Driving productivity growth through innovation in high value manufacturing

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

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"The Science and Innovation Audit priority focus areas are essential to enable UK industry to keep pace with its competition and position the north of England as a continued global sector leader in advanced engineering and manufacturing."

David Holmes

MAI Manufacturing Operations Director, Military Air & Information, BAE Systems plc

Foreword

"The Science and Innovation Audit (SIA) is a vital mechanism to ensure that much needed investment is targeted at the priority projects and programmes that will stimulate productivity and economic growth in Lancashire, Sheffield and across the Northern Powerhouse region."

"There is a critical need to build on the productivity performance of the advanced engineering & manufacturing sector, particularly within SMEs, to ensure we remain globally competitive. Key to delivering this will be maximising existing and developing new collaborations between industry and our science and innovation assets. This successful formula can be seen in practice with the emerging Northern Advanced Manufacturing Innovation Corridor and how this SIA drives new and better partnerships to deliver what's required."

"The pace of change within advanced manufacturing technologies is constantly accelerating and the UK's global competitors are well placed to take advantage of the potential benefits that step changes such as Industry 4.0 present. The SIA priority focus areas are essential to enable UK industry to keep pace with its competition and position the north of England as a continued global sector leader in advanced engineering and manufacturing."

David Holmes
MAI Manufacturing Operations Director, Military Air & Information, BAE Systems plc

"Between the geographies of the Sheffield City Region and Lancashire lies a unique opportunity. One which the UK economy desperately needs. Here lie the components required to equip the UK to deliver the vision of the 4th industrial revolution, Industry 4.0. Within our existing Northern Advanced Manufacturing Innovation Corridor, we have strong high value manufacturing industrial bases, innovative excellence, world-class science and multi-level skills training; ensuring that the region is ready to bring the right skills, people and technology to close the productivity gap not just for the North but for the UK as a whole".

"Both our individual regions are also ambitious about building on existing assets through the development of their own Innovation Districts coupled with a drive and willingness to collaborate; as demonstrated by the joint commitment to develop a Northwest Advanced Manufacturing Research Centre (NWAMRC) with private sector partners in the aerospace, automotive and energy supply chain sectors".

"The SIA also talks about productivity, competitiveness and winning work. To achieve this we need not only industrial investment and participation in skills, innovation assets and SME supply chains but we also need strategic ownership, vision and funding from Government to lead the charge".

"This SIA provides a robust picture of innovation, industrial excellence and world-class research and I am confident that the other SIAs conducted across the UK will also show the same. What we need now is a cutting-edge national strategy to help regions like ours to deliver real change which will create economic growth and with it the jobs and opportunities which are so crucial for all in our communities".

Professor Sir Keith Burnett, CBE, FRS, FRSW
Vice-Chancellor of the University of Sheffield

Summary report

0.1 Introduction & context

In Autumn 2015 the UK Government announced regional Science and Innovation Audits (SIAs) to catalyse a new approach to regional economic development. SIAs enable local consortia to focus on analysing regional strengths and identify mechanisms to realise their potential.

In the Sheffield City Region (SCR) and Lancashire a consortium was formed to focus on our strength in high value manufacturing. This report presents the results which include broad-ranging analysis of the audit region's capabilities, the challenges and the substantial opportunities for future economic growth.

The context for this audit is set by a UK-wide economic problem: stagnation of productivity growth since 2008. The audit region of Sheffield City Region and Lancashire contributes to this; regional productivity is well below the average for England.

This regional productivity gap has been attributed to three factors[1]: structural change in the economy through a shift away from manufacturing to lower productivity activities; a skills problem; and not enough innovation and entrepreneurship. This audit proposes concrete and substantive measures in response to each of these issues.

The two Local Enterprise Partnership (LEP) areas comprising the audit region share a specialism in high value manufacturing (HVM) in key sectors of *aerospace, energy* (particularly *nuclear*), transport (particularly *rail)*, and *health technology.* Manufacturing capability in these sectors makes a key contribution to the economy of the wider North. The audit finds that there is a highly complementary range of globally significant research excellence between the two regions, as well as successful and established innovation assets that underpin this industrial capability.

But manufacturing is changing. The full integration of digital capabilities in manufacturing – often referred to as *'Industry 4.0'* - and adoption of new materials and manufacturing processes, will drive high productivity growth in businesses able to adopt them.

The hypothesis tested by this audit is that the region has the necessary underpinning research and innovation assets in relevant areas of engineering, digital and data science to underpin a transformation in the performance of the region's manufacturing base.

Translational research facilities are crucially important for the spread of new technologies, especially to the Small and Medium Sized Enterprises (SMEs) that are such an important part of the regional economy.

The capacity for excellent management and leadership will be no less important, together with a system for developing technical skills at all levels, especially those digital skills that will drive Industry 4.0.

There is a growing consensus on the need to work collaboratively across the audit region, as a partnership between private and public sectors, to capitalise on the assets already in place within and between the two LEP areas by realising the potential of the region's high value manufacturing to drive economic growth and to close the productivity gap with the most prosperous parts of the UK. Significant initiatives have already begun with this goal in mind.

The vision presented here is of a *"Northern Advanced Manufacturing Innovation Corridor",* bringing existing, emerging and new science and innovation assets and programmes into collaboration with industry to drive productivity growth in advanced manufacturing and key linked sectors across the region to world-class levels.

The opportunity is to invest in key schemes which will enable the region to deliver innovation so the UK can maximise the benefits of Industry 4.0.

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"Between the geographies of the Sheffield City Region and Lancashire lies a unique opportunity. One which the UK economy desperately needs. Here lie the components required to equip the UK to deliver the vision of the 4th industrial revolution, Industry 4.0."

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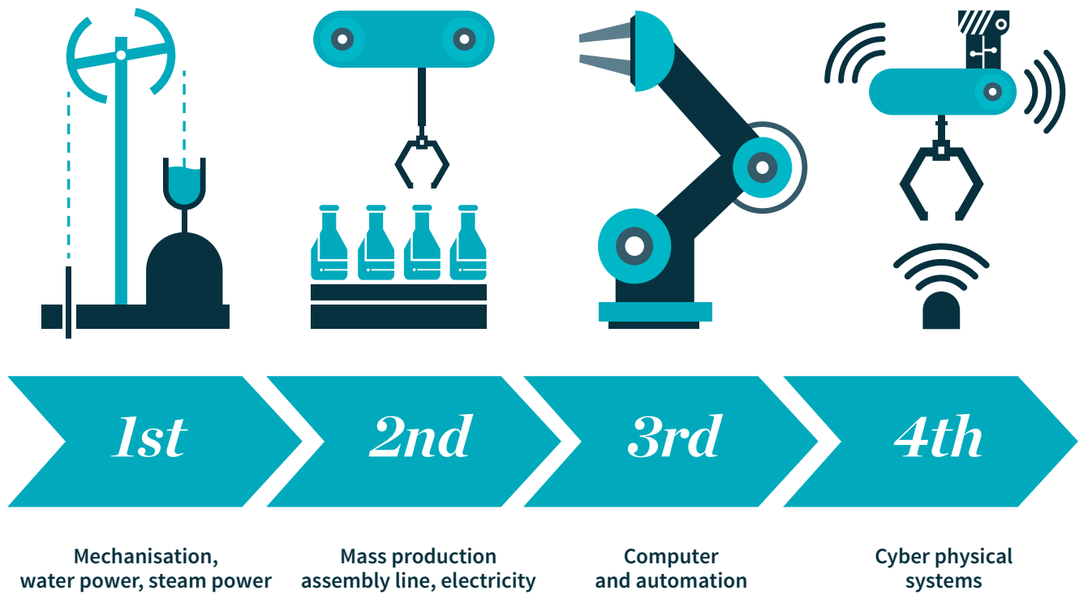

[1] Transport for the North, Independent Economic Review of the Northern Powerhouse, 2016.
The five work-stream reports are available from the SQW website here: www.sqw.co.uk/insights-and-publications/northern-powerhouse-independent-economic-review/

The vision presented here is of a "Northern Advanced Manufacturing Innovation Corridor", bringing existing, emerging and new science and innovation assets and programmes into collaboration with industry to drive productivity growth in advanced manufacturing and key linked sectors across the region to world-class levels.

0.2 The vision

The region has the elements required to be a globally significant centre for innovation and translational research, ensuring the rapid take-up in manufacturing of new materials and processes, new business models and the ubiquitous digital technologies of Industry 4.0. The resulting resurgence in high value manufacturing will drive productivity growth and strengthen the economy of the region, the wider North, and the UK more generally.

The suggested investments will build on an already strong base of existing and emergent science and innovation infrastructure and programmes, as follows:

- build on existing outstanding translational research assets (£207m research grant income per year [2])
- join up the skills landscape across the region from apprenticeships to Higher Education (HE) (sector-leading schemes already in place, in partnership with the key industrial sectors)
- develop excellent leadership and management, and support new enterprise and entrepreneurship (the HE sector leader in business and management is within the audit region, and has particular strengths in advanced manufacturing and SME engagement)
- support the internationalisation of the business base (innovation assets in the region have strong global links and are already being replicated in Korea, the US and China)
- expand the research base in areas that will be important for Industry 4.0 and the future of manufacturing (e.g. robotics, data analytics, new materials and processes for lightweighting, resource efficiency, leadership and management)

Strategic delivery of the vision will build on initiatives already taking place within and between the two LEP areas, based on the ***Advanced Manufacturing Innovation District (AMID) concept*** which recognises the need for a 'whole-place' approach to the development of innovation ecosystems.

Successful delivery of an Innovation District requires a high level of interconnected physical, economic and networking assets. The audit has considered the existence of these and has concluded that there is significant strength in each of the three areas, but a need to further develop and raise the performance of networking assets within and between the two regions.

Advanced Manufacturing Innovation Districts are being developed at each end of the proposed corridor (Sheffield/Rotherham boundary and Salmesbury, near Preston), and there is a need to connect the two.

The North West AMRC at Salmesbury, which links to the University of Central Lancashire's (UCLan) Engineering Innovation Centre, is the first substantial project which will begin to achieve this, and will formalise the link between the two Innovation Districts as it represents a formal partnership between Lancaster and Sheffield Universities

Success in implementing this vision will be demonstrated by:

- more rapid adoption of new technology by the existing industry base, particularly SMEs
- greater proportion of businesses led and managed at the highest level
- increased rate of formation of innovative new companies, and enhanced growth of existing businesses
- inward investment by multinational manufacturing companies at the technological frontier
- broad skills base, talented people attracted to and retained in the region
- growing high value services sector in support of manufacturing
- enhanced regional export performance and international collaborations
- significant and measurable improvement in productivity outcomes across our advanced manufacturing sectors and throughout the regional economy

[2] HESA research income for 2014-15, from HEIDI.

0.3 Key strengths

HE research base

- Six universities: £207m of grant research income (2014), 90% of research internationally recognised or better.[3]
- Tripling of engineering research income in the decade to 2014-15.[3]
- Research Excellence Framework (REF) results and research grant funding rank the University of Sheffield as a leader in the UK for engineering, and citation results illustrate the impact of its outputs globally.[3]
- Research impact outperforming national averages in key underpinning areas for *Industry 4.0*, including *Human-Computer Interaction, Computer Graphics/ Computer-Aided Design, Artificial Intelligence, Ceramics and Composites, Transportation, Business and International Management.*[4]

Public sector R&D facilities

- The National Nuclear Laboratory (based at Sellafield) has a laboratory in leased facilities at Westinghouse's Springfield plant, near Preston.
- Large teaching hospitals, with many leading clinicians and academics active in collaborative research with nearby universities and the private sector.
- Both Lancashire and the Sheffield City Region (SCR) are running NHS Test Bed programmes.

Translational research centres[5]

Translational research centres bring academia together with global and regional businesses, to accelerate the adoption of new technology. Examples in the region include:

- The University of Sheffield's Advanced Manufacturing Research Centre (AMRC) Group. £280m capex, £38m pa turnover. Includes: Factory 2050 (research/ demonstration factory for Industry 4.0), AMRC with Boeing (part of the High Value Manufacturing Catapult), Nuclear AMRC (part of the High Value Manufacturing Catapult).
- The Engineering and Physical Sciences Research Council (EPSRC) National Centre for III-V Technologies at the University of Sheffield.
- University of Central Lancashire Engineering Innovation Centre (EIC), £40m capex 7000 sq m.
- Sheffield Hallam University National High Power Impulse Magnetron Sputtering Technology Centre (HIPIMS).
- Lancaster University Health Innovation Campus (£167m capex, planned).

Private sector collaborative R&D[6]

- Research intensive companies already interacting with HE sector, with a combined turnover of circa £1bn and 6,000 employees.
- In 2014, BAE Systems managed overall research and development (R&D) investment of £902m, including £63m of its own funds.
- Siemens has invested £3.2m in funding research at the University of Sheffield since 2009, with a further £3.6m of in kind contributions and a further £8.3m in funding for collaborative research.
- Rolls-Royce is a lead partner in the University of Sheffield's Advanced Manufacturing Research Centre (AMRC) with Boeing.
- Significant and growing cluster of innovative design and manufacturing companies co-located with innovation assets within the Advanced Manufacturing Innovation Districts.

[3] REF 2014 results:results.ref.ac.uk, Research income: HESA research income for 2014–15, from HEIDI.
[4] SciVal (Elsevier), Field Weighted Citation Impact for publications between 2011 and 2016 as at Aug 2016.
[5] Internal figures from University of Sheffield, UCLan and Lancaster University
[6] Private correspondence with BAE systems and Siemens

0.4 Growth opportunities

The complete integration of digital technologies into manufacturing – Industry 4.0 – will increase productivity and add value for those firms able and willing to change. Future high value manufacturing will be digital, reconfigurable, customisable and will capture more of the value chain, blurring the line with services.

Sensors and networks will gather and integrate information from products in use (**"internet of things"**). Data analytics, machine learning and artificial intelligence (AI), machine/human interfaces, automation and robotics will underpin these trends, and issues of cyber-security will be more pressing. Innovation in materials and processes will be driven by the need to reduce weight, substitute scarce materials, and design for recycling *(the "circular economy")*. Customisation will be enabled by additive manufacturing (e.g. 3D printing), and these new technologies will demand new, optimised materials.

These technologies will transform the high value manufacturing sectors that the audit region specialises in. These sectors also offer great potential for market growth.

- In ***aerospace***, demand for air travel will grow, and new aircraft will need to be greener, quieter and more economical. The development of increasingly autonomous unmanned aerial vehicles (UAVs) presents a growing niche opportunity.
- In ***nuclear energy***, the challenge lies in ensuring that a supply chain with high value UK content delivers the UK's new nuclear build programme. The development of a UK driven small modular reactor programme is a particularly important prospect that would create substantial value for manufacturers in the region.
- In ***rail***, the global market is projected to grow at 2.7% pa worldwide, with an expansion of high speed rail in the UK and elsewhere driving the adoption of new technologies, such as the need for lightweighting and advanced control systems.
- In ***healthcare technology,*** there is intense pressure to develop technological solutions to the problems of supplying healthcare affordably to an ageing population.

0.5 Gap analysis

The audit has revealed gaps and shortcomings in the region's skills and innovation landscape. Some of these have emerged from data analysis, while others have recurred in industry consultations.

- Although there are some highly innovative companies, the overall level of private sector R&D is too low. This needs to be recognised and addressed.
- The excellence of the region's translational research institutions is acknowledged, but they should operate at a larger scale across the whole audit region to meet fully the demands and needs of the regional industrial base.
- There is a recognition of the excellence of the region's academic research base, but more could be done to connect this to regional industry. Areas in which the research base should be further strengthened include data analytics and cyber-security as applied to manufacturing problems.
- There is a widespread consensus that skills remain a problem. This includes intermediate technical skills and graduate attraction and retention.

0.6 Ambition, investment and growth opportunities

The audit's conclusions on the region's strengths, the relevant technological and market opportunities, and its gaps indicate the steps that need to be taken to realise the vision of a high value manufacturing sector revitalised through innovation and skills. The overall goal is an Advanced Manufacturing Innovation Corridor in which the widespread adoption of Industry 4.0 and the embracing of innovative materials and processes creates value and drives productivity growth.

Capital science and innovation infrastructure

Establish the **Northern Advanced Manufacturing Innovation Corridor** from Sheffield's Advanced Manufacturing Innovation District to the Lancashire Advanced Manufacturing Innovation District at Salmesbury, anchored by the Northwest Advanced Manufacturing Research Centre (NWAMRC).

Further capital science and innovation infrastructure opportunities include:

- Lightweighting Centre
- Robotics and Autonomous Systems translational research centre
- Data analytics for manufacturing, through strengthened links to the national Alan Turing Institute.

Talent attraction, development and retention

A **pan-Northern skills programme** to support the requirements of advanced manufacturing businesses and complementary aligned sectors for the emergent new skills needs of Industry 4.0. This will enthuse the younger generation and create a talent pipeline, tackle challenges around replacement demand for highly technical skills, mitigate risks around an ageing workforce and help to retain talent in the North.

New enterprise support will be provided for advanced manufacturing, and linked industries will create the ambitious entrepreneurs and high growth businesses of the future.

Northern innovation support

Collective innovation programmes (advanced manufacturing, digital, data science, cyber-security, robotics, eco-innovation, health and care, management, innovation) to link SME and corporate agendas to build resilient supply and value chains.

Develop a **Northern Powerhouse nuclear supply chain productivity/innovation support programme** for the **Small Modular Reactor** (nuclear) growth opportunity.

Northern productivity academy

Establish a **Northern Powerhouse Productivity Academy** to drive the transformational leadership and management change required to make a significant impact on the region's productivity and innovation behaviours. This builds on Lancaster's involvement through its partnership with BAE Systems on the Government's Productivity Leadership Group and a pilot Leadership for Productivity Programme under development.

Support for internationalisation

Deliver support for internationalisation exploiting regional HE and industrial networks and partnerships, working with the LEPs and UKTI etc.

Explore the potential for a **Northern International Catalyst Programme** building on Lancaster China Catalyst Programme, SCR internationalisation programmes.

0.7 Networking, collaboration, and the added value of the Science Innovation Audit process

In addition to the bottom-up data analyses and desk-based review work that has informed the region's science and innovation thinking, the open and inclusive process used to shape the SCR and Lancashire SIA Framework has itself delivered significant added value. Existing linkages have been enhanced, new relationships developed, and 'hidden' synergies and complementarities brought to the fore.

Whilst we must recognise that the collaborative working and common approaches evident across the two sub-regions are still very much in their infancy, the level of trust, shared commitment and ambition that now exists augurs well for both the two sub-regions (SCR and Lancashire), as well as the wider Northern Powerhouse. Indeed, it has become clear across the region's different partnership structures through recent discussions that the SIA process has already started to deliver beneficial impacts on the localised innovation systems and we are confident that it will leave a lasting legacy of a more outward-facing growth agenda. Notable aspects of our SIA process include:

- The first Northern Advanced Manufacturing Innovation Corridor collaboration - a new partnership formed between the Universities of Lancaster and Sheffield to establish a Northwest AMRC on the Salmesbury Enterprise Zone (EZ) in Lancashire, focused on supporting advanced manufacturing supply chains and driving productivity improvements in regional SMEs.
- Agreement by BAE Systems, Rolls-Royce, Siemens and the Lancashire LEP to fund a pilot Leadership and Management Programme under the Productivity Academy for mid-small supply chain businesses to be delivered by Lancaster University in early 2017.
- SIA consultation workshops held in Lancashire in January and August 2016, with a mix of university, industry and Research and Technology Organisation (RTO) representatives in attendance. The events provided excellent networking opportunities and there was strong support for the emerging SIA framework.
- A programme of primary research through in-depth consultations with 24 major advanced manufacturing firms and representative bodies active within the two sub-regional geographies. This work has helped to promote and champion existing growth plans, identify cross-sectoral synergies, common challenges and opportunities.
- A meeting with the Greater Manchester and East Cheshire SIA leadership team held in July 2016 in Manchester, to share lessons and good practice, as well as exploring opportunities for increased joint-working in relation to high value manufacturing and Industry 4.0 thinking.
- Discussion with colleagues in the Midlands Engine SIA in September 2016 regarding the complementarities in advanced manufacturing broadly, and particularly in rail, where the existing Doncaster involvement in the Birmingham-based National College for High Speed Rail could be a nucleus for further collaboration in Next Generation Transport.

