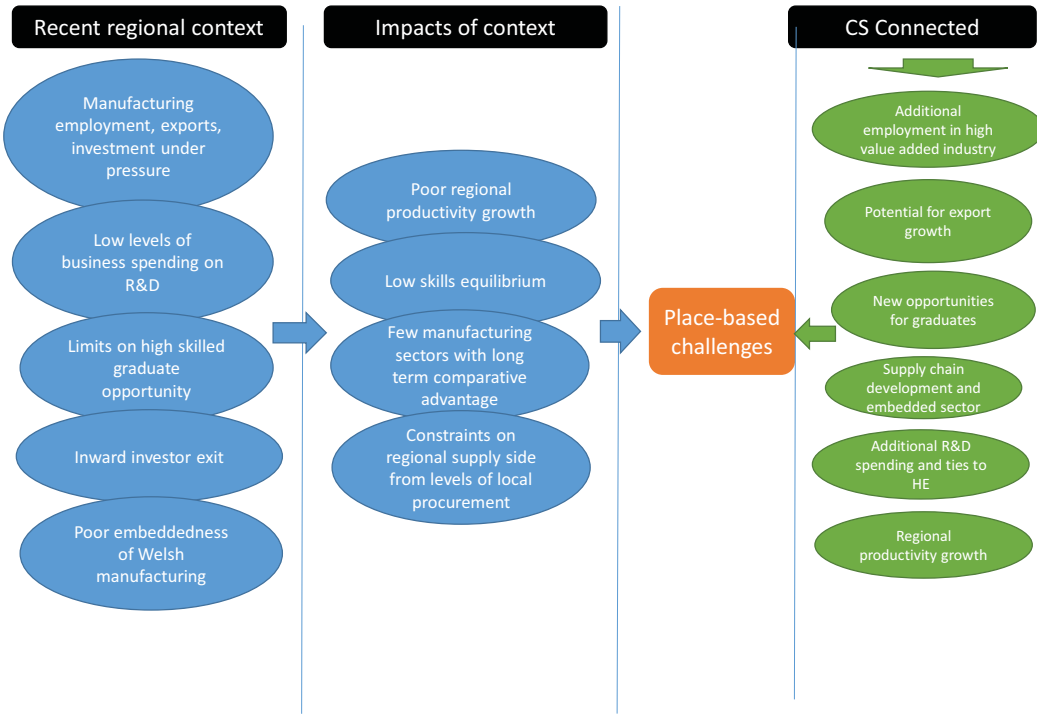


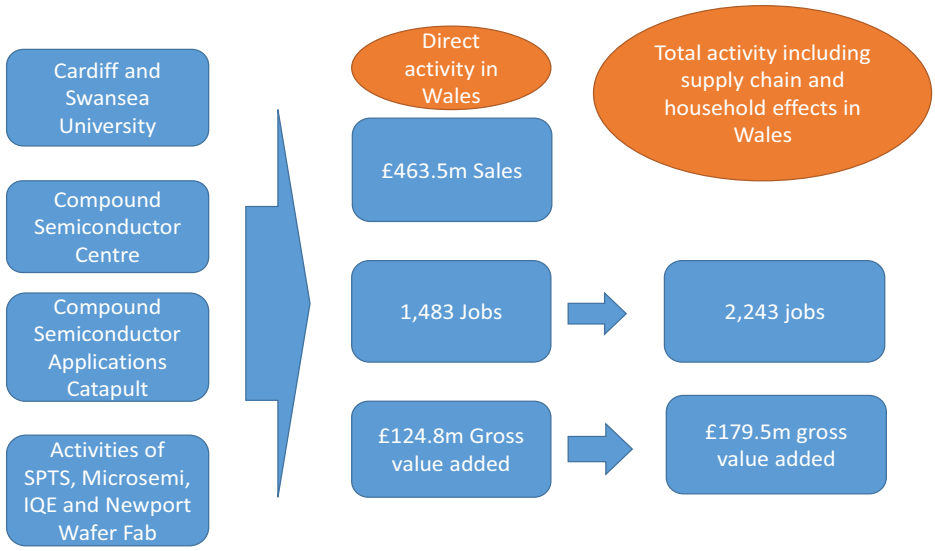
Figure 9 summarises the place based challenges. Progress towards to CS connected vision works in a series of interconnected ways to address the place-based economic problems.

4.4. CS Connected: Addressing place-based challenges?

The place-based proposal strengthens an existing group of compound semiconductor cluster members. As such by extending connections between the firms the proposals work to safeguard existing industry activity. For example Figure 10 reveals that in 2019 the principal private sector cluster members accounted for over 1,250 jobs, and £464m of sales, much of this (more than 90%) relating to overseas exports, and again with much of this destined for markets outside of the EU.

However, the place-based proposal seeks to increase the embeddedness of the compound semiconductor firms in the regional economy. Already the analysis suggests that the private sector cluster members support close to £125m of Welsh GVA directly i.e. each direct job in the cluster currently supports around £92,250 of Welsh GVA (average Wales c. £50,000 in 2017). When account is taken of existing local purchasing behaviour and the local spending of wages and salaries then each direct job in the cluster supports close to £120,000 of Welsh GVA. The analysis also suggests that each direct job in the cluster further supports around 0.51 of a full time job elsewhere in the regional economy.