The Science Innovation Audit (SIA) process has been a highly positive and successful one, with momentum and enthusiasm building over time as stakeholders have become more engaged and inspired. Partner representatives from across all of the pan-regional universities, and key Research Technology Organisations, science parks, incubators, the NHS and industry have provided constructive 'check and challenge' throughout, whilst the assembled qualitative and quantitative data have ensured that the resulting SIA Framework is grounded in robust evidence.

Introduction to the Science and Innovation Audit (SIA)

If the region can take a UK lead for the implementation of Industry 4.0, this will benefit productivity and economic growth not just in the region, but throughout the North and the UK more widely.

1.1 The hypothesis and SIA process

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The UK has a serious productivity problem. One part of the solution to this could be through driving innovation, skills, and the transfer of best practice in the high value manufacturing (HVM) sector. Manufacturing in the future will be digital, reconfigurable, customisable and will capture more of the value chain; these developments – collectively known as Industry 4.0 – will boost productivity and create more value for those firms in a position to exploit them.

There is a significant opportunity to drive transformational impact in the HVM sector, presented by the partnership brought together to deliver this SIA, through collaborations between industry and the world-class science and innovation base to establish the North as the epicentre for making Industry 4.0 a reality in the UK.

The audit area – Sheffield City Region and Lancashire – has a strong manufacturing specialism, in the key sectors of aerospace, energy (especially nuclear), transport (especially rail) and healthcare technology. These sectors all meet the definition of high value manufacturing, which encompasses any manufacturing activity whose ability to create value is protected by high barriers to entry from lower cost competitors, through tough safety and regulatory requirements, through being highly knowledge intensive, and through being part of a complex supply chain delivering to customers who have to meet such demands.

An extensive base of science and innovation assets has been built up in the area, through Government and private sector investment. Many of these assets are strongly relevant to the implementation of Industry 4.0. The potential now exists for the region to use these assets to develop its manufacturing base to a globally competitive level.

If the region can take a UK lead for the implementation of Industry 4.0, this will benefit productivity and economic growth not just in the region, but throughout the North and the UK more widely.

Given the right interventions, the result will be a growing (by output) HVM sector which will lead to wider economic benefits, through attracting other high productivity businesses in professional services, manufacturing and advanced technical services, design and marketing functions. Indeed, the essence of Industry 4.0 is that digital technology and the insights from data analytics increasingly blur the line between manufacturing and services.

A very wide range of science and technology areas will underpin and drive this broader conception of manufacturing. The development of new materials and manufacturing techniques remains central, but data analytics, robotics and automation will take centre stage, together with the development of the new business models and new working practices that will allow the manufacturing firms of the future to benefit from these new technologies.

This SIA has focused on identifying those science and innovation strengths in the audit region that will enable the UK to capitalise on the expected changes in manufacturing; the institutions and systems of innovation that will enable the transfer of knowledge to take place; opportunities for diffusion of technological best practices across companies and between sectors to maximise productivity growth; and the skills needs and interventions required to allow the region to use Industry 4.0 and other drivers to build its HVM base.

The consortium overseeing the SIA represents the key innovation partners in the Sheffield City Region (SCR) and Lancashire Local Enterprise Partnership (LEP) areas, as well as innovation experts from outside both regions. It includes industry, two components of the HVM Catapult, universities, funders, innovation bodies, and the two LEPs. It is led by Professor Sir Keith Burnett (Vice-Chancellor, The University of Sheffield, SCR LEP Board member), and Professor Mark E Smith (Vice-Chancellor Lancaster University, Lancashire LEP board member). More details of the process are given in Annexe 1.

The recently published Northern Powerhouse Independent Economic Review (IER)[7] highlights the strong synergies that already exist across the North and the opportunities that will flow from continued collaboration. In undertaking this audit, we have worked particularly closely with the Greater Manchester/Eastern Cheshire SIA team, with whom we have shared information about our approaches and our preliminary conclusions throughout the process.

Considering the two audits together will help to reveal the wider picture of Northern assets and their connectedness, which will be complemented by the subsequent waves of audits.

The opportunity posed by this SIA is to drive the required transformational change through proposed interventions which will build on current and planned assets, leading to increased productivity across the North and a significant rebalancing of the UK's economy. These proposals are set out in Chapter 9.

[7] Northern Powerhouse Independent Economic Review, Transport for the North, June 2016. www.sqw.co.uk/insights-and-publications/northern-powerhouse-independent-economic-review/ 8 ONS 7th April 2016 release

[9] Fixing the Foundations: Creating a More Prosperous Nation, HM Treasury 2015

[10] See for example The Future of Productivity, OECD, December 2015. http://www.oecd-ilibrary.org/economics/the-future-of-productivity_9789264248533-en

[11] Andrews, D., C. Criscuolo and P. Gal (2015), "Frontier Firms, Technology Diffusion and Public Policy: Micro Evidence from OECD Countries", OECD Productivity Working Papers

[12] The Northern Powerhouse Independent Economic Review, Workstream 2: City Region & Local Area Profiles – Final Report – www.transportforthenorth.com/pdfs/NP/Local-Area-Profiles-NP-Independent-Economic-Review.pdf

1.2. SIA region: Why Sheffield and Lancashire?

Sheffield City Region and Lancashire are not usually considered as a single economic unit. However, a deeper assessment of the economic and innovation landscape within and between these regions reveals that:

- In both regions, there is a focus on high value manufacturing; within this, aerospace, nuclear and healthcare technology are sectors of national significance. Both regions have a concentration of innovative manufacturing SMEs that operate in the supply chains of these sectors, as well as a number of globally significant primes.
- There has been significant public and private sector investment in physical innovation assets and support ecosystems in both regions. These facilities and support systems are already interacting but there is a strong desire to deepen the collaborations to provide a much more coherent offer across the geography.
- The combined region has a well-developed, globally competitive, and highly complementary science base of relevance. The research undertaken, if considered as a whole, presents a significant offer to industries which rely on advanced manufacturing. In summary, Sheffield leads on engineering and manufacturing, whilst Lancaster has the lead on leadership and management, with specialisms relating to advanced manufacturing industries.
- The development of a Northwest Advanced Manufacturing Research Centre in Lancashire is a significant development – outlined in Chapter 2 and Chapter 5 – which shows the commitment of key public and private sector actors in the two LEP areas to work together to drive innovation, productivity and skills in manufacturing across the region.

1.3. The economic context

The economic context for the SIA is set by the UK's current productivity problem as shown below in Figure 1.1[8]. Since 2008, productivity growth has been weak, widening the productivity gap and leading to stagnating living standards and a persistently challenging fiscal position[9].

The productivity record of the region covered by this Science and Innovation Audit is poor, even by comparison with the rest of the country. Figure 1.2 shows the productivity, expressed as Gross Value Added (GVA) per job, of our two LEP regions.

The IER identified three common causes for the evident productivity gaps in both LEP regions: **Structural change** (there has been a shift away from manufacturing to lower productivity occupations); **Skills** (the region suffers from a legacy of educational underachievement, and a high proportion of employers report skills gaps); and **Innovation and entrepreneurship** (low levels of inward investment and private sector business formation, and lower than expected levels of R&D).

Manufacturing is a sector of potentially high productivity growth. The PwC report *Industry 4.0 – Opportunities and Challenges of the Industrial Internet*, states that by 2019, 80% of German companies surveyed will have digitised their value chains, and that the implementation of this digitisation can produce an 18% increase in efficiency within five years. If the promise of Industry 4.0 can be captured in the region through a much stronger focus on innovation and skills, then the regional specialisation in manufacturing can become a source of strength, helping to close the productivity gap.

Recent analysis of the productivity problem[10] has highlighted the extent to which productivity performance within a sector such as manufacturing is far from uniform. Firms operating at the global technology frontier are able to apply new technologies and new business models, develop new products and improve their processes. In this way they can drive ongoing, strong productivity growth. Fast followers are able to assimilate these new practices to remain competitive. However, there is evidence[11] that a growing gap has been opening up between these technology leaders and a long tail of technology laggards. This suggests a need to pay as much attention to the institutions and mechanisms through which the outcomes of innovation diffuse across a sector, as to the original innovative process itself, to ensure that the productivity gains from new technologies are captured in full.

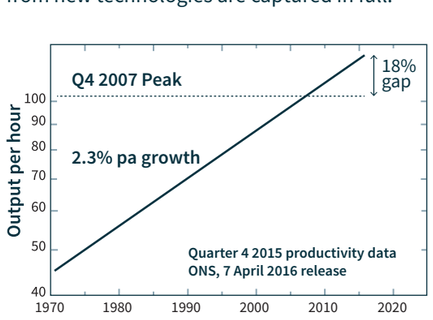


Figure 1.1 UK Labour Productivity since 1970. Data ONS Quarter 4 2015 Productivity Bulletin

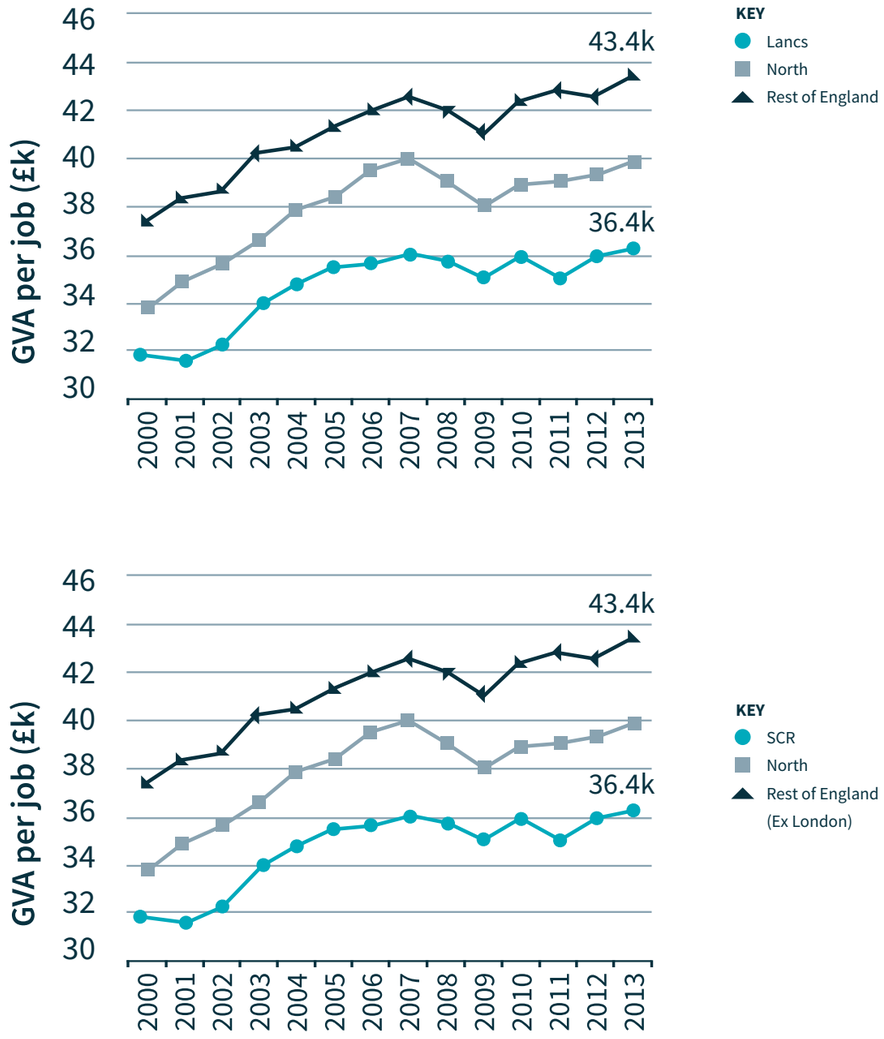


Figure 1.2: GVA per job in and Lancashire (top) and the Sheffield City Region (bottom)[12]

1.4 The wider regional, national and global context

1.4.1 Northern Powerhouse

The economic strategies of the two LEP regions involved in this audit were set out in documents issued to support the March 2014 growth plans[13,14]. These are set in a wider context, together with plans and strategies for other LEP regions in the North, by the recent Northern Powerhouse IER[15] which identified four 'prime capabilities' of the North as a whole which are "differentiated and distinctive at a pan-Northern level, highly productive, and able to compete at national and international levels". These are:

Advanced Manufacturing: with a focus on materials and processes.

Energy: generation, storage, low carbon technologies and processes, especially nuclear and offshore wind.

Health Innovation: established strengths in life sciences, medtech and devices, growing competence in new service delivery models brought about by e-health and the devolution of responsibilities for Health and Social Care.

Digital: high performance computing, cognitive computation, data analytics, simulation/modelling, machine learning, relevant sector strengths (esp. media).

Lancashire and the Sheffield City Region contribute to this pan-Northern agenda through a specialisation in advanced manufacturing. There are actual and potential interactions with the other three "prime capabilities". Healthcare technology and energy themselves are important loci for high value manufacturing, with a significant industrial base in the region, while the digital underpinnings of modern manufacturing are becoming ever more important.

The interconnected nature of the Northern economy make it important not to consider the audit region in isolation. The linkages between the audit region and that represented by the Greater Manchester and East Cheshire audit are already strong. There is much synergy between innovation activities in the two geographies. For example, the University of Sheffield's AMRC with Boeing, a world-class centre for advanced machining and materials research for aerospace and other high value manufacturing sectors, draws upon materials research in Manchester.

The Nuclear AMRC draws on research from facilities within the Department of Materials Science and Engineering at The University of Sheffield and the University of Manchester's Dalton Nuclear Institute. The Sir Henry Royce Institute for Advanced Materials has its main centre in Manchester, and the research in advanced metals processing and manufacturing and nuclear materials is led by the University of Sheffield.

1.4.2 National and international context

The science and innovation base within the audit region is already part of an integrated national system; a significant part of national institutions such as the High Value Manufacturing Catapult and the Sir Henry Royce Institute are hosted in the region, and there are broad and deep research networks connecting the region to the rest of the country. As a national industrial strategy takes shape, it will be important to consider the contribution of the region to wider sector strategies in key areas such as aerospace and nuclear.

The region's innovation assets will be magnets for inward investment, attracting to the area global companies at the technology frontier.

Links with East Asia, North America and Europe will matter more than ever as a post-Brexit UK develops new trading relationships. The region's innovation assets will be magnets for inward investment, attracting to the area global companies at the technology frontier. Innovative firms based locally have developed their competitiveness to trade more widely and become ever more deeply integrated into global supply chains, while the region's scientists and technologists are integrated in international networks of the world's leading researchers.

1.5 Conclusions

What emerges from the evidence presented in the following report is a picture of two LEP regions which have already identified economic, science and innovation complementarities and begun to combine these for economic gain in the creation of a new facility (the Northwest AMRC) which will enable them to work together to the benefit of the economy in both LEP areas. This SIA outlines the next steps required to make the most of the opportunities identified.

[13] Lancashire Strategic Economic Plan: A Growth Deal for the Arc of Prosperity, March 2014 www.lancashirelep.co.uk/about-us/what-we-do/lancashire-strategic-economic-plan.aspx

[14] Sheffield City Region Strategic Economic Plan: A focused 10 Year Plan for Private Sector Growth 2015 – 2025 sheffieldcityregion.org.uk/about/growthplan/

[15] Northern Powerhouse Independent Economic Review, Transport for the North, June 2016 www.sqw.co.uk/insights-and-publications/northern-powerhouse-independent-economic-review/

Overview of the region's science and innovation assets

The audit region is home to globally significant universities with total research grant income in 2014/15 of more than £200m, of which £161.7m is relevant to high value manufacturing sectors.

02

The hypothesis of this SIA is that significant productivity growth in the high value manufacturing sector in the region and beyond could be unlocked with the aid of the substantial government and private sector innovation–related investments within and between the two LEP areas. This chapter sets out what those investments are, what they have achieved, and what opportunities there are to capitalise on them to build capacity and efficiency within the resident manufacturing community.

2.1 Universities overview

Institution	Number of staff submitted to REF 2014	HESA research expenditure for academic year 14–15	% research internationally recognised or better
University of Sheffield	1,008.3 FTE	£158.4m	98
Lancaster University	579.8 FTE	£33.1m	98
University of Central Lancs	247.0 FTE	£6.9m	93
Sheffield Hallam University	226.2 FTE	£7.9m	94
Edge Hill University	138.5 FTE	£420k	79
University of Cumbria	26.8 FTE	£332k	78
SIA Audit area total	2226.6 FTE	£207m	90

Table 2.1: Higher Education institutions in the audit region.[16]

Institution	Units submitted (breadth)	Largest submission areas (depth)
University of Sheffield	35	Engineering, Health, Medicine, Biological Sciences, English Language and Literature.
Lancaster University	16	Business and Management, Health, English Language and Literature, Earth and Environmental Sciences and Physics.
University of Central Lancs	16	Health, Social Work and Social Policy, Sport and Exercise Sciences, Leisure and Tourism and Physics.
Sheffield Hallam University	11	Sport Sciences, Materials and Electronic Engineering, Communication and Computing and Art and Design.
Edge Hill University	12	Social Work and Social Policy, Law, Sport Sciences, English Language and Literature.

Table 2.2: Breadth and Depth of REF 2014 submissions from audit region HE Institutions.[16]

The audit region is home to globally significant universities with total research grant income in 2014/15 of more than £200m, of which £161.7m is relevant to high value manufacturing sectors.[17]

In total, the five universities submitted 2226 staff to the REF 2014, as set out in Table 2.1. Table 2.2 gives a summary of REF submissions, detailing breadth and depth. This information is analysed further in Chapter 4.

[16] REF 2014 results: results.ref.ac.uk, Research expenditure: HESA research income for 2014–15, from HEIDI.

[17] Research income for 2014-15 from HESA (HEIDI) for Engineering, Medicine and Health, Science and Business Management Cost Centres

2.1.1. University-owned translational research centres

A number of globally relevant translational research centres are connected to the universities in the region. Each operates with a strongly business-led philosophy. Table 2.3 summarises the existing and planned facilities across the audit area. Those which are currently operational and of direct relevance to high value manufacturing are set out in more detail below. Fuller summaries of the facilities not detailed here can be found in Annexe 4.

The AMRC Group is the largest facility, representing nearly £300m investment. It was founded in 2000 as the AMRC with Boeing and has expanded to include Factory 2050, two HVM Catapult Centres (AMRC, Nuclear AMRC), the Medical AMRC and the AMRC Training Centre. It currently employs more than 600 staff and has a turnover of £38m. It has a high degree of global visibility and its model is in the process of being replicated in South Korea, Oman and the USA. Lancaster's Management School ranks number one in the UK, and has significant experience of delivering to SME customers and of dedicated provision for HVM sectors. The planned UCLan Engineering Innovation Centre and North West AMRC represent significant investment totalling over £100m which will bring together technical engineering expertise with management expertise to create a holistic translational research offer to businesses within the audit geography.

Facility name	Existing/planned	Focus areas
AMRC Group	Existing – £280m investment	High value manufacturing
UCLan Engineering Innovation Centre	In development – £40m+ investment	High value manufacturing
SHU National High Power Impulse Magnetron Sputtering Technology Centre	Existing – £6.2m investment	High value manufacturing
Lancaster Management School	Existing – see details below	Business and Management in high value manufacturing
Centre for Eco-Innovation	Existing – £9.8m investment, £20m new funding confirmed	Sustainability, circular economy, best practice SME engagement
North West AMRC	Planned – £69m proposed project	High value manufacturing
BAE Systems' Training Academy	Existing – £15.7m investment	High value manufacturing
National Centre for Food Engineering	Planned – £11.2m funding confirmed	Food Manufacturing
Advanced Wellbeing Research Centre	Planned – £20.1m funding confirmed	Health Technology and Wellbeing
Lancaster Health Innovation Campus	Planned – £40m funding confirmed	Health Technology
ScHARR	Existing – see details below	Health Economics and Health Technology
The Collaborative Technology Access Programme (cTAP)	In development – £11.4m investment	Design, manufacture of chemical products

Table 2.3: Investment in existing and proposed translational Research Centres in the audit region.

	Patient/staff participants	Studies
Sheffield Teaching Hospitals NHS Foundation Trust	7786	327
Lancashire Teaching Hospitals NHS Foundation Trust	2155	109
Lancashire Care NHS Foundation Trust	1498	37
Blackpool Teaching Hospitals NHS Foundation Trust	1264	81
Sheffield Children's NHS Foundation Trust	915	55
Doncaster & Bassetlaw Hospitals NHS Foundation Trust	771	65

Table 2.4: Collaborative relationships between HEIs and NHS within the audit region.[18]

2.2 Other public sector R&D facilities

Nuclear. The National Nuclear Laboratory (based at Sellafield) is the most relevant publicly-funded non-university R&D facility, and has a laboratory in leased facilities at Westinghouse's Springfield plant, near Preston. This focuses on nuclear physics, advanced reactors, fuel design and manufacture, and process and analytical chemistry.

Health Technologies. The region's hospitals have a good reputation for translational activity, with many staff members research-active in collaboration with nearby universities and the private sector. These interactions have an importance beyond their monetary scale in bringing a translational, patient-focused perspective to academic research in clinical medicine and healthcare technology. Table 2.4 below gives an idea of the scale of this activity.

NHS Test Beds. Two out of seven test beds are in the audit region and both focus on digital technologies that care for patients in the home. The Lancashire Test Bed, a partnership of two universities, six NHS trusts, local SMEs and industrial partners such as Philips, is exploring the development and implementation of digital technologies to enable the elderly to remain independent and within their own home environments. The Sheffield City Region Test Bed is looking at the use of new technology, coupled with new ways of delivering care, to keep patients with conditions such as diabetes, mental health problems, respiratory disease, hypertension and other chronic conditions well at home, often avoiding the need for hospital admission or further support. The 'Perfect Patient Pathway' Test Bed (as it is also known) involves more than 30 partners including the region's NHS, social care, industry and voluntary organisations and its two universities.

2.3 Private sector R&D

As a combined geography, the area outperforms the England average in two out of three significant indicators of innovation activity. There are more firms in the consortium area engaged in product or process innovation, with a higher average proportion of turnover from product or process innovation.

A weighted average of companies undertaking product and process innovation[19]. In the region shows values of 25.4% in Lancashire, 21.8% in Sheffield City Region, compared to 23.6% in England as a whole. However, overall business R&D intensity is very low: on 2013 data, SCR ranked 36 out of the 39 LEP areas, with total business R&D expenditure of £104 million (£171 per FTE), while Lancashire ranked 27 out of 39 LEPs, with expenditure of £204 million (£390 per FTE).[20]

2.3.1 Private sector tier 1 R&D

BAE Systems managed overall R&D investment of £902m in 2014, including £63m of its own funds. Of the £9.6m spent on R&D with UK universities, nearly 20% (£1.6m) was spent within the audit region.

Siemens has invested £3.2m in funding research at the University of Sheffield since 2009, with a further £3.6m of in-kind contributions of cutting edge technology. Siemens has been a key partner in leveraging a further £8.3m in funding for collaborative research.

Rolls-Royce spent £1.2bn gross on R&D in 2014, and filed for 600 patents. It is a substantial supporter of the region's university research, and is a lead partner in the University of Sheffield's AMRC with Boeing. Rolls-Royce has invested £21.7m in research at the AMRC, leading to further commitment to the region in the construction of a £110m Rolls-Royce Advanced Blade Casting Facility on the Advanced Manufacturing Park in Rotherham.

[18] NHS Research Activity League Table for 2014–15 www.crn.nihr.ac.uk/about-crn/our-performance/nhs-research-activity-league-table/

[19] Mapping local comparative advantages in innovation. Department for Business, Innovation & Skills (BIS) (2015). www.gov.uk/government/publications/local-enterprise-partnerships-evidence-on-local-innovation-strengths

[20] Mapping local comparative advantages in innovation. Department for Business, Innovation & Skills (BIS) (2015)

2.4 SME and supply chain R&D

The summary statistics above hide valuable R&D activity which is taking place across the audit region, where there is a diffuse pattern of strongly product-focused R&D in a number of small and medium size companies in a variety of high value manufacturing sub-sectors.

It has not been possible within the audit resources to fully investigate these sub-sectors; however, even by looking at the group of companies that regularly interact with the HE sector in the region one can estimate that the cluster of research intensive companies have a combined turnover of circa £1bn and 6000 employees.[21] Magellan Aerospace is representative of this sample of companies. It designs and manufactures aeroengine and aerostructure assemblies and components for aerospace markets, advanced products for military and space markets, industrial power generation, and specialty products; it is dedicated to a continuous investment in advanced technologies for the manufacturing of aero structure components and assemblies.

2.5 Private sector contract research organisations

The role of contract research, engineering design and consultancy companies is likely to be important in raising innovation capacity in a region, through support to existing businesses and the creation of new ones (for example, the central role of such organisations in driving the formation of the Cambridge cluster has been noted[22]).

Further work is required to map the scale and reach of this potentially important sector, but examples of such private sector organisations in the SIA region include Performance Engineered Solutions, Bromley Technologies, Eadon Consulting, Materialise, P1 Technology, Additive Manufacturing Technologies, Parexel International. Many of these companies are clustered around the Advanced Manufacturing Park, where, in addition, Cambridge-based TWI (formerly The Welding Institute) has a branch and Nikken Kosakuso has a demonstration centre, while Lancashire hosts aerospace-focused services companies such as James Fisher Aerospace and Assystem Design and Engineering Services.

[21] MINT UK database, summary figures for AESSeals, ELE Advanced Technologies Ltd, Euravia Engineering & Supply Co Ltd, FDM Digital Solutions Ltd, Gripple, ITM Power, JRI International, Kaman Composites – UK Holdings Ltd, LabLogic, Magellan Aerospace, Magnomatics, Metalysis, Paradigm Precision Burnley Ltd, RLC Engineering Group, Senior Aerospace Weston, Servelec, Sheffield Forgemasters, T & R Precision Engineers Ltd and Velocity Composites Ltd.

[22] SQW Report: Cambridge Cluster at 50. The Cambridge Economy: retrospect and prospect. Final report to EEDA and partners. March 2011

2.6 Science and innovation talent

Both Lancashire and the Sheffield City Region have a low skills profile, which makes it harder for the region to generate transformational growth. In Lancashire, despite some enterprising places, high levels of deprivation concentrated in Blackpool and East Lancashire generate an overall low skills profile.

Across the SCR, there is a legacy of educational underperformance up to 19 years, and only 27.9% of the working age population are qualified to NVQ 4+, compared to the rest of England excluding London average of 34.5%. The proportion of SCR firms reporting skills gaps is among the highest in the country, yet employer investment in workforce training remains insufficient.[23]

Across the UK, most engineering enterprises (97.1%) are either small or micro and, overall, 86.9% of engineering enterprises have fewer than 10 employees. However, companies with at least 250 employees represent 0.4% of all engineering enterprises and they employ over two fifths (42.4%) of those working in engineering enterprises.[24]

Whilst the output of the region's HEIs includes substantial numbers of STEM and management graduates (Table 2.5) and some can demonstrate good 6-month retention rates (Table 2.6), the percentage of the overall workforce working in science, research, engineering and technology professions and associated professions is 6.2% in Lancashire and 5.8% in the Sheffield City Region. Both Sheffield and Lancaster Universities experience a longer-term loss of highly trained graduates who find the opportunities within the local region to be less attractive than those in the south of the UK. This has been recognised by both universities, and they have responded by developing award winning or best practice schemes to combat the issue, working with the SME community to unlock barriers to graduate employment and to break down graduate perceptions of SME careers.

Region	First degree STEM subjects and management	Doctorate degrees STEM subjects and management
Lancashire	3,783	155
Sheffield City	4,167	468
Audit region total (% of England)	7,950 (7.6%)	623 (5.5%)

Table 2.5: Number of graduates for 2013–14 by level of study.[25]

Graduating institution	Employed regional retention rate*
University of Central Lancashire	78.2%
Edge Hill University	77.9%
Lancaster University	45.3%
Sheffield Hallam University	69.6%
University of Sheffield	42.5%

Table 2.6: Proportion of employed graduates domiciled in the same region as their university six months after graduation.[26]

*For Lancaster, the NW region is used for domicile and for Sheffield City Region, Y & H and the East Midlands are used.

[23] Source: Northern Powerhouse Independent Economic Review

[24] Engineering UK 2015 The state of engineering

[25] Mapping local comparative advantages in innovation. Department for Business, Innovation & Skills (BIS) (2015).

[26] Destinations of Leavers from Higher Education (DLHE) survey for 2014–15, provided by HESA (HEIDI).

The AMRC Training Centre

Is regarded as a Centre of Excellence for apprenticeship and CPD delivery. The state of the art centre identifies and provides the skills that manufacturing companies need to compete globally. In 2014 it won the Times Higher Education Outreach Award. There are currently more than 400 people aged from 16 engaged in learning at the centre. Apprentices can go on to study for higher-level qualifications up to doctorate and MBA level. The Centre is the joint headquarters of the National College for Advanced Manufacturing; this status is a reflection of the quality of its training and the opening up of new pathways for young people.

The Advanced Manufacturing Centre for Skills Development and Employer Engagement

Is a £1.3m partnership between Lancaster University and BAE Systems to facilitate skills development through cadet, apprentice, undergraduate and postgraduate levels (14–25 age range predominantly) with significant employer engagement at all stages. The environments at both Lancaster and the Enterprise Zone (EZ) will provide Lancashire learners with access to nationally leading and highly relevant equipment, supported by underlying research expertise.

UNITE With Business

This UCLan led project was a partnership of six NW universities covering all areas of the NW region outside Merseyside. The project worked with a wide range of SMEs to deliver innovative knowledge exchange projects, delivering 1842 business assists of 150 hours each, benefits to students and graduates through SME experience gained in their internships, and in some cases aiding graduate retention through their subsequent recruitment. A new project has been applied for in Lancashire with 250 placements over three years.

The LEAD Programme

Was a ten-month intensive leadership development programme, created by Lancaster University Management School and derived from research into entrepreneurial learning, for owner-managers, MDs, and senior managers of SMEs. Participants were from all business sectors and exhibited a strong growth orientation. LEAD was reviewed and revised, based on learning from its widespread delivery, and re-launched as LEAD2Innovate in October 2014. LEAD supported 1,700 businesses across the UK and an independent evaluation (Wren and Jones, 2012)[27] has shown that participants reported post-LEAD mean annual turnover growth rates of 13.8%, and employment growth of 16.8%, with 70% reporting profit increase and 65% reporting productivity increase.

RISE

Is an innovative and award-winning talent retention and business support scheme. Initially a partnership between Sheffield Hallam University, the University of Sheffield, and Sheffield City Council, RISE was launched in 2013 to support SMEs to create jobs, retain talented graduates in the region and recruit skilled staff. Due to its success (over 150 permanent graduate posts created) RISE is now being rolled out to cover the whole Sheffield City Region. This roll-out will see 250 interns placed over the next three years, with at least 150 of these placements becoming permanent posts. This will equate to an economic impact for the region of approximately £7m. There is commitment and funding to support the RISE programme until 2019.

In order to meet the demands of future manufacturing, both regions are in the process of developing a digital skills strategies. The existing best practice and delivery mechanisms identified above will be important both in terms of scaling up to meet future demands but also in ensuring that developing strategies remain employer led. SCR LEP is developing a skills strategy, which includes ambitious targets for progression from advanced to higher and degree level apprenticeships. In addition, Doncaster will host part of the National College for High Speed Rail because of the strength and depth of the rail sector in the area. This arm of the college will focus on Traction, Rolling Stock and Advanced Manufacturing. In Lancashire, a Growth Deal proposal will establish a pilot Technology Exploitation Centre (TEC), with plans for a national training academy to train current and future BAE Systems employees and build training capacity for its supply chain.

[27] Wren, C. & Jones, J. (2012), Quantitative Evaluation of the LEAD Programme, 2004–11, Newcastle University, Newcastle.

International trends: the science and technology of manufacturing

The very boundaries of what we mean by manufacturing are being rethought. We have grown accustomed to thinking of supply chains, but we must go further to consider the entire value chain.

3.1 Developments needed to support manufacturing in the future

03

Manufacturing is changing, and high value manufacturing in the future will look very different – both in the business models that successful manufacturers will follow and in the technologies that will be used to deliver it.

The international drivers for these changes have been identified by a UK GO Science Foresight project [28], which held workshops in Europe, the US and Asia. Sustainability in its broadest sense emerges as a key driver, encompassing social and economic aspects as well as resource efficiency, and embracing the possibilities of radically new models of production and consumption.

Increased automation and use of robotics, coupled with focused efforts to increase productivity and drive efficiency gains, will likely see a reduction in the numbers of certain jobs in manufacturing replaced by new higher-skilled employment opportunities in high value areas such as software development and related 'manu-services'.

Large scale data analytics is already driving significant change, with many organisations already using a growing wealth of data encompassing everything from supply chains and manufacturing processes to consumer behaviour. New models of distributed manufacturing, enabled by additive manufacturing techniques such as 3D printing and emergent niche micro-manufacturing capabilities, could radically transform manufacturing as a sector.

[28] Future of Manufacturing Project: Evidence Paper 1 Foresight, Government Office for Science October 2013.

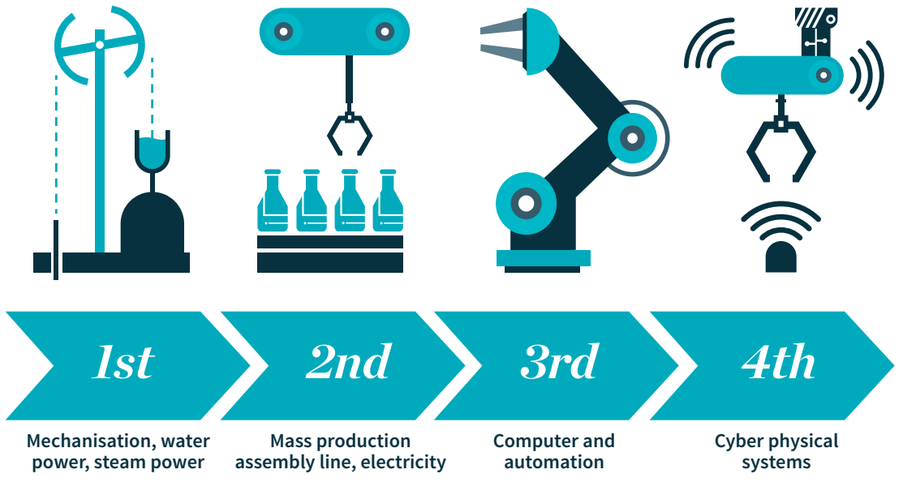
3.2 Industry 4.0 and the digitisation of manufacturing

The term Industry 4.0 refers to the combination of several major innovations in digital technology that together are likely to transform the energy and manufacturing sectors, and any sector which relies on manufacturing. When employed simultaneously they are capable of joining the physical and virtual worlds in a way that enables companies to organise their operations in a completely new way. Product design and development take place in a virtual environment and products are totally customisable. A high rate output of individual, customised products becomes possible.

The key factor will be the incorporation of digital technologies at all stages of the manufacturing process. Manufacturing is being reconstituted as the embodiment of digital ideas in the physical world – a process recognised in the UK Government's recent Foresight Project on the Future of Manufacturing[29], in a recent major report from the USA's National Academies[30], and in other leading competitor manufacturing nations, for example Germany's Industrie 4.0 initiative[31]. The very boundaries of what we mean by manufacturing are being rethought. We have grown accustomed to thinking of supply chains, but we must go further to consider the entire value chain.

The manufacture and assembly of components into a product is the core of a wider process, and successful companies will be the ones who capture much more of the value that is added at the pre-production and post-production stages of this value chain. Future manufacturing will focus on the circular economy and on making value, not just making things.

Digitised manufacturing allows customers to be integrated into the design process at a much earlier stage, bringing mass customisation within reach and supporting the move to increased servitisation of manufacturing. Within use, sensors and networks gather and integrate information, monitoring the use and performance of the product. At the end of the life cycle, resource economy and customer and regulator drivers for more sustainability dictate the need to design for product reuse, remanufacturing and recycling.



[29] Future of manufacturing: a new era of opportunity and challenge for the UK, Government Office for Science, May 2013. www.gov.uk/government/collections/future-of-manufacturing

[30] Making Value for America: Embracing the Future of Manufacturing, Technology, and Work, National Academy Press, 2015 www.nap.edu/catalog/19483/making-value-for-america-embracing-the-future-of-manufacturing-technology

[31] Industrie 4.0: Innovationen für die Produktion von morgen, 2015, German Federal Ministry of Education and Research www.bmbf.de/de/zukunftsprojekt-industrie-4-0-848.html

3.3 Developments needed to underpin Industry 4.0

At the preproduction stage, **data analytics and integrated design, including design for manufacturability,** will be key. We will see increasing use of **digital prototypes** to replace physical prototypes and allow users/customers to try them out in immersive VR environments.

Large scale data analytics, together with forecasting, simulation and optimisation methodologies, will be the key to connecting the manufacturing process more closely to customers; incorporating real time data from sales and marketing functions in order to get a more responsive and customisable manufacturing system will be the key methodologies for complex global supply chains; network analysis will be key to maintaining robustness.

The focus on making manufacturing systems more flexible and reconfigurable, and in some cases more decentralised, will spotlight **automation and mechanisation. Autonomous systems** and **robotics** will play an increasing role; this will be underpinned on one hand by more sophisticated **machine learning** and **artificial intelligence**, and on the other by much more sophisticated **human/machine interfaces**.

In use, we will see increased prevalence of advanced built-in sensors, for example for the **real-time monitoring of structural health**, and advanced warning of fatigue or failure. Data gathered in use will have its own value, and **cloud computing and large scale data analytics** including **machine learning** will be needed to capitalise on these developments, a key element of the developing **'internet of things'**[32]. One key application for machine learning will be **anomaly detection** using the real-time output of sensor networks. In manufacturing, one seeks to maintain up-time for capital intensive plant, while in safety critical applications, such as nuclear power plants, utterly reliable detection of deviation from safe operation conditions is crucial.

The continuous monitoring of products in use offers opportunities for extracting additional value through servitisation; the classic example is the monitoring of the condition of jet engines in flight. In all these cases one knows what normal operation looks like, but the form an anomaly may take is not known a-priori. In these environments it is very easy to end up with too many false positives, or to fail to detect serious situations.

A particular problem arises when a system integrates (or fails to integrate) many units from different manufacturers. Rather than have a situation in which so many independent units are sounding alarms that the operators end up switching them off, the units need to be integrated in a system in which analysis is carried out in real time on the totality of the information arriving and is presented to the operators in a usable way.

Cybersecurity is another key issue that will become even more pressing as the outputs from many sensors and artefacts are connected together in the 'internet of things'[33]. In the manufacturing process itself, digitally controlled plant needs to be secured against malicious interference (the Stuxnet worm offers a graphic example of the damage that a determined cyber-attack can wreak on a vulnerable system).

An additional security dimension appears in connected systems of products, where to be economic, sensors and processors need to be very low cost. Such systems will need to use existing infrastructure and software, where international standards are not yet settled. The challenge will be to achieve security in very inexpensive systems. Power consumption, energy storage and harvesting will be other key issues for these systems.

At the end of its life, the product will not simply be disposed of; instead, products will increasingly be remanufactured or recycled. This will change the way products are designed and add new constraints to materials choice. But together with a focus on energy efficiency during manufacture, it will lead to a more sustainable manufacturing sector, and will contribute towards the move to a circular economy.

[32] Internet of things: making the most of the second digital revolution, 2014, Government Office of Science www.gov.uk/government/publications/internet-of-things-blackett-review

[33] Progress and research in cybersecurity supporting a resilient and trustworthy system for the UK, 2016, Royal Society www.royalsociety.org/topics-policy/projects/cybersecurity-research/

3.4 Other key technological breakthroughs for manufacturing

The development of new materials and new manufacturing processes will go hand-in-hand. Materials development will be driven by the need to reduce weight in structures, the need to substitute for scarce materials (e.g. rare earths), and the requirements of design for ultimate remanufacturing and recycling.

Lightweighting will be driven by the increased use of composite materials, where design and manufacturing principles need to be fundamentally rethought to account for and take advantage of the intrinsically anisotropic properties of the materials. Taking advantage of the superior properties of nanomaterials (including 2D materials such as graphene) requires fundamental understanding of processing/property relationships. Development of substitutes for materials such as rare earths will require a combination of fundamental understanding and combinatorial methods.

There will be opportunities for smart/functional materials and the increasing integration of materials and devices. New manufacturing techniques will include additive and near-net shape manufacturing (3D printing); these require parallel advances in areas of materials processing (such as powder metallurgy) to optimise the properties of the products.

Developments in joining and coatings technology will drive down manufacturing cost and increase functionality. Joining technologies like robotic e-beam welding have the potential to dramatically reduce cost and improve reliability in the nuclear sector.