Figure 10 Existing Activity: Economic Appraisal Summary 2019



Note: Activities of the main manufacturing firms and other CS Connected members are combined for commercial confidentiality reasons. While direct employment and turnover information was provided by the cluster firms the estimates of GVA/employee were informed by GVA estimates for Wales in the industries to which the cluster firms belong (SIC 26, 27 – see https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/nominalandrealregionalgrossvalueaddedbalancedbyindustry) and overall Welsh employment estimates in these same industries. Note that estimates of GVA per employee in SIC 26 and 27 in 2017 are assumed to hold for 2018-19. Indirect and household effects were estimated using multipliers developed from the Welsh Input—Output tables for SIC 26 and SIC 27, but with some adjustment to multiplier values to allow for some purchases and sales between firms. It is noted that the firms mentioned in Figure 10 do not share all the characteristics of the wider sector – particularly in the case of SIC 26. Multiplier estimates are therefore indicative. For the cluster firms multiplier effects through supply chain in Wales are currently quite limited because of low local purchasing, but with the multiplier effects through wage spending higher because of the relatively high wages and salaries paid in firms in Figure 10. For details of the Welsh Input-Output framework used to estimate indirect effects please see the Appendix.

In the context of the place-based economic issues the analysis reveals:

- Where economic activity is created and supported in compound semiconductor firms that it provides relatively high levels of GVA per employee. **Activity is being supported in a sector where productivity is around 85% higher than the Welsh average.**
- That firms linked to the CS Connected brand already support a regional supply chain but with scope to increase regional supply of goods and services to these firms, and this being a core part of the CS Connected SIP proposal.
- In part this high GVA per employee reflects relatively high earnings. The analysis reveals average earnings in parts of the sector in excess of £40,000 pa (Welsh average in 2018 was around £24,500pa in 2018. *Annual Survey of Hours and Earnings*).
- The strengthening of this cluster of firms with their average productivity characteristics would work to provide an uplift to regional productivity. Few sectors of regional manufacturing possess these productivity characteristics.
- Growth of activity in the realm of compound semiconductors will have important multiplier effects in other parts of the regional economy through both supply chain and household effects. Moreover, expansion of activity here is unlikely to create any displacement of economic activity in other parts of Wales (or the UK) and with significant sales activity being exports overseas.

4.5. CS Connected: Future vision

The previous section reveals that work to deepen the cluster will safeguard a series of existing contributions from the private sector firms. Critically however, the funding from SIP works to support new economic activity through the four projects detailed in the application. This section examines the economic outcomes in terms of GVA and employment directly and indirectly supported in these projects. It is difficult to estimate the full range of economic outcomes consequent on the vision detailed in the proposal. Here the vision in terms of estimated employment outcomes is linked to an uplift in regional GVA, and then a consequent improvement in regional productivity levels.

It is estimated that the CS Connected future projects would be associated with around 1,160 FTE jobs (Table 1) divided between new employment is Computer, electronic and optical products (SIC 26) and Electrical equipment manufacture (SIC 27). Note that these employment opportunities are spread over the period 2020-2025, but with much of the employment creation not expected until the end of the period (i.e. 2025 and possibly beyond that date).

In the following analysis the expected changes in the cluster in the period 2019-2025 under organic growth (i.e. no SIP) is compared with the uplift linked to the CS Connected bid. Table 2 shows that in 2019 the cluster employed nearly 1,500 people, and supported £125m of Welsh GVA directly. Once account is taken of multiplier effects in the Welsh economy (supply chain and household spending effects) then an estimated total of close to 2,250 jobs and £180m of GVA is supported in Wales in 2019. It is assumed that organic growth in the cluster could create employment growth of 5% pa in the period to 2025. This organic growth leads to an estimated direct employment in the cluster of close to 2,000 people (around 3,000 if all Wales supply chain and household effects are accounted), and with the cluster directly and indirectly supporting a little over £240m of Welsh GVA.

The uplift associated with successful completion of the projects listed in Table 1 and the wider CS Connected project sees direct cluster employment of an estimated 3,148 by 2025, supporting £265m GVA directly, and once indirect supply chain and household effects are accounted, around £381m of total GVA. The difference over base linked with the CS Connected activity is estimated to connect through over £140m of Welsh GVA once direct and supply chain/household effects are accounted.

Table 2: Estimated effects of CS Connected: 2019-25

Base case 2025 Organic growth of cluster at 5% employment growth				
	2019	2025	Uplift 2019-25	
Employment direct	1,483	1,987	504	
Total employment	2,243	3,005	762	
Direct GVA £2018m	124.8	167.2	42.4	
Total GVA £2018m	179.5	240.5	61.0	
SIP Case: Successful completion of core projects 1-4 (see Table 1)				
	2019	2025	SIPF uplift 2019-25	Difference over base
Employment direct	1,483	3,148	1,665	1,161
Total employment	2,243	4,761	2,518	1,756
Direct GVA £2018m	124.8	264.9	140.1	97.7
Total GVA £2018m	179.5	381.0	201.5	140.5

Placing these numbers into their wider context, 2017 employment in Computer, electronic and optical products (SIC 26) and Electrical equipment manufacture (SIC 27) was around 10,500, such that additional direct job creation connected with activity underlying the SIP bid (c.1,160) would be just over 10% of current estimated FTE employment in the sector. Direct GVA associated with the expansion of activity in these same sectors (c.£98m) would be around 10% of total sector GVA in 2017.

5. Conclusion

The report reveals that further development of activity with the Welsh compound semiconductor cluster could bring significant economic dividends for the regional economy. A sustained increase in activity is shown in this report to support high quality/relatively high earning employment. More importantly the activities supported are characterised by high productivity, and have been evidenced as being highly innovative.

The economic analysis identified a series of place based challenges which are currently being met by the existing activities of firms which are part of the CS Connected vision. Critically the compound semiconductor cluster is very well embedded in the regional economy through linkages with the higher education sector and the local supply chain. It is likely that the Brexit transition process will cause further problems for much of Welsh manufacturing. However, activity in the compound semiconductor cluster is focused extensively on non-EU markets and the deepening of the cluster activity and linked inward investment resulting from a successful SIP bid could do much to allay uncertainty in local business confidence. Indeed the future development of the cluster is likely to have a series of effects in terms of improving inward investor confidence in the regional economy. It is difficult to model these more 'psychic' effects in the quantitative analysis contained in this report.

In any evaluation of funding it is important to take due account of deadweight (how much of the activity would occur without funding), displacement, multiplier, leakage effects etc. The four core projects identified in the SIP bid require a successful funding bid for effective progression. Importantly the export orientated nature of activity means that the additional activity supported by funding is unlikely to displace other economic activity in Wales, and with leakage of benefits outside of the 'place' quite limited. The report reveals that employment and GVA directly supported by any funding could have important multiplier effects in other parts of the Welsh economy. Then the expected return to funded activity could be significant, and the analysis in Section 4 of the report shows clearly the types of KPIs which could be used to evaluate the performance of the cluster after 2019-2020.

In summary, the further evolution of compound semiconductor cluster through the SIP proposal adds greatly to the strength of the regional economy, and could provide a means of addressing some of the more pressing and persistent socio-economic problems identified in Section 4 of this report.

6. Appendix: Authors and Methods Outline for Economic Modelling

6.1. Authors

Professor Robert Huggins was appointed as Chair of Economic Geography at Cardiff University and Director of its Centre for Economic Geography in September 2011. He also has private sector experience managing a research and management consultancy. Professor Huggins's areas of interest highlight regional economic development, in particular the study of clusters and competitiveness, knowledge flows, entrepreneurship, innovation, and inter-organisational networks.

Professor Max Munday has been a member of Cardiff Business School since 1990, and over this period has developed a wide range of research interests on Welsh economy, the economics of inward investment, tourism economics, regional economics and policy, and on corporate restructuring. Research on inward investment, regional economics and policy, have led to successful research bids and a wide range of consultancy work for organisations in both the public and private sector.

Dr Annette Roberts is Reader in Economics at Cardiff Business School. She specialises in regional economic modelling and heads up the Welsh Input-Output project. The Welsh input-output framework was used in the analysis in this report. She has published widely in regional economics.

6.2. Methods for modelling Welsh economy effects of CS Connected Activity

To estimate the indirect (or multiplier) consequences of the compound semiconductor cluster activity it is necessary to have a picture of the local economy that specifies how various industry sectors 'fit together' in terms of their trading relationships. This then allows the effects of activity in one sector to be traced through the entire local economy. The most comprehensive picture available of the Welsh economy is an Input-Output table.

The table presents a detailed financial map of the economy for a particular time period, typically one-year, and shows the flow of goods and services between industries, consumers and government. As well as being an important descriptive tool, the Input-Output tables can be used for economic modelling and for impact assessment. Input-Output Tables for Wales are the product of a continuing research project to develop a comprehensive picture of the Welsh economy and the way it is changing over time, undertaken by the Welsh Economy Research Unit at Cardiff Business School. Further description of the Welsh Input-Output project, its strengths and limitations, can be found in (Jones et al., 2010). [23]

[23] https://www.cardiff.ac.uk/__data/assets/pdf_file/0010/698869/input-output-tables-2007-final-30-6.pdf

The methodological approach adopted in this report involved estimating direct employment, output and gross value added connected with current cluster operations, and then expected future development, and with this including additional activity linked to the CS Connected projects. The indirect (supply chain) and induced (household spending) effects connected with this activity are estimated through the use of employment and GVA multipliers derived from the Welsh Input-Output tables. However, multipliers used were adjusted to take account of features of the specific firms in the cluster and with analysis also assisted with information from the firms showing their local purchasing linkages (and the direction of their sales).

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