3.5 Conclusion

Future manufacturing will draw on a much broader range of technology than previously, as Industry 4.0 principles become widespread. This has implications for the absorptive capacity of existing manufacturing businesses; the institutions and mechanisms by which this much broader base of underpinning science and technology is transferred into the manufacturing sector will need to be rethought.

Excellence in science & research

The Sheffield City Region and Lancashire research base is strong and well aligned to a specialisation in high value manufacturing, with most of the subjects that will be important underpinnings for Industry 4.0 well represented.

04

As we have seen from the previous chapters, the UK has a significant productivity problem; manufacturing can play a part in solving this, notably in the audit region. In particular, there is an opportunity to capitalise on the significant public and private sector investment in innovation assets outlined in Chapter 2 and to put these to use in making Industry 4.0 a reality, as well as responding to drivers particular to the sectors the region specialises in.

In order to do this, we need to reassess the quality of the research base that feeds this innovation ecosystem, the degree to which it is globally relevant and capable of interacting with the primes and their supply chains, as well as with the growing number of highly technical SMEs that exist in the audit region. This chapter delves deeper into the issue of research strengths and sets out the general picture across the audit region, as well as examining more closely those areas of technology required for the implementation of Industry 4.0, looking specifically at the scale and excellence of relevant research being carried out in the region.

4.1 Measuring excellence in science and research

The essence of a successful audit of the science resources of any region has to be a critical, objective and fine-grained assessment of the quality of the research produced in all the relevant fields and sub-fields, measured against national and international standards. Such an assessment can be carried out using the opinion of experts, or through the use of metrics.

Metrics need to be chosen carefully and used appropriately. The justification behind our choice of metrics and some cautions about their use are laid out in more detail in Annexe 1. Briefly, we use the results of the Research Excellence Framework (REF), as a large-scale national assessment of the quality of research outputs, impact and environment based on peer review, supplemented by bibliometrics (citation analysis) which can make comparisons against international quality benchmarks at a finer grained level of subject detail.

Measures of research income give an indication of both the scale of research activity and, indirectly, its quality, on the basis that funds are awarded competitively following peer review (in the case of research council funding) or direct assessment of business relevance (for industrial collaborative funding).

In making these assessments, we need to take care over the range of fields we cover and the way we classify them. This is particularly important in this Science and Innovation audit, where we focus on the research that will underpin high value manufacturing. The audit needs to be forward-looking. This means that we must focus, not just on those areas of research that support manufacturing as it is now, but the research that will support the manufacturing of the future.

Chapter 2 made it clear that a much broader range of research and skills are needed to underpin Industry 4.0 than was the case for traditional manufacturing. We therefore give special attention to the following underpinning areas for Industry 4.0:

- Manufacturing and design
- Robotics and autonomous systems, machine learning and artificial intelligence
- New, smart and functional materials
- Virtual reality, internet of things, cloud computing and large scale data analytics
- New business models, new working practices and entrepreneurship

In addition, we assess research strengths underpinning those application areas for Industry 4.0 that are of particular importance for the regional economy: aerospace, transport (especially rail), healthcare, and energy (especially nuclear).

The methodology and data sources behind the statistics presented below are detailed in Annexe 1. Amongst the research strengths of the region, the most directly-relevant broad disciplines for this audit are engineering, where the University of Sheffield had the 4th largest submission in the UK to the REF 2014, and Business and Management, where Lancaster University had the largest submission in the UK. Figure 4.1 shows data from HESA demonstrating that research income for engineering has more than tripled between 2004–05 and 2014–15 in the audit region, with the University of Sheffield second only to Imperial College in the UK in its engineering research income in 2013–14 and 2014–15[34].

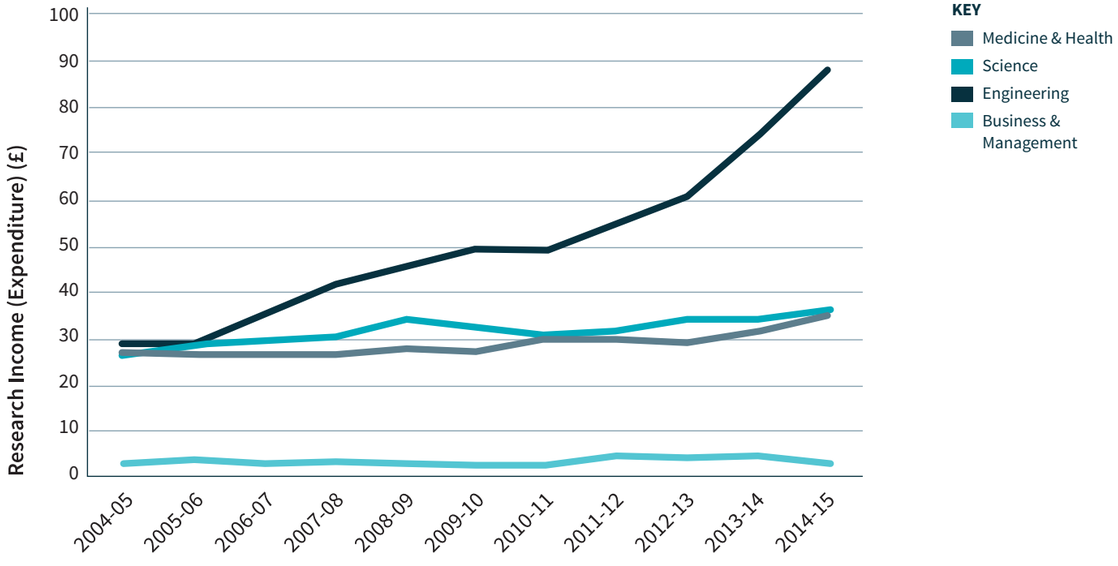


Figure 4.1 – Research income in the audit region by cost centre group 2004–05 to 2014–15

[34] HESA income (expenditure) for audit region from HEIDI. Cost Centres: Medicine and Health (1,5,6,101,103,105, Science : 10,11,12,112,113,114, Engineering: 16,17,18,19,20,21,25,115,116,117,118,119,120,121, Business and Management: 27, 133)

4.2 Underpinning research strengths for Industry 4.0 and future manufacturing

Within the broad area of engineering and related areas of physical science, there is some heterogeneity at a finer scale of analysis. Figure 4.2 illustrates the relative performance of key sub-sectors in citation impact relative both to world averages and UK averages[35]. This measure focuses on academic research outputs, so does not reflect translational impact.

Whole-UK averages substantially outperform world average performances across all these sub-fields, as expected from the overall strength of the UK research base. The region slightly outperforms UK averages in Materials and Materials Chemistry, Computer Science, Business, Management and Accounting, Electrical and Electronic Engineering, Computer Science Applications, Aerospace Engineering and Industrial and Manufacturing Engineering.

There is substantial outperformance of national averages in Human-Computer Interaction, Computer Graphics and Computer Aided Design, Artificial Intelligence, Ceramics and Composites, Transportation, Statistics, Probability and Uncertainty, business and International Management, Polymers and Plastics and Nuclear and High Energy Physics.

Manufacturing and Design. HEIs in the audit region have received £248m of research income in this area since 2004–05, representing 7.3% of the UK's total income. (Source: HESA research income 2004–05 to 2014–15 for cost centres 16, 21, 23, 115, 120 and 143). The University of Sheffield's Mechanical Engineering and Advanced Manufacturing submission to REF 2014 (Unit of Assessment (UoA)12) was ranked 7th of 25 by Grade Point Average (GPA) for outputs in the UK and included research groups covering manufacturing, structural health monitoring and solid mechanics. Lancaster University's General Engineering submission (UoA 15), ranked 22nd of 62 overall by GPA, included staff working on laser processing and additive manufacturing, whilst the University of Central Lancashire's submission, ranked 33rd by GPA on its outputs, includes staff working on digital and mechanical engineering.

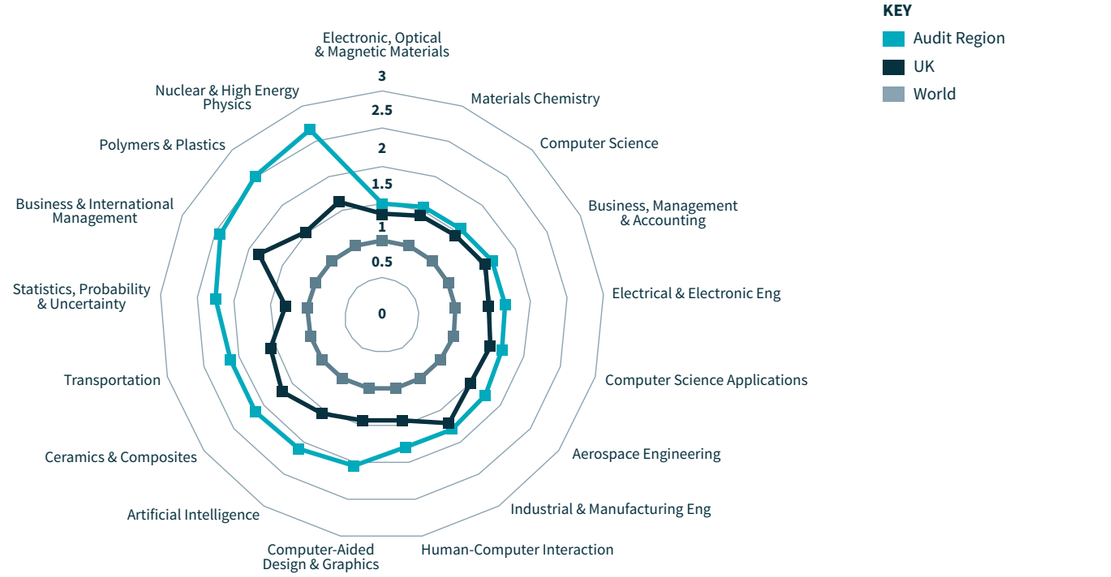


Figure 4.2 – Field Weighted Citation Impact by Subject Area.

[35] SciVal (Elsevier) for publications between 2011 and 2016 to date as at Aug 2016

The region accounts for 19% of RCUK funding in Mechanical Engineering and 20% of funding in Process Engineering. The University of Sheffield is also ranked 4th in the UK by value of current EPSRC projects falling in the Manufacturing Technologies research area.

The region's publications in Industrial and Manufacturing Engineering between 2011 and 2016 outperformed the UK average with a Field Weighted Citation Impact (FWCI) score of 1.8, indicating that they are cited 80% more than the global average.

Robotics and Autonomous Systems, Machine Learning and Artificial Intelligence. The University of Sheffield's outputs in this area were ranked 1st of 62 in the UK by GPA in REF 2014 (UoA 15). The region's publications in Artificial Intelligence have an FWCI score showing they are cited 2.23 times more than the average for similar publications. The University of Sheffield also ranks third by value of research funding from EPSRC in its current portfolio in the Artificial Intelligence Technologies research area.

New, smart and functional materials. The University of Sheffield's outputs were ranked 9th of 37 in the UK by GPA in REF 2014 (UoA 13 for Materials Science & Engineering). The region's publications outperform the UK average in Polymers and Plastics (FWCI 2.92), Ceramics and Composites (FWCI 2.08) and Electronic, Optical and Magnetic Materials (FWCI 1.4). EPSRC's current portfolio ranks the University of Sheffield for the value of awards 2nd for Materials Engineering – Metals & Alloys and 3rd for Polymer Materials. Data from the RCUK Gateway to Research shows that the region accounts for 14% of RCUK funding in Materials Sciences. Submissions in Chemistry, with substantial proportions of staff working on materials science, were also well-received in REF 2014, with the University of Sheffield and Lancaster University ranked 8th and 10th of 37 respectively by GPA for their outputs (UoA 8).

Virtual reality, internet of things, cloud computing and large scale data analytics. Research funding data from RCUK's Gateway to Research shows that more than £21m has been awarded to the region in Information and Communication Technologies between 2010 and 2015. The University of Sheffield's and Lancaster University's outputs in Computer Science & Informatics (UoA 11) were ranked 7th and 12th of 89 respectively in the UK in REF 2014. Lancaster University was ranked 5th of 53 in the UK overall for Mathematical Sciences (UoA 10), where Statistics make up the majority of staff submitted and the region's publications in Statistics, Probability and Uncertainty between 2011 and 2016 have a FWCI score of 2.62, well above the UK's score of 1.30. Lancaster is also ranked 3rd in the UK for EPSRC funding in the Statistics and Applied Probability area.

New business models, new working practices and entrepreneurship. Lancaster University was ranked 1st of 101 in the UK by overall power in Business and Management Studies (UoA 19) in REF 2014, with the largest number of staff submitted to this UoA of any UK institution. Citation scores for Business and International Management (2.97 for Lancaster, 2.74 for the University of Sheffield) and Strategy and Management (Lancaster 2.14) and Management of Technology and Innovation (Lancaster 2.24) are particularly high compared to the UK scores (1.86, 1.84 and 1.93 respectively). Lancaster University also account for 51% of EPSRC's current portfolio in Mathematical Aspects of Operational Research.

4.3 Research underpinning sector specialisms: Aerospace, Healthcare and Energy (Nuclear)

Aerospace: the University of Sheffield's REF results for Aeronautical Engineering and Materials Science are detailed above. The region's publications in Aerospace Engineering have an FWCI of 1.76, well above the UK average of 1.5.

Healthcare: the University of Sheffield was ranked 5th of 94 in the UK by GPA for outputs in Allied Health Professions, Dentistry, Nursing and Pharmacy and 11th in Clinical Medicine. Sheffield Hallam University, the University of Central Lancashire and Edge Hill University were ranked 8th, 26th and 27th of 51 respectively by power for their submissions including Sport and Exercise Sciences in UoA 26. Sheffield Hallam's submission in Art and Design (UoA 34) was ranked 8th of 84 overall in the UK by GPA, with a significant proportion of the submissions relating to design in heathcare and wellbeing applications. The region also accounts for 22% of RCUK funding at the Medical & Health interface, while Science and Engineering and HESA data shows that the region accounted for 15.3% of UK academia's research income in Health and Community Studies in 2014–15.

At Lancaster University, the whole Faculty of Health and Medicine entered into a single unit of assessment, namely Allied Health Professions (UoA 3). The Faculty of Health and Medicine achieved a perfect 100% 4* rating for research environment, and were ranked 3rd of 94 in the UK for intensity weighted GPA.

Energy: the region currently holds £25m of research awards in EPSRC's Energy theme (with particular representation in nuclear waste, carbon capture and storage, and energy storage) and its FWCI score of 2.66 in Nuclear and High Energy Physics far exceeds the UK score of 1.62. The REF results detailed for engineering subjects above also have many elements contributing to energy applications.

4.4 Conclusions – what are the areas of particular research strength in Sheffield City Region and Lancashire?

This analysis reveals substantial strength in the SIA region in fields relating to the audit hypothesis. The overall scale of research activity across engineering is now very substantial and of national significance.

There is well established international excellence across many engineering and management disciplines, including automatic control and systems engineering, materials science (especially polymers and ceramics), design, artificial intelligence, and organisational behaviour. Forward looking metrics show a remarkable expansion in the scale of engineering research, with areas such as the medical & health interface with science and engineering emerging as strong on the national level.

For **engineering**, REF results and research grant funding suggest that the University of Sheffield is a leader in the UK and the citation results illustrate the impact of its outputs globally. In **business and management**, the large amount of high-quality research produced by Lancaster University is highlighted in the REF and citation results. For **health innovation**, REF results demonstrate good assessments across the region, with **sport and exercise science** particularly strong at Sheffield Hallam University, and the University of Sheffield taking one ninth of UK higher education's research income in **health and community studies**.

In conclusion, the Sheffield City Region/ Lancashire research base is strong, and well aligned to a specialisation in high value manufacturing, with most of the subjects that will be important underpinnings for Industry 4.0 well represented.

It is now timely to take a more holistic view of the region's innovation system, and examine the extent to which the necessary connections are in place to realise the benefit of this research strength in innovation and productivity growth.

Innovation strengths

The universities within the audit region are specialists at winning funding and investment for translational R&D, and have complementary strengths and experience in this area, and as a result have a combination of significant expertise in facilitating innovation in the private sector.

05

Within the audit region, there exists a combination of a) a particular set of drivers and opportunities, especially around Industry 4.0 and b) significant (in size, scale of investment and global relevance) innovation and research assets. Together these represent an opportunity to make interventions within manufacturing which will result in improvements to UK productivity. However, one question remains: is the audit region adequately prepared, and does it have the right culture, networks, people and experience to enable it to bring about the change? Crucially, we need to assess the degree of connectivity of the research and business base; the degree to which the region has a coherent innovation system. Are the institutions, mechanisms and networks for translation and skills development appropriately directed and of sufficient scale?

5.1 Metrics

As described in Chapter 1, the audit area outperforms the England average in two out of three significant indicators of innovation activity (firms engaged in product or process innovation, proportion of turnover from product or process innovation). However, overall business R&D intensity is very low.

This is discussed in more detail in Chapter 2. The Higher Education Business and Community Interaction (HEBCI) survey benchmarks UK Universities' external relationships using income as a proxy for interactions, see Table 5.1. As with the research and innovation assets in the audit region, there is a complementarity of expertise. Sheffield is a sector leader in combined contract and collaborative R&D, ranking 5th behind Imperial, UCL, Cambridge and Manchester Universities. Lancashire LEP area is a sector leader in the provision of HE consultancy services, with an income of more than £8m per year representing significant expertise in SME engagement especially.

For these projects, Lancaster University and the University of Central Lancashire are ranked 4th and 6th respectively for the value of their projects with SMEs, with a total of £8.4m income (Table 5.2). SME engagement is also a strength at the University of Sheffield, which has consistently been in the top three UK universities by number and value for delivery of Knowledge Transfer Partnerships (KTPs) over the past ten years. In total, the audit region has delivered 1673 KTPs worth £13.5m over this period[37]. Lancaster is also a sector leader (1st) in the UK for regeneration and economic development programmes, with £32.4m income in the year 2014/15.

	Contract R&D (fully funded by the partner)				Collaborative R&D (funded in part by the public sector)	
	SMEs		Large Enterprises			
	Value (£k)	UK rank	Value (£k)	UK rank	Value (£k)	UK rank
University of Sheffield	2,426	4	15,581	7	53,399	4
Lancaster University	262	39	989	43	18,471	27
University of Central Lancashire	32	76	309	75	3,262	57
Sheffield Hallam University	89	62	301	76	4,464	47
Edge Hill University	–		13	111	–	–

Table 5.1 – Commercial Contract and Collaborative Research (academic year 2014–15).[36]

	Consultancy (SMEs)		Consultancy (large enterprises)		Economic development and regeneration	
	Value (£k)	UK rank	Value (£k)	UK rank	Value (£k)	UK rank
Lancaster University	6,439	4	183	68	32,357	1
University of Central Lancashire	1,954	6	117	76	1,681	32
University of Sheffield	379	36	1,482	21	1,920	27
Sheffield Hallam University	325	38	850	33	534	55
Edge Hill University	39	91	93	80	54	93

Table 5.2 Commercial consultancy and regeneration income.[38]

[36] HEBCI data provided by HESA (HEIDI) for academic year 2014–15

[37] https://www.gov.uk/government/publications/innovate-uk-funded-projects

[38] Source: HE-BCI data provided by HESA (HEIDI) for academic year 2014–15

5.2 A place-based approach: Innovation Districts

Innovation Districts have proven to be effective solutions for cities to modernise their economies and evolve from traditional industrial-based production to technology-driven services[39] (Figure 5.1).

Both LEP areas within the audit region are working together to build on the assets described in Chapter 3 and are specifically focusing on a 'whole-place' approach to transforming the collection of assets within and between the regions into fully functioning innovation districts, with an emphasis on high value manufacturing.

5.2.1 Economic assets: ability to win funding and investment

A detailed breakdown of recent public and private sector investment in innovation assets is detailed in Chapter 2, and relevant research detailed in Chapter 4. Because of their outstanding performance, both universities receive the maximum HEIF allocation. The universities within the audit region are specialists at winning funding and investment for translational R&D, and have complementary strengths and experience in this area, and as a result have a combination of significant expertise in facilitating innovation in the private sector. Because of this, considerable practical expertise has been built up in delivering public/private sector projects at scale. A large proportion of the investment won has been to deliver SME focused innovation projects, which has placed both Sheffield and Lancaster as leaders in the provision of SME support (as detailed in Tables 5.1 and 5.2). Further detail of income to the universities in the audit area, by funding type, is set out in Table 5.3 below.

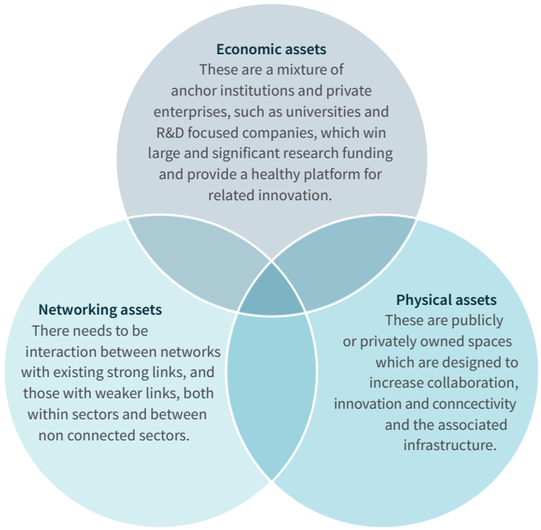


Figure 5.1: Innovation District Theory.

Funding stream	Consortia 5 yr income total	Highlights
Innovate UK.	£112.6m (19.6% of UK academic total)	Sheffield University is sector leader, ranking 1st for total value of Innovate UK funding, and 1st for collaborative R&D funding. It consistently ranks in the top 3 for KTPs. Sheffield hosts 2 HVM Catapults and a satellite of the Transport Systems Catapult Above-average Innovate UK funding for Energy and Advanced Manufacturing projects (Audit Region)
ESIF	£41.6m (9.4% of UK HEI total)	Lancaster University was ranked first in the UK for income in regeneration projects (£32.4m in 2014–15). Both regions have considerable experience and assets relating to ESIF funding and a strong track-record of cross-HE collaboration.
RPIF	£10m from HEFCE (2% of UK total) (£24m pipeline)	Factory 2050 Lancaster's Advanced Joining Technologies Centre project with TWI (£40m) has gained full approval at outline and the university has been invited to submit a full proposal by 16 December 2016. Sheffield's Steel Research Centre bid (£24m RPIF + £50m private sector) has gained full approval without conditions and the University has been invited to submit a full proposal by 16 December 2016.
HEFCE Catalyst	£20.7m from HEFCE (14% of UK total)	Including £20.5m to deliver translational research programs at Lancaster University, University of Sheffield and Sheffield Hallam University.
HEIF	£33.7m (4.4% of UK total)	In 2015/16 the University of Sheffield and Lancaster University both received maximum HEIF funding.
Private Sector	£176.6m (3.9% of UK total)	University of Sheffield ranks 5th in combined contract and collaborative research income University of Lancaster and UCLan have particular expertise in the provision of consultancy (4th and 6th respectively).

Table 5.3: Summary of innovation income, 5 year totals to the audit region.[40]

Commercialisation and IP development. All the universities in the audit region have well-developed approaches to maximising the commercialisation of intellectual property. In 2013/14 the region's university income from IP was £3.4m, rising to £4.7m in 2014/15[41]. EPO PATSTAT[42] data shows that the region has an overall share of 3% of total patents submitted by UK inventors. Areas in which the share is higher in the region include engines, pumps and turbines, mechanical elements and machine tools. The University of Sheffield is about to launch a new model of technology transfer activity which has partnerships at its centre, using IP as a tool to underpin the engagement and moving away from a purely patent/spinout view of commercialisation of IP. Whilst the AMRC model has been highly successful with multinationals and larger companies, a specialist fund will be set up to enable engagement with innovative SMEs as part of this partnership model.

5.2.2 Physical assets

The physical innovation assets within the audit geography are significant and have largely been set out in Chapter 3. Both LEP areas have a current focus on the physical development of Innovation Districts which focus on supporting advanced manufacturing industries. Consortium partners are currently not bound by LEP boundaries and best practice from both Sheffield and Lancaster is being shared already in the development of these Innovation Districts (see NWAMRC description below).

Advanced Manufacturing Innovation District, Sheffield City Region. An advanced manufacturing innovation district (AMID) is being developed around the Advanced Manufacturing Park (AMP), with the AMRC Group at its nucleus. As well as the AMRC assets listed above and in Chapter 2, the Technology Centre at the AMP houses more than 40 innovative and fast growing companies from the advanced engineering, manufacturing and environmental energy sector, including a number of design engineering and solutions companies. Also located on the same site are TWI, EEF and global companies such as Rolls-Royce and Sandvik Coromant.

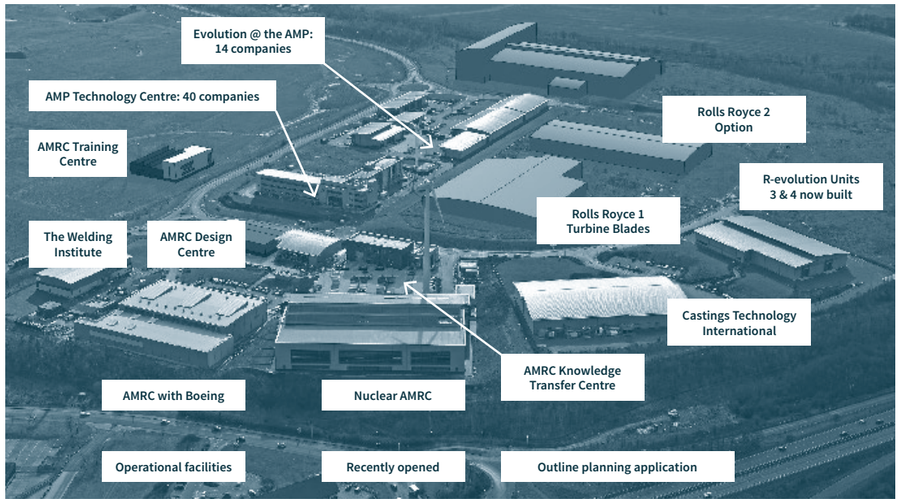


Figure 5.2: The UK's 1st Advanced Manufacturing Innovation District, Sheffield City Region

[39] Katz B and Wagner J The Rise of Innovation Districts: a New Geography of Innovation in America, Brookings 2014

[40] Sources: Innovate UK: Innovate UK funded projects to 7 July 2016. https://www.gov.uk/government/publications/innovate-uk-funded-projects, ESIF: ERDF &ESF Income reported to HE-BCI 2010–11 to 2014–15, HESA (HEIDI), RPIF: Funded projects rounds 1 to 4, http://www.hefce.ac.uk/rsrch/ukrpif/projects/, HEFCE catalyst: http://www.hefce.ac.uk/funding/catalyst/projects/ (excluding Police Knowledge Fund, for which funding values are unavailable), HEIF: allocations for 2011–12 to 2014–15 and 2015–16 from http://www.hefce.ac.uk/kess/heif/, Private Sector: Commercial income in contract research, consultancy, intellectual property, CPD courses, and use of equipment and facilities from HE-BCI for 2010–11 to 2014–15 (Source; HESA, from HEIDI).

[41] HESA HEBCI data 2014/15

[42] ECO PATSTAT, 2004–2013

The nucleus of the AMID is a 2000 acre site in the heart of the UK within the Sheffield/ Rotherham economic corridor, where there is an intensity of advanced manufacturing and technology firms and which has seen a highly successful long term renewal since the turn of the century (Figure 5.2). It will be built to bring together the science and innovation assets described in earlier Chapters 2 and 4, and is underpinned by a single masterplan for the area which is being developed with multiple Local Authority, private and public sector stakeholders. It will link to the Lancashire LEP area through the development of NWAMRC and more specifically through digital links to Factory 2050.

The North West Advanced Manufacturing Park, Salmesbury Enterprise Zone (EZ). (See further detail in Annexe 4). In Lancashire, the BAE Systems Salmesbury site is developing as an Innovation District. Existing BAE Systems engineering and manufacturing operations have generated major employment opportunities and brought important investment into the area for many years. The EZ site has the potential to build on these strengths, an already thriving aerospace supply chain cluster and skills infrastructure to attract new investment delivering strategic economic benefits. The North West Advanced Manufacturing Park (NWAMP) will enable Lancashire to maximise opportunities for high growth manufacturing companies. The NWAMRC is being developed as an industry focussed centre of excellence for innovation, product development and manufacturing skills for Industry 4.0. Its focus is on aerospace, automotive and energy supply chain sectors, and it is a partnership project between the Universities of Lancaster and Sheffield, and founding industrial partners such as BAE Systems, Siemens, Cammell Laird, Starrag, Sandvik Tooling, Technicut, Dessault Systems, Renishaw, Hexagon Metrology. The funding for this development was recently announced, and it will build on the growing cluster of innovation assets in this region, including extending partnership to the UCLan Engineering Innovation Centre.

5.2.3 Networking assets

Both regions have well developed business networks relating to innovation, representing the focus sectors, as well as those relating to SMEs. However, given the need for enhanced diffusion (in terms of speed of diffusion, and breadth across sectors) of technology relating to the developments of Industry 4.0, there is a need to review how these networks are responding. Without attempting to provide a comprehensive list of all networking assets, detail of sector based networks and best practice found within the audit region is set out below.

5.2.4 Sector networks

Energy (nuclear). The Fit For Nuclear (F4N) programme, based at the Nuclear AMRC, helps companies measure their current operations against the standards required to supply the UK's new generation of nuclear power stations, and take the necessary steps to enter this £40bn market. It is designed to help UK manufacturers prepare for the huge global business opportunities in nuclear new-build.

Aerospace. The AMRC is a highly successful model for university/business interaction, typically engaging with around 700 companies per year, of which around 400 are SMEs. The AMRC hosts a well-established quarterly manufacturing forum targeted solely at the region's manufacturers. **Northwest Aerospace Alliance (NWAA)** represents approximately 25% of the UK aerospace industry with more than 240 member companies with a combined turnover in excess of £7bn and workforce of over 26,000 and has delivered over £20m of supply chain improvement programmes.

BAE Systems (Operations) Ltd, in conjunction with Lancaster University, is building on the University's flagship leadership and management programme, LEAD, to nurture the innovation capacity of SME owner-managers, in the advanced engineering and manufacturing sector, in the North West of England. The initiative will develop strategic thinking, innovation capacity and leadership and management skills through masterclasses, workshops, innovation challenges and action learning groups, as well as supporting access to regional and national innovation infrastructure, such as the proposed NWAMRC at Samlesbury/ Warton, Lancashire. The project should improve SMEs' capacity for innovation as well as explore how to encourage SMEs to gain a better understanding of, and ability to exploit, market opportunities.

Transport (rail, automotive). The Northern Automotive Alliance (NAA) has 80 full member companies, 120 cluster members and a further 760 members in regular communication from across the North West and Yorkshire & Humberside areas and provides networking, signposting, training and project management. Doncaster Rail Partnership was formed by national and international companies in the rail sector, brought together to support Doncaster's bid to host the National College for High Speed Rail, and continues to take advantage of the new opportunities that HS2 offers for industry consortia. The Rail Partnership has grown rapidly to 100 members including Hitachi, Wabtec, Unipart, Rhomberg Sersa, Amey, Schwihag, Pandrol, Hird Rail, TTS, Volker, DB Schenker, Progressrail, EM Diesel, SPL Powerlines, Carillion and HS2. As a direct result of this network the exterior track facility at the Doncaster Rail College will be supplied and installed by a consortium of local suppliers working together: Rhomberg, Schwihag, Volker and Pandrol.

5.2.5 SME networks for innovation

Lancaster Management School (LUMS) has been running the Lancaster Forum for more than 10 years, regularly bringing together senior managers from growth-oriented regional businesses and drawing audiences in the hundreds from across the North West's SME networks.

Managing Directors' Club. The University of Sheffield and Sheffield Hallam University collaborate in promoting the exchange of knowledge and ideas and stimulating future partnerships through membership and networking opportunities at the Managing Directors' Club (www.mdclub.org.uk). Quarterly events attract up to 100 attendees from industry and both universities. Membership extends to more than 400 companies predominantly in materials manufacturing and engineering.

5.2.6 International networks

A number of formal and informal structures exist to facilitate networking between HE institutions and industry in the UK and overseas. China is considered to be a particularly important partner across the audit region; the University of Sheffield currently has over 3,000 Chinese students and an alumni network of over 11,000. Its Confucius Institute has twice been awarded the title 'Global Confucius Institute of the Year' and is seen as a worldwide exemplar in its work with schools and the public, and in outreach to the business community. There are a number of research collaborations, such as the Joint Research Centre for Wide Band-Gap Semiconductor Optoelectronics with Nanjing University. The University is a member of the 'Sheffield City Region China Business Incubator' (SCRCBI) supporting the New Era Development (NED) – a gateway to enable Chinese enterprises to invest in the Sheffield City Region, and a regional hub for intelligence and network sharing for local enterprises doing business with China.

The £5.1m Lancaster China Catalyst Programme was created by Lancaster University in 2014 with initial investment from the Higher Education Funding Council for England (HEFCE) and Lancashire County Council to support to UK companies to develop partnerships with businesses in China. The programme takes participants on a competitively focused, phased journey from initial investigation of the Chinese market to active collaboration with Chinese business partners on commercialisation projects. Key partners include the Guangdong Provincial Department of Science and Technology, the Chinese Academy of Sciences, UK Trade and Investment, China-Britain Business Council, and Innovate UK.

Established industrial capacity & growth points

With the widespread adoption of Industry 4.0 principles, and the realisation of the need to appropriate more of the value chain, a number of key supporting sectors will need to expand. Product design, software and data analytics, logistics and professional and technical services will grow in importance and in their contribution to the overall productivity of the region.

06

6.1 Introduction

This chapter summarises the industrial capacity of the audit region, concentrating on high value manufacturing. This analysis draws largely on existing work (particularly the Northern Powerhouse Independent Economic Review, which itself drew on extensive previous work carried out by the two LEPs), supplemented by a consultation of key industry representatives, described in more detail to read in Annexe 5.

This programme of primary research comprised in-depth consultations with 20 major advanced manufacturing firms active within the two sub-regional geographies. This work has helped to promote and champion existing growth plans, identify cross-sectoral synergies, common challenges and opportunities. This chapter begins by summarising a data-driven analysis of the existing principal sector strengths of the two LEP regions in the context of the wider Northern economy and subsequently distils the key common messages from the consultation.

6.2. Sector strengths in the audit region

The Northern Powerhouse Independent Economic Review carried out a combination of top-down and bottom-up analyses of sector strengths across the North, based on both quantitative indicators and assessments of regional strategies. For our audit region, the sector strengths are summarised in Table 6.1 below[43].

6.3 High value manufacturing and Industry 4.0

We take high value manufacturing to encompass any manufacturing activity whose ability to create value is protected by high barriers to entry from lower cost competitors, through tough safety and regulatory requirements, through being highly knowledge intensive, and through being part of a complex supply chain delivering to customers who have to meet such demands.

These requirements are met by some of the key sectors for our region – particularly aerospace, nuclear, and medical technology. These are examples of sectors that are already early adopters of Industry 4.0 principles, although manufacturers in all sectors will be under pressure to adopt these to remain competitive.

With the widespread adoption of Industry 4.0 principles, and the realisation of the need to appropriate more of the value chain, a number of key supporting sectors will need to expand. Product design, software and data analytics, logistics and professional and technical services will grow in importance and in their contribution to the overall productivity of the region.

Industry agree that a wider incorporation of the principles of Industry 4.0 is key to the growth of high value manufacturing sectors in the region.

Sheffield City Region	Lancashire LEP area
Advanced manufacturing and materials – incl. high precision engineering, metals, rail, automotives and aeronautical engineering, manufacturing services	Advanced manufacturing, esp. aerospace, automotives
Healthcare technologies – medical devices, advanced wound care, orthopaedics, clinical	Energy – offshore wind, nuclear
Digital/computing – programme engineering, software, analytics, data processing	Chemicals
Low carbon – nuclear research	Legal/accountancy
Logistics	Tourism

Table 6.1: Sector strengths

[43] Northern Powerhouse Independent Economic Review Workstream 3: Competitive Advantage and Sector Strengths – Final Report.

6.4 The key sectors for high value manufacturing in the audit region

6.4.1 Aerospace

Aerospace is a historical strength in Lancashire, which now holds the greatest concentration of aerospace production in the UK. Around 20,000 people are employed in 120 companies, including major players such as BAE Systems, Rolls-Royce and Safran-Aircelle, and supply chain companies such as Kaman, Assytem and Spirit Aero Systems. Lancashire sites are contributing roughly £6bn of output to the F35 fighter jet programme, which is the UK's single largest trade contract.

Lancashire's key capabilities include the design, testing, manufacture and assembly of aerospace components, with large employers and a tightly integrated supply chain feeding into those larger companies. Sheffield City Region has complementary strengths in the application of advanced manufacturing R&D, especially in terms of the development of new products and processes within the aerospace sector, building on the critical mass of world-leading R&D relevant to the aerospace sector centred around the Advanced Manufacturing Park, which includes the AMRC, Sheffield's universities and partner industries (including Boeing and Rolls Royce).

BAE Systems has a national and international supply chain supported by a local ecosystem of suppliers based in and around Lancashire. BAE's average procurement spend for the Eurofighter Typhoon in the North West is almost £25m, and spending in Preston by all of BAE's business units was £165m in 2013. Key suppliers include Lancashire-based Kaman Composites UK and Magellan Aerospace (in Blackpool), which specialises in components and assemblies for aero-structures and landing gear.

For Boeing, a number of UK capabilities support the development of the 787, some of which are sourced from suppliers in the SCR (e.g. Rolls-Royce provides engines, AMRC provides research in manufacturing). In addition, some of Boeing's top UK suppliers sub-contract activity to SCR-based businesses. For example, Rolls-Royce and Messier Dowty sub-contract inputs from AML Sheffield (expertise in machining technology) and Alcoa Sheffield (expertise in forging and extrusion), and UTC Aerospace Systems in Wolverhampton sub-contracts to AML Sheffield.

6.4.2 Health technologies

The Sheffield City Region has a well-established health technologies sector, producing a GVA per employee of £47k pa, involving companies such as B. Braun, JRI Orthopaedics, Swann-Morton and Sheffield Precision Medical. Specialisms in medical (and dental) devices, advanced wound care, orthopaedics, and clinical research build on the region's wider specialisms in materials and high quality precision manufacturing.

Many of the companies already employ advanced digital production techniques, including computer-controlled manufacturing, computer-modelled quality assurance, and digital print manufacturing of materials. The nascent sub-sectors of telehealth and additive manufacture/3D-printing offer high productivity opportunities for the future, exemplifying many of the principles of Industry 4.0. In Lancashire there are strengths in innovative materials for the medical sector (such as anti-microbial treatments and intelligent textiles) which have clear complementarities with the SCR offer. Supply chains are tightly regionally integrated. For example, the three largest suppliers of JRI Orthopaedics, an innovative medical technology company based in Sheffield, are Symmetry Medical, Sheffield Precision Medical and Orchid. These companies are also Sheffield-based.

6.4.3 Energy (nuclear)

Nuclear is a potentially important growth sector for the region; there are four advanced gas cooled reactors in Heysham, operated by EDF, while Westinghouse's large Springfield nuclear licensed site in Lancashire (the first plant in the world to produce fuel for a commercial nuclear power station) gives the area the capability to manufacture fuel for all major designs of nuclear reactors.

The SCR has specific expertise in designing, testing and manufacturing internationally unique and often very technically challenging components for the nuclear sector, through companies such as Sheffield Forgemasters. The Nuclear AMRC gives the SCR large scale testing capabilities, together with new material development and process improvements, drawing on computer modelling capabilities.

The supply chains have a strong regional dimension. In 2014/15, the Westinghouse Springfields site spent more than £100m with some 800 suppliers. Most of Forgemasters' inputs are sourced from within the SCR.

6.4.4 Transport (rail and automotive)

The audit region is home to some key rail businesses and many smaller-scale specialised manufacturing companies who supply products and services to the larger firms. Key capabilities include the production and repair of rail equipment – drawing on the area's reputation for the manufacture of high tech products, processes and materials that can be applied to the rail industry – as well as expertise in technical support, and the design and management of infrastructure schemes.

Alstom's Preston site sources directly, usually within the UK, to deliver long-term service contracts. Its key suppliers include William Cook, a specialist supplier of steel castings to the rail and other industries, based in Sheffield and Leeds. Most of Doncaster-based Schwihag UK's suppliers are located in the SCR or nearby. For example, it sources steel from Scunthorpe and gets the casts for its rail plates from foundries in Sheffield and Nottingham.

The South Ribble region of Lancashire is the nucleus of an automotive cluster providing 4,000 jobs across the region. Key employers include PACCAR (Leyland Trucks), Sanko-Gosei, and Erlson, supported by an extensive supply chain (particularly in Burnley). Key strengths include the design and manufacture of vehicles and component parts for the automotive industry, including high value parts for European Original Equipment Manufacturers (OEMs) Aston Martin, and Bentley.

6.4.5 Supporting sectors for Industry 4.0

The high value manufacturers of the audit region have attracted some small but growing clusters of high value manufacturing services firms to support their activities. For example, the Lancashire automotive sector has attracted design and development companies such as Torotrack, Clean Air Power and Scorpion Automotive, while Sheffield's Advanced Manufacturing Innovation District hosts companies such as Performance Engineered Systems, supplying contract design and R&D to HVM sectors such as aerospace and automotive. The logistics sector is important for the Sheffield City Region due to its strong strategic location, with multimodal access (rail, road, air and links to ports), and international firms such as Amazon, ASOS and TNT. Logistics is a large employer (28k jobs), but the sector has typically had low productivity. However, with the emphasis on internationalisation in markets and supply chains, specialised logistics is likely to be a significant enabler for Industry 4.0 in the region's manufacturing base, as well as a significant component of the regional economy in its own right.

6.5 Growth opportunities for high value manufacturing in the Sheffield City Region and Lancashire

There was widespread consensus from industry respondents to our consultation that a wider incorporation of the principles of Industry 4.0 was key to the growth of all high value manufacturing sectors in the region, with wider adoption of automation and robotic systems in particular being associated with the potential to accelerate process improvement and drive up business productivity.

In aerospace, the fundamental drivers remain the rapid international growth of markets, fuelled by increasing demand for air travel and the need for modern aircraft in both civilian and defence sub-sectors. As a result, opportunities lie in the processing of inputs, advanced/lightweight/high-integrity materials, and expertise in how best to exploit these. A specific opportunity for Lancashire lies in its potential to become a centre of excellence for Unmanned Aerial Vehicles (UAVs) in the future. The 'Taranis' semi-autonomous Unmanned Aerial Vehicle (UAV) was developed by BAE Systems at their Warton site.

In medical technologies, the drive is to design 'whole system solutions' that offer clients healthcare products and packages (i.e. of components, tools etc.), very much in line with broader Industry 4.0 trends to capture more of the value chain by blurring the lines between products and services. Cost pressures on health systems are severe, putting a premium on developing high quality medical instruments at lowest possible cost, which requires innovation in automated/advanced manufacturing technologies. There is also huge international demand for medical equipment and technologies, particularly in large countries with ageing populations (e.g. China). These are all drivers for the planned Health Innovation Campus at Lancaster (Annexe 2) and there are significant opportunities for greater cross-regional collaboration with key assets such as the Medical AMRC at Sheffield.

In rail, the pressure to use infrastructure more effectively in an environment of growing capacity constraints suggest a greater role for digital platforms and big data, while the need to improve energy consumption and utilisation will ensure the development of new lightweight materials and the processes required to manufacture them.

Nuclear presents a major growth opportunity for the SCR, Lancashire and the North more broadly, especially in the development of new generation plants (e.g. Moorside) as the nuclear new build programme progresses. Substantial work has already begun to build supply chains that involve regional companies through the Nuclear AMRC's Fit for Nuclear programme.

One particularly exciting possibility concerns the development of a new generation of Small Modular Reactors (SMRs). SMRs are attracting considerable attention as a way forward for civil nuclear worldwide. They offer the promise of savings in capital costs through the application of advanced manufacturing techniques and learning-by-doing process improvements in a controlled, factory environment. Westinghouse's analysis has concluded that most of an SMR supply chain is accessible to the UK, with several specific suppliers in the Northern Powerhouse well positioned to exploit this growth opportunity.

Whatever design of SMR emerges as a contender for a UK manufacturing programme, the area is believed to have the manufacturing and ancillary expertise to be a first mover in SMRs. For example, opportunities exist to significantly reduce manufacturing lead times by using advanced manufacturing techniques such as advanced welding, advanced non-destructive examination, portable machining for critical safety-related components, powdered metal hot isostatic pressing, and various additive manufacturing technologies. A study by NAMRC indicated that whilst the UK had the capability to respond to global opportunities (e.g. large forgings, advanced manufacturing techniques), supplier capacity could be the limiting factor if several reactors were to be ordered simultaneously.

6.6 Industry perspectives on barriers to growth for high value manufacturing in the Sheffield City Region and Lancashire

Respondents to the consultation from all manufacturing sectors agreed that the key barriers to the region exploiting these potential opportunities were shortages of key skills and lack of industry innovation capacity.

There is a need to ensure that the engineers of the future are fully equipped with the right skills to work in an Industry 4.0 setting. This will include increased training for engineering students in digital skills such as visualisation, and promoting this emerging side of the engineering industry to digital graduates who would otherwise go down more established pathways, using their skills in the games sector etc. As highlighted by the Lancashire LEP Sector Skills Baseline Study for advanced engineering and manufacturing, replacement of an ageing workforce will become increasingly pressing.

There is also concern about gaps in leadership and management in the sector, to enable businesses to compete in international marketplaces. Other skills issues include difficulties in finding individuals with language and engineering skills, and engineers with marketing skills.

There is a need to ensure that the engineers of the future are fully equipped with the right skills to work in an Industry 4.0 setting.

National & international engagement

The geographical scope of the region's leading companies goes well beyond the region too. For national and multinational companies, facilities in the region are just part of their own much wider footprint, and many SMEs will be involved in international supply chains.

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7.1 The need for connectivity

Innovation is international, and the overwhelming majority of knowledge that is needed to underpin the manufacturing ambitions of Northern England will be generated outside the region. The assets assessed so far in this audit are vital in building the region's absorptive capacity for innovation, but they must also crucially be connected to national and international facilities, talent and networks.

For fields of research in which the region is strong, access to these national and global networks are essential to maintain competitiveness in fast-moving areas. Likewise, in those fields where the region has national and international leadership, this needs to benefit not just the economy of the region, but also the rest of the country. Internationally outstanding institutions such as the AMRC are national assets, not merely regional ones.

The geographical scope of the region's leading companies goes well beyond the region too. For national and multinational companies, facilities in the region are just part of their own much wider footprint, and many SMEs will be involved in international supply chains. However, the importance of international trade, and competitiveness within global markets, is going to be of increasing importance for the manufacturing ambitions of Northern England. There is much evidence that companies of any size that operate internationally have significantly higher productivity due to the competitive pressure and exposure to international best practise that this brings.

7.2 Regional and national engagement

The region's research base is involved in a range of large-scale formal collaborative structures, as well as a large number of smaller national and international collaborations.

Together these add up to deep engagement with national and international research systems, as the following examples demonstrate. They represent only a small sample of an extensive range of collaborations in research and research training between Lancashire and Sheffield City Region institutions and the rest of the country. A measure of the total scale of this collaboration can be seen in Table 7.1, which demonstrates that the majority of research projects involve collaboration outside the region.

7.2.1 Catapult centres

The University of Sheffield's Advanced Manufacturing Centre with Boeing and Nuclear Advanced Manufacturing Research Centre are both core members of the High Value Manufacturing Catapult. This consists of 5 other members: the Advanced Forming Research Centre near Glasgow; the National Composite Centre at Bristol; the Manufacturing Technology Centre near Coventry; the Warwick Manufacturing Group; and the Centre for Process Innovation, which has sites in Teeside and the Northeast. The NAMRC is itself a partnership between the University of Sheffield and the University of Manchester. Professor Keith Ridgway, Executive Dean of the AMRC group, is also Executive Chair of the Advanced Forming Research Centre, University of Strathclyde.

Collaboration	None	Only regional	Outside region
Number of research projects	895 (21.7%)	20 (0.5%)	3204 (77.8%)

Table 7.1 – Number of UK Research Council and Innovate UK research projects starting since 2010 with participation from the audit region, by extent of collaborating partners.[44]

[44] RCUK Gateway to Research.

7.3 Regional university consortia with a research focus

Collaboration between Northern research universities, including the University of Sheffield and Lancaster University, is formalised through the N8 collaboration. The universities share the use of expensive research capital, for example the High Performance Computing Centre. Large scale collaborative research programmes have begun in areas such as Agritech and Policing. The University of Sheffield works with Leeds and York in the White Rose Partnership, which is particularly active in creating joint postgraduate research programmes.

7.3.1 Materials

The University of Sheffield is a founding partner in the Sir Henry Royce Institute for Materials Science, currently being established. This is based at the University of Manchester, with other partners at the Universities of Leeds, Liverpool, Cambridge, Oxford and Imperial College; Sheffield takes a lead role in materials for manufacturing. The University of Sheffield and Manchester University collaborate in the EPSRC-supported Centres for Doctoral Training in Advanced Metallic Systems, and both Sheffield and Lancaster are partners in the Next Generation Nuclear CDT, based in Manchester. EPSRC Centres for Doctoral Training have proved to be very effective ways of cementing collaborations between HE institutions across the country and industrial partners. A complete list of CDTs involving HE institutions in our region is in Annexe 2.

Innovation in 2D materials such as graphene has its world centre in our neighbouring region, Manchester. However, Lancaster is a partner with Manchester in the Graphene NOWNANO Centre for Doctoral Training. Both the University of Sheffield and Lancaster University are partners in the EU Graphene Flagship project, which brings together 150 industrial and academic partners in 23 countries across Europe. The UCLan EIC is also partnering with engineering and advanced materials initiatives and facilities in Lancashire and Greater Manchester to promote progression in terms of skills and technology development. UCLan and the University of Manchester are now developing a national technology road-map for the exploitation of graphene within the aerospace sector.

7.3.2 Cyber-security

Lancaster University is a key partner in the newly established PETRAS research hub. This is a consortium of nine leading UK universities which will work together over the next three years to explore critical issues in privacy, ethics, trust, reliability, acceptability, and security in the 'internet of things'. Funding for the hub includes a £9.8m grant from the Engineering and Physical Sciences Research Council (EPSRC) which will be boosted by partner contributions totalling approximately £23m. Lancaster takes a lead role in safety and security, and adoption and acceptability.

The UK's national institute for data science is the Alan Turing Institute (ATI), based in London. Lancaster University has extensive activity in this area through the interdisciplinary Data Science Institute, which holds one joint grant with the ATI, but given the importance of data analytics and machine learning for Industry 4.0 there is room for more formal and far-reaching partnerships between the ATI and institutions in our region, for example with the Data Science Institute and the machine learning and AI skills in the University of Sheffield's Department of Computer Science.

7.3.3 Health technologies

In the area of healthcare, both Sheffield and Lancashire participate in the pan-Northern £20m Connected Health Cities Programme of Health North, under the auspices of the Northern Health Science Alliance, a partnership organisation funded by University, Academic Health Science Network (AHSN) and NHS organisations. This programme will focus on bringing together data and people across health, social care and local government, voluntary, commercial and other public sector organisations.

7.4 International engagement in universities and research institutes

The region's universities are strongly international in character. Table 7.2 shows the numbers of overseas students in the region. More than 45% of research students are from outside the UK. This represents a significant flow of talent into the region, whether they stay to the direct benefit of the region's industry and research base, or return to their home countries, where they act as ambassadors for the region as their careers progress.

The five HEIs in the audit region have collaborated with 2550 partners in 49 countries in the EU Framework Programme 7 (FP7) and Horizon 2020 programmes. Their collaborations with 212 of these partners in 28 countries have extended to five or more projects. They have worked on research with a collective value of €1,935m, with grants relating to information and communication technologies making up 30% of FP7 funding. Amongst these, the University of Sheffield's INSIGNEO Institute is ranked 2nd in the world for its participations in the EU's Virtual Physiological Human scheme for In-silico Medicine.[46]

The international character of the University of Sheffield's Advanced Manufacturing Research Centre was stressed from the outset by the involvement of the American aerospace giant Boeing as the founding partner. Many more international companies have subsequently become involved, and in a recent development AMRC launched a new branch in Korea in collaboration with the Korea institute of Carbon Convergence Technology (KCTECH), Jeonju University and Jeonju City.

The £5.1m Lancaster China Catalyst Programme supports UK companies to develop partnerships in China. The programme takes companies on a competitively focused, phased journey from initial investigation of the Chinese market to active collaboration with Chinese business partners on commercialisation projects supported by students on a new Masters degree in international innovation, designed to cultivate the next generation of international entrepreneurs.

Student FTE (% of row)	UK	Non-UK EU	Outside EU
First degree	64,037 (87.1%)	2,179 (3.0%)	7,270 (9.9%)
Postgraduate Taught	7,137 (56.4%)	529 (4.2%)	4,983 (39.4%)
Postgraduate Research	2,507 (54.2%)	435 (9.4%)	1,684 (36.4%)

Table 7.2 – Student FTE by level of study and domicile for audit region for academic 2014–15.[45]

[45] Source: HESA (HEIDI), FTE for HE students by Domicile (basic) and level of study (4 detailed) for academic 2014–15

[46] FP7 and Horizon 2020 projects from CORDIS on the EU data portal (https://data.europa.eu/euodp/en/data) as at 14 July 2016

7.5 International engagement of firms in Lancashire and the Sheffield City Region

Figure 7.1[47] shows the total value of the UK's import and export trade in goods for the year ending March 2016.

Between 8–10% of businesses in the SCR regularly export (4,000 – 5,000 companies). The value of these exports is estimated to be around £6bn in goods and services exported from the SCR every year (approx one third Y&H total). The top five export markets for the SCR 2013–15 were USA, France, Germany, Australia, and UAE. In Lancashire, 4,000 companies (about 20% of total) regularly export, with a total value around £5bn. The main markets are USA, Germany, Saudi Arabia, France, and UAE.[48]

Many of the SCR and Lancashire's advanced manufacturing companies operate globally (e.g. BAE Systems, Nikken, Magnomatics and Unipart), although some (e.g. Volker Rail, Alstrom and B Braun) are UK subsidiaries of foreign-owned firms which are designed to primarily serve UK markets such as Network Rail and the NHS. The reach and strength of international relationships varies considerably. Some firms, for example, are well established in European and US markets and have recently expanded in South Africa, Australasia, Russia, and the Middle East; for others, the Middle East is their core market for exports. In addition to manufacturing fuel, Westinghouse's Springfields operations also provide conversion services for intermediate products such as uranium dioxide powder for overseas customers in Europe, Korea and Japan.

Where companies are exporting, this can include advanced manufacturing products and services, but a number of consultees also reported considerable export growth in expertise, knowledge and the demand for increasingly customised products. For example Forgemasters, 50% of whose revenues are generated through exports, are experiencing increased demand for plant and equipment design expertise from countries such as India and China; most of Magnomatics' international work involves collaboration to develop bespoke magnetic gearing products with large-scale international clients; and Nikken is finding that more international clients are seeking bespoke tool holding solutions, rather than off-the-shelf products.

A number of factors have enabled the SCR and Lancashire's businesses to access international markets. Given the growth in demand for customised products, the R&D capabilities of many businesses has been critically important. Linked to this, their ability to demonstrate access to world-leading research assets, alongside a breadth and depth of expertise in the area, to design and develop solutions for their clients is vital. The reputation and ability of businesses in the area to manufacture products at the highest possible quality has also been critical in accessing international markets. This is particularly important in safety critical products such as medical implants and the highly regulated healthcare sector, and components for the nuclear sector.

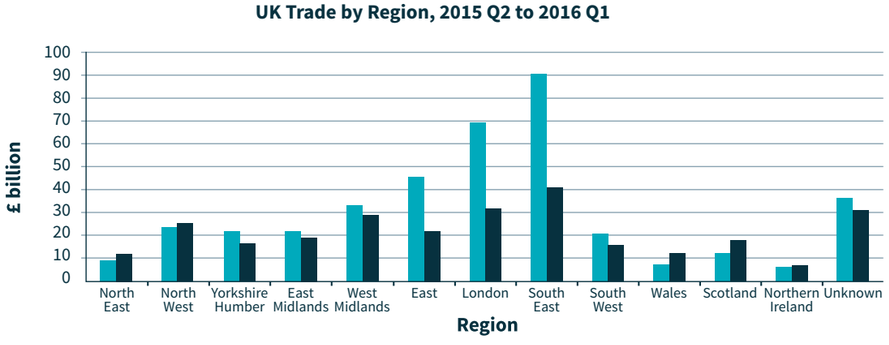

Figure 7.1 UK Trade by Region, 2015 Q2 to 2016 Q1

[47] Regional Trade Statistics HM Revenue and Customs

[48] Source: SCR and Lancashire LEPs

7.6 Conclusions – towards globally connected innovation

The research institutions in the Sheffield City Region and Lancashire are well connected to national and international innovation networks, bringing cutting-edge scientific knowledge and understanding to the regions. However, not all businesses in the region are similarly building wider connections in their customer base, despite clear evidence that the ability to operate as part of international supply chains is vital, not only in terms of export income, but also as a driver for productivity and competitiveness.

Support schemes which aim to help SMEs connect with international supply chains and global trade opportunities will be vital for creating a globally connected innovation manufacturing base in the region. Such schemes could build on existing successful programmes such as Lancaster University's China Catalyst programme or the Sheffield City Region's China Business Incubator.

Developments in national & international markets

Leading industrial multinationals such as Siemens and GE have declared that industry 4.0 is now a core part of their identity.

8.1 The impact of Industry 4.0

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The idea of Industry 4.0 was born in Germany, where there is already a high rate of engagement with the concept (e.g. BASF, Bosch, Daimler, Deutsche Telekom, Klöckner & Co. and Trumpf). Engagement is also growing in other countries such as the United States, Japan, China, and the Nordic countries. The UK is not currently seen as a big participant.

Leading industrial multinationals such as Siemens and GE have declared that Industry 4.0 is now a core part of their identity[49]. In 2015, PwC[50] surveyed more than 2,000 companies from 26 countries in the industrial production sectors, including aerospace and defence; automotive; chemicals; electronics; engineering and construction; forest products, paper, and packaging; industrial manufacturing; metals; and transportation and logistics. In this global Industry 4.0 survey, one-third of the respondents said their company had already achieved advanced levels of integration and digitisation, and 72 percent expected to reach that point by 2020. As a general view, across sectors, Industry 4.0 is impacting in the following ways:

A more dynamic marketplace. Faster, more responsive, and closer to customers. Production is distributed, with the development of large super factories and smaller reconfigurable factories including local mobile and domestic production sites. Digitised manufacturing supply and value chains bring customers into the design process, driving demands and opportunities around customisation and personalisation, and supporting the move to increased servitisation.

The creation of new markets. Reshoring becomes a reality as low cost economies become less competitive, domestic industry efficiency is increased, and business models improved according to customer need.

More sustainable and resilient production capabilities. Greater efficiencies naturally result in lower impact products. But more than that, digitisation leads to a more resilient and dynamic industry which can accommodate the uncertainties of climate change, an increasing regulatory burden and greater consumer pull for eco-products. The emergence of the circular economy and need to understand value chains through life cycle analysis is also accommodated.

Higher value jobs with mobility, and a dependence on highly skilled workforce. Skills are a crucial part of the implementation of Industry 4.0. There is a sustained demand for a highly skilled workforce. This presents a need for enhanced school and early career training, as well as a general upskilling of an ageing workforce. In particular, there is an increased demand for individuals with both highly technical skills and problem solving abilities. There are also opportunities for the development and use of human enhancement and augmentation capabilities.

[49] See for example: Siemens CEO Joe Kaeser on the Next Industrial Revolution, Strategy+Business, February 2016

[50] Industry 4.0: building the Digital Enterprise, PwC, 2016

8.2 Sector specific developments

8.2.1 Aerospace

The civil aerospace sector contributes £24bn to the UK economy annually, representing a 17% share of the global market. In 2015, the sector was responsible for exports worth £27bn. The latest BEIS Global Aerospace Outlook reflects a consensus that global demand for air travel will grow at around 5% year-on-year into the mid-2030s – a rate which has held steady for several decades. This compound growth rate would see the sector more than double in size over that period.

New aircraft must be greener, quieter and more economical to run than those they replace. This represents a great opportunity for the UK given our leading capability in complex, high value components and in emerging technologies. By 2034 it is estimated that more than 38,000 fixed-wing new passenger aircraft, worth US$5.5tn, will be needed; and in a similar timescale the global requirement for new helicopters is expected to be in excess of 40,000 units, worth circa $165bn. Demand for 9,000 business jets worth $267bn is also anticipated over the next ten years[51].

The National Smart Specialisation Strategy (NSSS)[52] and the National Aerospace Growth Partnership[53] agree that UK aerospace is number one in Europe and the largest aerospace industry outside the US. By 2031 the global civil aerospace market is estimated to be worth in excess of $5tn and for military air, the F35 programme alone projects a market value of a further $1tn. Approx. 25% of the UK's Aerospace industry and a combined turnover in excess of £7bn resides in and around the audit region. Lancashire alone hosts an estimated 13,200 aerospace jobs, representing 15.6% of the total manufacturing workforce in the LEP area, 14.6% of direct aerospace jobs in the UK and a total GVA of around £4bn. The sector performed well during the recent recession and is expected to grow, but the UK's position will be at risk without rapid adoption of substantially different manufacturing technologies, leadership and management techniques, and the enhanced productivity improvements that will follow across the supply chains.

8.2.2 Nuclear

Worldwide, 72 new nuclear reactors were under construction in 2014, while in the UK it is government policy to implement a programme of new nuclear build to help meet the country's energy security and carbon reduction needs, with currently 16GW new capacity at the stage of firm plans.

As part of a new approach to government innovation spending in low carbon energy, DECC (now part of BEIS) plans to invest £250m in an ambitious nuclear research and development programme. This includes a competition to identify the best value small modular reactor (SMR) design for the UK. The Government's interest in the potential benefits offered by SMRs was first set out in the Nuclear Industrial Strategy[54], published in 2013. In particular, SMRs may have the potential to enable shorter deployment times, reduce the costs of nuclear power for energy consumers, and present a possible area of high value opportunity for UK industry.

In 2014, the Government commissioned a feasibility study to assess the technical, economic and commercial case for the deployment of SMRs in the UK[55]. This indicated that "some SMRs were potentially viable within a 10 year timeframe and that they offered the possibility for the UK to engage in collaborations with vendors and UK industry" and establish technology leadership in this domain. The potential exists for the UK to become a global technology vendor in these fields, developing a supply chain which substantially engages British businesses. The study estimated a potential world market for SMRs of 65-85GW by 2035, valued at £250–£400bn. Mike Tynan, CEO of NAMRC, estimates[56] that the UK could capture 12GW of SMR by 2035 at a value to the economy of approx. £50bn.

This brings forward a significant opportunity for the audit region to develop a nuclear advanced manufacturing hub that supports the global nuclear industry; with Westinghouse in Lancashire a potential technology vendor and with the Nuclear AMRC in the Sheffield City Region ideally placed to support the development of the technologies and the development of supply chains.

8.2.3 Rail

The global rail market has been growing significantly and almost continuously since 2000. A growth rate of 2.7% per annum is predicted for the world's total rail supply market over the next six years. The total market will amount to approximately £128bn per year for 2017 – 19. According to data from the international railway union UIC, there are 15,790km of high-speed track under construction around the world. A further 35,061km are planned. If completed, this flurry of projects would more than double existing capacity.

In the UK, the Government has committed more than £70bn to improving road and rail transport infrastructure. Rail network upgrading and the £55bn HS2 project present enormous economic opportunities as well as challenges for skills and advanced manufacturing capabilities. Building on the Rail Technical Strategy and the work of the Rail Research UK Association, the Rail Supply Group has investigated capabilities within the supply chain and the pipeline of investment opportunities within the UK and abroad (including HS2 and Digital Railway) to identify five key technology areas where the UK has the potential to be a world leader over the next 5 to 20 years[57]. These are:

1. High value rolling stock systems (industrial/ergonomic design and human factors, lightweighting, propulsion systems)
2. Whole life asset optimisation/through life management (remote condition monitoring, asset management systems, simulations and synthetics, retrofit in operating environments)
3. Advanced control (control systems, positioning, cyber security)
4. Customer experience (data management and analytics, design and use of payment systems).
5. Energy management (energy storage, energy systems management)

In addition, over the next five years more than 3,000 new rail engineering Level 3 graduates (A-level equivalent) are required just to maintain current skills levels.

At least 7,000 more Level 4 advanced technicians (undergraduate equivalent) will be needed across the sector. HS2 will also demand 600 advanced rail engineering technicians (Level 4–6+) every year from 2019 onwards.

[51] Means of ascent: the Aerospace Growth Partnership's industrial strategy for UK aerospace 2016. Department for Business, Energy and Industrial Strategy, July 2016

[52] https://www.gov.uk/government/publications/smart-specialisation-in-england

[53] 'Lifting Off – Implementing Strategic Vision for UK Aerospace'. 2013

[54] Nuclear industrial strategy: the UK's nuclear future. Departments of Energy and Climate Change and Business, Innovation and Skills, March 2013

[55] Small Modular Reactors Feasibility Study, National Nuclear Laboratory, December 2014.

[56] Mike Tynan, Director NAMRC, Personal Communication, August 2016

[57] Fast Track to the Future – A strategy for productivity and growth in the UK rail supply chain, Rail Supply Group, Dept of Business Innovation and Skills, Dept of Transport, February 2016

Within the region there is an emerging centre of excellence in rail engineering which combines industry, innovation and skills assets, with Doncaster now a partner in the £40m + National College for High Speed Rail (NCHSR) where upskilling is being designed to meet the demands of new and changing technologies and processes while enhancing productivity.

8.2.4 Health

A recent analysis of the life science sector in the UK[58] reported that the core sectors of biopharmaceuticals and medical technology employed 222,000 in 5,600 companies generating £61bn in revenue. The sector provides 39% of all UK science employment.

A major driving force for innovation in healthcare is the NHS, whose current five year plan[59] aims to meet the challenges of creating a more equitable care landscape and to cope with surging demand while tackling a projected £30bn funding gap. One of the key elements in delivering this plan is the development of new models of care to deliver greater local flexibility aided by investment in new workforce models and adoption of technology. This NHS vision has been projected further in a recent analysis[60] and emphasizes the impact of digital technology and the ability to connect people to information about their health and care options.

The business opportunities this represents, both in the UK and globally, are widely recognised, and we are seeing more companies from sectors outside of healthcare entering and exploring the market, particularly in the preventative and wellness segments. A recent USA analysis[61] found new entrants to healthcare from a variety of sectors, including automotive, retailing, consumer products, finance, ICT and technology. Well known examples, of course, include Apple's launch of the iWatch, which includes sensors that integrate with fitness and dietary apps.

8.3 The opportunity

The partnership brought together under this Science and Innovation Audit and the proposals set out in the next chapter will be a powerful enabler for regional industries to exploit the opportunities and meet the challenges presented by Industry 4.0. The audit further lays the foundations for new science and innovation collaborations that will put the region at the vanguard of developing and exploiting new innovations to ensure it can sustain and grow Northern advanced manufacturing industries.

[58] Strength and Opportunity 2015: The landscape of the medical technology and biopharmaceutical sectors in the UK. Office for Life Sciences and UKTI, 2016

[59] NHS Five Year Forward View, NHS England, October 2014

[60] The NHS in 2030. A vision of a people-powered knowledge-powered health system, Nesta, July 2015

[61] Healthcare's new entrants: Who will be the industry's Amazon.com? PwC Health Research Institute, April 2014

Conclusions

The region has the elements required to be a globally significant centre for innovation and translational research, ensuring the rapid take-up in manufacturing of new materials and processes, new business models and the ubiquitous digital technologies of Industry 4.0. The resulting resurgence in high value manufacturing will drive productivity growth and strengthen the economy of the region, the wider North, and the UK more generally.

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9.1 Regional strengths in the audit region

9.1.1 Overall conclusions

The starting point for this Science and Innovation Audit was the recognition that the high value manufacturing of the future will be digital, reconfigurable, customisable and will generate greater value through stronger connectivity and responsiveness to the changing requirements of customers. These trends, summed up in the slogan Industry 4.0, will be driven and supported by technological innovation in many areas, including data analytics, robotics, automation, new materials and manufacturing techniques, and new management practices and business

The audit found that the region has significant innovation strengths in all these areas, and has also developed new and highly successful types of translational research institutions with the potential to drive up levels of skills, innovation and productivity in the private sector.

A focus on high value manufacturing and a more widespread application of the principles of Industry 4.0 has the potential to drive a significant increase in the value created by manufacturing for the region in its priority sectors of aerospace, energy (especially nuclear), transport (especially rail) and health technologies. Broader benefits would accrue through the expansion of a variety of relevant professional and technical service sectors, helping to close the productivity gap with the rest of the country.

9.1.2 Manufacturing, Industry 4.0 and the economy of the audit region

The audit region's overall productivity performance is below the average for England. However, the regional specialisation in high value manufacturing sectors with considerable growth potential offers scope for a significant improvement in productivity through innovation and skills, particularly through the full exploitation of digital technologies that is Industry 4.0.

Industry leaders in the area recognise the importance of capitalising on Industry 4.0, and there is a common understanding of the barriers. The suggested solutions include a more joined up, forward-looking skills landscape, better connection to the research base, and more access to translational research and demonstration facilities.

9.1.3 Research strengths in Lancashire and the Sheffield City Region

The audit area's research base is strong, and well matched to the needs of future high value manufacturing. The overall volume of engineering research has grown spectacularly, with a tripling of research income in the region's HE institutions over the past decade.

International research excellence is found across many engineering and management disciplines, including automatic control and systems engineering, materials science, design, artificial intelligence, data science, cyber security, leadership and organisational behaviour.

In the private sector, the overall level of industrial R&D is less than would be expected. There needs to be more SME engagement with innovation, which could be helped by the expansion of initiatives such as Lancaster University's outstanding programmes for SME engagement.

The region's translational research facilities are a major source of competitive advantage, with the University of Sheffield's Advanced Manufacturing Research Centre (AMRC) in particular having global reputation and scale.

9.1.4 The innovation system

There is a high degree of connectivity between the region's innovative manufacturing firms, though there is evidence of a long tail of less innovative companies.

The research base is well connected to national and international networks, though more could be done, for example in some aspects of digital. There is a strong track record of collaboration between and across all of the region's universities which can be further built upon. While large companies are nationally and internationally connected, again more could be done to encourage SMEs to operate internationally.

The 'place' dimension of industry clustering is recognised in the concept of Advanced Manufacturing Innovation Districts (AMID) with translational research institutes acting as anchors. These districts can promote innovation and skills in the existing business base, act as nuclei for new business formation, and attract inward investment.

9.2 Aligning regional, northern and national strategies

This Science and Innovation Audit should be regarded as a contribution to the development of a national industrial strategy. It is important to place it in wider regional and national contexts, including the emerging, more unified, national research and innovation landscape, as the Research Councils, Innovate UK and Research England are brought together under UK Research and Innovation. Its findings are aligned to the Northern Powerhouse Independent Economic Review and there are strong complementarities with the Greater Manchester/East Cheshire SIA.

The goal is to boost productivity, in the regional economy and across the UK as a whole, with a focus on high value manufacturing. In this context, strategy and future investment should support the role of innovation and skills, and the focus on management and leadership in an environment of rapid technological change.

Productivity will, in practise, be increased through:

- the spread of best practise, which takes full advantage of new technologies, throughout the existing business base
- new investment into the region, including from global firms at the international technology frontier
- new business formation, through start-ups able to exploit new technologies developed in the region or elsewhere to address market needs.

Within the audit region, good progress has been made in developing the concept of Advanced Manufacturing Innovation Districts. These embody the networks of skills and innovation that link companies with the research and training assets that will drive productivity growth, and they need to be supported with an appropriate infrastructure and planning environment.

The Sheffield/Rotherham AMID is well-established, and in Lancashire plans for a Salmesbury AMID will be cemented by the North West AMRC (NWAMRC). The ambition for the Northern Advanced Manufacturing Innovation Corridor is to link the Sheffield/Rotherham AMID and the wider Sheffield City Region manufacturing base, through the Salmesbury AMID and the Ribble Valley manufacturing cluster, to UCLan's Engineering Innovation Centre.

9.2.1 International networks and the implications of Brexit

Support for internationalisation can build on existing regional HE/industrial networks and partnerships, including the strong international networks of our universities, working with LEPs and UKTI, united within a larger overall programme. Inward investment activities should prioritise opportunities to bring to the region new, internationally-leading, high value manufacturing firms.

The changing nature of the UK's trading relationships that will follow from the vote to leave the European Union will clearly have an impact on the region's industry. While the details of this impact are not yet clear, the need for the industry to become even more internationally competitive through innovation and skills is not in doubt.

One concrete consequence of the UK leaving the European Union will be the loss of EU structural funds. These have been of great importance in providing both capital and revenue funding for business and innovation support in the region, particularly to SMEs.

The replacement of these funds with new funding streams from UK government will allow the region to retain these benefits, while providing an opportunity to make replacement programmes less bureaucratic, more cost-effective, and more aligned to our regional and national priorities.

9.3 Investment opportunities: building on established success

9.3.1 Current investment opportunities

This audit has identified some excellent areas of progress; recent initiatives have done much to improve the competitiveness of the audit region's innovation system. Substantial value will be achieved by building on these initiatives, scaling them up and connecting them better.

The region's translational research centres have been an outstanding success and their scale and reach should be expanded.

The proposed new Lancashire branch of AMRC (NWAMRC), working in collaboration with UCLan's EIC, will bring demonstration and development facilities for Industry 4.0 closer to the SME manufacturing base in Lancashire and link them into national and international networks.

Translational engineering research in Lancashire will be further boosted by a proposed new research centre with TWI on joining technology; linked to this is a current £30m Research Partnership Investment Fund (RPIF) bid with BAE Systems.

The proposed AMRC Lightweighting Centre, to be sited next to AMRC Factory 2050, will focus on the development of manufacturing techniques for materials with exceptional strength-to-weight properties. This will be a major attractor for inward investment opportunities, and as an open access applied research centre it will help regional manufacturing companies make lighter, greener products more competitively. An economic impact assessment for the project indicates a GVA benefit of £286m to SCR and a further £157m outside the region.

The Sheffield branch of the Sir Henry Royce Institute will, through the Royce Institute's hub in Manchester, serve as the critical connection to the materials specialism identified in the Greater Manchester/East Cheshire Science and Innovation Audit, through which new lightweight alloys, composite materials and ceramics will be incorporated into cost-effective manufacturing processes in the AMRC Lightweighting Centre.

Small Modular Reactors. One of the most exciting prospects highlighted in this audit is the possibility that a new generation of Small Modular Reactors (SMR), with substantial UK intellectual property and local manufacturing content, might contribute to the government's plans for significant new nuclear build. The Government is currently running a competition to identify a best value Small Modular Reactor design for the UK, so it is not yet possible to identify which, if any, pathway the government will choose for implementing an SMR programme.

Whichever pathway is chosen, it is clear that the promise of SMRs to supply low-carbon energy affordably will rely on the kind of innovation in advanced manufacturing processes that has been the focus of this audit.

Assets such as the Nuclear AMRC and the Springfields site will be well placed to act as the nuclei for a substantial Northern component to an SMR nuclear supply chain, and to drive the innovation that will be needed for this programme to contribute to the Government's strategic energy goals while at the same time making an important contribution to productivity growth in the region.

Skills. There is a need to respond to the new skills challenges presented by manufacturing in a digital era. The AMRC Training Centre offers a model for linking skills development to innovation agendas, and this needs to be extended across the region in partnership with Further Education, and the crucial new pathways into higher education should be broadened.

The region's record in producing high quality graduate talent in relevant science, technology, engineering and mathematics (STEM) and management subjects is good, but more progress is needed on retaining that talent within the region. Raising awareness of career prospects in regional SMEs through internships and placements is a key part of this, and also serves to raise the absorptive capacity of participating SMEs.

These successful initiatives could be brought together and built on as part of a wider Northern Advanced Manufacturing skills proposal. This would support the replacement agenda for highly technical skills, including the crucial new digital expertise that Industry 4.0 demands.

Leadership and management need to be addressed through a transformational Northern productivity programme, underpinned by a strong research agenda (for example, through Lancaster's plan to establish a trans-disciplinary Productivity Research Centre in its Management School, and the increasing collaboration between the region's Management Schools and AMRC). This will build on work with BAE systems on the Productivity Leadership Group.

9.3.2 Future investment opportunities

Looking to the future, this analysis makes clear that the future of manufacturing will be increasingly digital in character. To respond to this, further development of the research and innovation base in data science, robotics and autonomous systems (as applied to manufacturing) is needed, and connectivity with national networks and facilities in these areas should be increased.

- In data science, the national centre is the newly-established Alan Turing Institute (ATI), based in London, with university partners in London, Cambridge, Oxford, Edinburgh and Coventry.

A mechanism should be established to translate the outstanding work of the ATI into areas relevant to manufacturing, bringing Sheffield City Region and Lancashire academic research strengths together with translational research capabilities, such as AMRC's Factory 2050.

- A national centre for Robotics and Autonomous Systems is under consideration; there is a strong case for a major element of this to be located in the Sheffield/Rotherham Advanced Manufacturing Innovation District. There it can link with the extensive activities in industrial robotics within AMRC; build on existing strong and fast-growing activities in robotics and related academic disciplines at both Sheffield universities; and contribute to a growing pan-Northern collaboration, organised through the N8 group of universities and the Northern Manufacturing Corridor, to support the cluster of private sector autonomous system activities growing around BAE Systems' Warton site.
- One underplayed dimension of Industry 4.0 is the importance of logistics in knitting together global 'just-in-time' supply chains to serve increasingly customisable manufacturing processes. This will involve 'smart' digitised, potentially satellite-linked, multi-model systems for international freight, with potential for the use of autonomous delivery devices for the last mile. The growing logistics hub around Doncaster Airport would be an ideal location for a translational research centre modelled on AMRC, to accelerate the uptake of new technology and business models in the logistics sector.
- For healthcare technology, Lancaster's Health Innovation Campus, together with translational research assets in Sheffield such as the Advanced Wellness Research Centre and the Medical AMRC, should be further developed in the context of private sector/NHS/academic partnerships established through the two Testbed projects in Lancaster and Sheffield, to accelerate the development and uptake of cost-saving technology in our health and social care sectors.

Annexes

1 Methodologies

The Science and Innovation Audit process

The consortium overseeing the SIA represents the key innovation partners in the Sheffield City Region (SCR) and Lancashire Local Enterprise Partnership (LEP) areas. The consortium includes industry, two components of the HVM Catapult, universities, funders, innovation bodies, and the two LEPs. It is led by Professor Sir Keith Burnett (Vice-Chancellor, The University of Sheffield, SCR LEP Board member), and Professor Mark E Smith (Vice-Chancellor Lancaster University, Lancashire LEP board member).

The nationally appointed consultants, Technopolis, have provided data through analysis of existing national and bespoke datasets to inform the SIA as well as supporting Quality Assurance of the audit.

In addition to the data supplied by Technopolis, the consortium project team delivering the SIA has performed its own analysis of both publicly available and proprietary data (including the Higher Education Statistics Authority, Research Councils UK and Elservier's Scopus database) on research performance, national and local strategies, sector / industry reports and has consulted widely with regional and national stakeholders, the latter including funding bodies and membership organisations.

The writing team was led by Professor Richard A L Jones (Pro-Vice Chancellor for Research and Innovation, University of Sheffield) and included Dr Sarah Want (Head of Research Partnerships and Engagement, University of Sheffield), Mrs Yasmin Knight (Research and Innovation Services, University of Sheffield), Mr Dion Williams (Director of Enterprise and Innovation, Lancaster University), Dr Mark Rushforth (Head of Business Partnerships and Enterprise, Faculty of Science and Technology, Lancaster University) and Mr David Briggs (Consultant).

As a discrete part of assembling our evidence, the consortium has engaged SQW Ltd (economic development consultants) to undertake, through consultation with industry, a "deep dive", assessing the degree of international activity and significance of SCR-Lancashire advanced manufacturing assets, the interactions between our advanced manufacturing assets and supply chains, and canvassing industry views of the key opportunities for the regions' advanced manufacturing base. The industry consultees are listed in the table below.

General advanced manufacturing	Nikken Kosakusho Europe Magnomatics Siemens Footprint tools Precision Polymer Engineering BAE Systems (Maritime)
Aerospace	Boeing BAE Systems (Military Air and Information) NWAA
Medical Technologies	JRI Orthopaedics Sheffield Precision Medical B Braun Panaz
Nuclear	Forgemasters Westinghouse Electric Company UK Limited
Rail	Volker Rail Unipart

Table 7.2 – Student FTE by level of study and domicile for audit region for academic 2014–15.[45]

Metrics for measuring research quality

The national Research Excellence Framework, last published in 2014, represents a large-scale assessment of the quality of research outputs, impact and environment depending on careful peer review. As such it represents a source of excellent data on research quality in our region. However, it has drawbacks:

- The division of subjects in the Research Excellence Framework is relatively coarse-grained (there are 36 "Units of Assessment" to cover all research) and driven by academic disciplines rather than application areas.
- While the measures of quality applied make reference to international standards, because the exercise was a national one, explicit quality comparisons can only be made within the UK.

The use of citation metrics can give a finer grained view of research quality, which permit direct international comparisons. However such metrics need to be chosen carefully and used responsibly, as discussed in the recent Independent Review of the Role of Metrics in Research Assessment and Management.[62]

Some key issues that need to be considered include:

- The need to recognize the different cultures of citation in different fields and sub-fields. A paper in, say, biomedical science will tend to be cited much more frequently than a paper of similar quality and importance in mathematics. To overcome this it is necessary to use "field-weighted" metrics.
- A requirement to avoid using inappropriate proxies for quality, such as characteristics of the journal a paper was published in. Evidence shows that the correlation between the quality of an individual paper and journal-level metrics such as "impact factor" is weak. Journal level metrics should not be used to judge research quality.
- Whilst the results below offer a useful insight into how our outputs are received, we should note that disciplines differ in the importance they place on academic publications. Of particular relevance to the audit are the more translational sectors of engineering, which often publish in conference proceedings that cite peers' work much less than the typical academic journals found in science and medicine.

Another potentially useful set of metrics are provided by input measures such as amount of research funding awarded. These naturally measure the volume of research carried out (recognizing, of course, that research in some fields is more expensive than others). The volume of funding provides some measure of the quality of research groups, to the extent that, for academic research, they reflect judgments from peer-review on track record and quality. For more applied, industrially funded research the award of private sector funding is a measure of its relevance and usefulness to users.

Research funding metrics also have the advantage that they are forward looking, in contrast to both citation metrics and the REF outcomes. REF2014 looked at outputs published between 2008 and 2013, while the citation impact of a paper needs several years to become apparent. Rapid growth in research funding can therefore give an early indication of areas of fast improvement in research volume and quality.

The question of how one divides up research areas into fields and sub-fields also leads to potential issues to bear in mind. The choice of ontology is subjective, but important when one attempts to map underlying research strengths to the technology areas that might drive innovation in chosen industrial sectors.

[62] The Metric Tide: the report of the Independent Review of the Role of Metrics in Research Assessment and Management, July 2015, HEFCE. http://www.hefce.ac.uk/pubs/rereports/Year/2015/metrictide/Title,104463,en.html

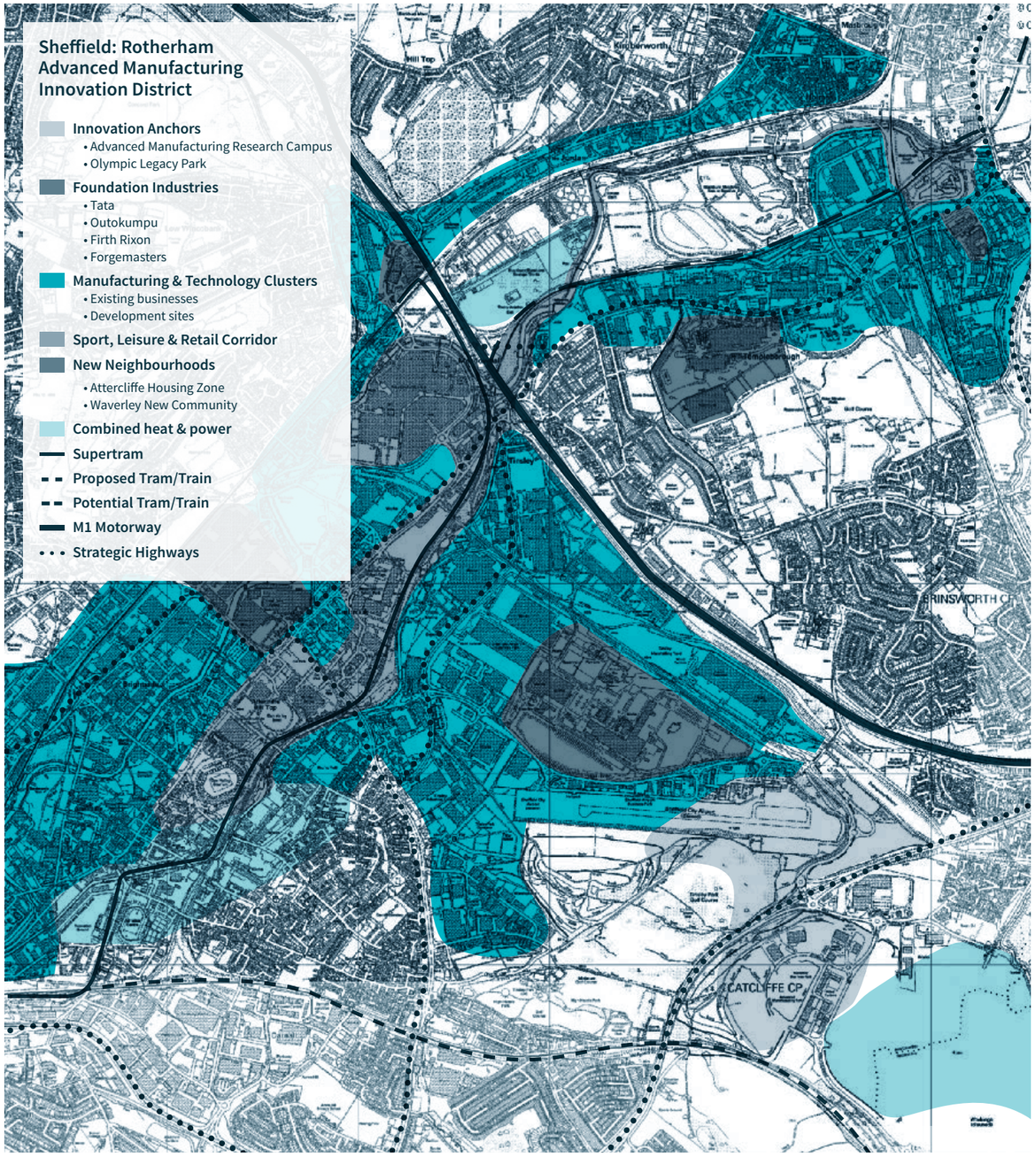
Measure	Source	Definition	Utility
Field-Weighted Citation Index	Elsevier SciVal for publications between 2011 and 2016 as at Aug 2016	Average number of citations per publication compared to that expected for publications of the same type, discipline and publication year. A result of 2 indicates that a group of publications has been cited twice as much as would be expected for a similar publication.	A measure of how much impact publications have made globally, mostly within academia. Although this measure is field-weighted to allow for differing citation behaviours between disciplines, some disciplines may place more importance on publication types not indexed in SciVal or on translational work with impacts outside academia.
REF GPA	Elsevier REF2014 Results Analysis	The sum of percentage scores multiplied by assessed grade (4*/3*/2*/1*/unclassified), with grades assigned weights of 4, 3, 2, 1 and 0.	A measure of average quality for a REF submission in the UK, irrespective of the number of staff submitted for a particular Unit of Assessment (UoA).
REF Research Power	Elsevier REF2014 Results Analysis	[(Quality Index x Cat A FTE submitted) = weight] / largest weight with weighting of 4 for 4* and 1 for 3*.	A combined measure of quality and quantity to illustrate the scale of high-quality research.
RCUK funding	Gateway to Research, summarised by Technopolis	Value of new awards from Research Councils UK and Innovate UK starting between 2010 and 2015, split by topic assigned by RCUK, to institutions in the region when acting as lead partner.	An indicator of national competitiveness and ability to convince peer review panels that proposed research is worthy of funding.
EPSRC funding	EPSRC Visualising our Portfolio	Value of currently-active awards from EPSRC, allocated to research areas by EPSRC and assigned to institutions in the region when acting as lead partner.	An indicator of national competitiveness and ability to convince peer review panels that proposed research is worthy of funding.

2 EPSRC Doctoral Training Centres in the region[63]

Title	Audit region partner	Other partners
Doctoral Training Centre in Advanced Metallic Systems – Challenges in Global Competitiveness	University of Sheffield	Alcoa Europe Flat Rolled Products, BP British Petroleum, Capcis Ltd, Cummins Turbo Technologies, Defence Science & Tech Lab DSTL, Firth Rixson Limited, Magnesium Elektron Ltd, National Nuclear Laboratory Ltd, Novelis Global Technology Centre, Tata Steel UK, Timet UK Ltd, Westinghouse Electric Company
EPSRC Centre for Doctoral Training in Statistics & Operational Research in Partnership with Industry(STOR-i)	Lancaster University	ATASS Ltd, AstraZeneca plc, BT Group, Defence Science & Tech Lab DSTL, IBM United Kingdom Limited, JBA Trust, National Nuclear Laboratory Ltd, Naval Postgraduate School, Northwestern University, Numerical Algorithms Group Ltd, Perceptive Engineering Limited, SAS Software Limited, Scottish and Southern Energy SSE plc, Shell Global Solutions UK, Smith Institute, University of Oslo, University of Washington, Winton Capital Management Ltd., marketingQED
EPSRC Centre for Doctoral Training in Advanced Metallic Systems – Challenges in Future Metals Manufacturing	University of Sheffield	AGH University of Science and Technology, Airbus, Alcoa Europe Flat Rolled Products, B P International Ltd, BAE Systems, CSIRO, Constellium, Defence Science & Tech Lab DSTL, Delft University of Technology, EADS UK Ltd, EDF, European Space Agency, Firth Rixson Limited, Ford Motor Company, GKN Aerospace, Helmholtz-Zentrum Geesthacht, INSA de Lyon, ISIS Facility, Indian Institute of Science Bangalore, Magnesium Elektron, Max Planck, Metalysis Ltd, Novelis Global Technology Centre, Osborn Steel Extrusions Limited, Otto Fuchs KG, Pohang University of Science and Techno, Rolls-Royce plc, STFC - Laboratories, Shanghai Baosteel Group Corporation, Sheffield Forgemasters Engineering Ltd, Siemens Public Limited Company, Special Metals Wiggin Trustees Ltd, TWI Limited, Tsinghua University, University of Cape Town, University of Oulu, Westinghouse Electric Sweden AB
EPSRC Centre for Doctoral Training in Energy Storage and its Applications	University of Sheffield	ABSL Space Products, ACAL Energy Ltd, Alexander Dennis, Arup Group Ltd, CTech Innovation Ltd, Defence Science & Tech Lab DSTL, E A Technology Ltd, E ON Central Networks plc, EURATOM/CCFE, Electricity Storage Network Ltd, Energy Institute, Energy Technologies Institute, ISIS Facility, Isentropic Ltd, Johnson Matthey Plc, Karlsruhe Institute of Technology (KIT), Liquid Air Energy Network, Lotus Engineering Ltd, MAST Carbon International Ltd, National Grid PLC, Oxford Instruments plc, Oxis Energy Ltd, Parsons Brinckerhoff, Qinetiq Ltd, REAPsystems Ltd, Ricardo UK Limited, Scottish Power, Scottish and Southern Energy SSE plc, SgurrEnergy Ltd, TSL Technology Ltd, Technology Strategy Board, Uni of Southampton Malaysia Campus, University of Southampton, Yuasa Battery UK Ltd
EPSRC Centre for Doctoral Training in Integrated Tribology	University of Sheffield	Afton Chemical Corporation, BP British Petroleum, Cameron Ltd, Changan, Cummins Turbo Technologies, Daido Metal Europe Limited, GE Oil & Gas, Infineum UK Ltd, L. B. Foster Rail Technologies, National Physical Laboratory NPL, Network Rail Ltd, Philips Research Laboratories, Proctor & Gamble Technical Centres Ltd, Ricardo UK PLC, Rolls-Royce plc, Siemens Public Limited Company, Tecvac Ltd
EPSRC Centre for Doctoral Training in Machining Science	University of Sheffield	Boeing Co, EADS Airbus, Messier-Dowty Ltd, National Composites Centre, Nikken UK, Rolls-Royce plc, Sandvik Coromant UK Ltd, Technicut, University of Bristol, University of British Columbia, University of Huddersfield
EPSRC Centre for Doctoral Training in Polymers, Soft Matter and Colloids	University of Sheffield	Akzonobel, Ashland Inc, BASF AG, Castrol UK Ltd, Cytec Engineered Materials Ltd (UK), DSM, GE (General Electric Company) UK, GEO Speciality Chemicals UK Limited, L. B. Foster Rail Technologies, Lubrizol Ltd, Nuplex Resins BV, Ossila Ltd., Philips Research Eindhoven, Proctor Group Ltd, Scott Bader Co Ltd, Syngenta, Synthomer Ltd, Unilever UK Central Resources Ltd
Industrial Doctorate Centre in Machining Science	University of Sheffield	BAE Systems, Boeing Co, Craftsman Tools Limited, Houghton PLC, Messier-Dowty Ltd, Mettis Aerospace, Sandvik Coromant UK Ltd, Technicut, Timet UK Ltd
The Digital Economy Innovation Centre	Lancaster University	BT Group, British Broadcasting Corporation - BBC, CSMTC Limited, Clifford Chance LLP, HP Research Laboratories, Knowledge Business Centre, Microsoft Ukp Ltd, Mott Macdonald UK Ltd, O2 Telefonica Europe plc, Sony Broadcast and Professional Europe
Next-Generation Nuclear	Lancaster University, University of Sheffield	University of Manchester, University of Leeds, University of Liverpool, EDF Energy Nuclear Generation Ltd, AREVA NP, France, Nuclear Decommissioning Authority, National Nuclear Laboratory Ltd, AWE, Rolls-Royce plc, EDF Energy Plc, Sellafield Ltd, AMEC Nuclear UK Limited

[63] Source: Gateway to Research.

3 Innovation Districts



Detail of the UK's 1st Advanced Manufacturing Innovation District, Sheffield City Region

4 Additional information on innovation assets within the audit region

Information is provided below, to further detail the university-owned translational research centres listed in Chapter 2: Overview of the region's Innovation Assets

The University of Sheffield's Advanced Manufacturing Research Centre Group has continually expanded since its inception in 2000 as the AMRC with Boeing. The AMRC Group unites a number of important translational research assets, described in more detail below. The AMRC Group currently employs more than 600 staff including 335 researchers and 35 teaching staff and has an annual turnover of £38m; it has a high degree of international visibility and its model is in the process of being replicated in South Korea, Oman and the USA. The national High Value Manufacturing Catapult includes two of the AMRC Group centres – the AMRC with Boeing and the Nuclear AMRC. The key components of AMRC are:

Factory 2050, a £43m reconfigurable digital demonstrator factory with a focus on the technologies required for the implementation of Industry 4.0, including next-generation manufacturing and assembly technologies, advanced robotics, flexible automation, next generation man-machine interfaces (including virtual reality) and new programming and training tools.

AMRC with Boeing (HVM Catapult Centre) has an international customer base, and operates a membership model for companies ranging from top-tier suppliers to SMEs, offering specialist equipment and services. Tier 1 members from the SIA geography include: BAE Systems, Technicut, Rolls-Royce, while Tier 2 members include; AML Sheffield Ltd, Agemaspark, Alcoa, Exova, FMS, Footprint Tools, MTT, Machineworks, Maher, Nikken, RLT, RLC, Rotary Eng Ltd and William Cook Castings. The centre is structured around a number of research themes: Machining, Composites, Structural Testing, Casting, Design and Medical.

Nuclear AMRC (HVM Catapult Centre) has two principal work streams: innovative manufacturing, focusing on machining and joining technologies for large and ultra-large, complex components deployed in challenging environments; and supply chain development. It operates across the entire nuclear industry marketplace, including existing nuclear operations, waste management and decommissioning, new nuclear build and advanced nuclear technologies, and is involved in the potential development of a small modular reactor (SMR) for the UK. Nuclear AMRC operates a membership scheme and its founder members include EDF, Areva, Westinghouse, Rolls-Royce, Tata Steel and Sheffield Forgemasters. It also works closely with SMEs in the nuclear supply chain and in the wider energy sector.

The AMRC Training Centre was opened in January 2014 and is currently training more than 400 people aged from 16, including second year apprentices who spend one day a week at the 5,500m2 facility. Thanks to its links with both Sheffield universities, apprentices can go on to study for higher-level qualifications up to doctorate and MBA level. The Centre also offers a range of courses for continuing professional development, and is seen as a leader in the field of higher level and degree apprenticeship schemes.

Lancaster University Management School (LUMS) is one of the largest research focused business schools in the world, ranked in the UK's top 10 and world top 1%. Research conducted in LUMS focuses on furthering understanding of the technological, economic and working practices that are unfolding within contemporary organisations and their management. Multidisciplinary groups provide world-leading, one-stop-shop capabilities for addressing advanced manufacturing issues. With more than 17 years' experience of SME engagement, LUMS also specialises in the application of its research expertise into the development and delivery of a suite of SME knowledge exchange programmes in the areas of innovation, enterprise development, leadership, productivity, supply chains and business management, including delivery of the programme in partnership with BAE Systems (Innovation in Manufacturing and Engineering (IME)), to help drive innovation in management practices.

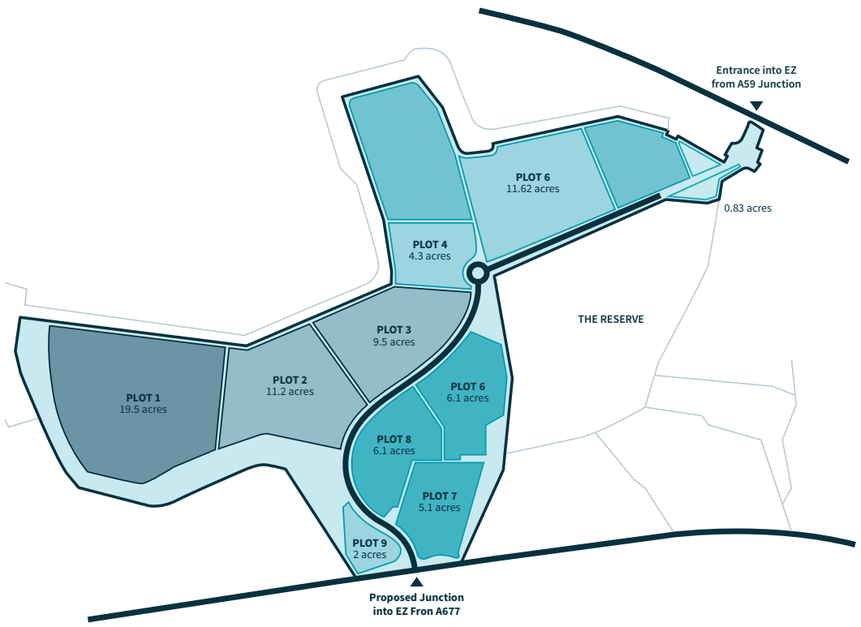
North West Advanced Manufacturing Research Centre (NWAMRC). The NW AMRC is being developed as an industry focussed centre of excellence for innovation, product development and manufacturing skills for Industry 4.0. Its focus is on aerospace, automotive and energy supply chain sectors, and it is a partnership project between the universities of Lancaster and Sheffield.

The University of Central Lancashire (UCLan) Engineering Innovation Centre (EIC) is a £40m+ project developing the University's teaching, research and knowledge transfer capabilities in engineering. The EIC, a signature knowledge transfer project within the Lancashire Strategic Economic Plan, will work with local SMEs as well as primes within the advanced engineering and manufacturing sector.

Sheffield Hallam University's National High Power Impulse Magnetron Sputtering (HIPIMS) Technology Centre provides an industry facing centre for innovation, training and product development using advanced vacuum plasma coatings for applications including aerospace and power generation gas turbines, cutting tools and biomedical implants. The Centre's industrial membership includes Rolls-Royce, Biomet, Ionbond, IHI Group, Sandvik, Gencoa and NPL.

The University of Sheffield School for Health and Related Research (ScHARR). With more than 300 multidisciplinary staff, ScHARR is the focus for a large, diverse and internationally recognised programme of health services and public health research, knowledge transfer and research-led teaching. It studies and evaluates health, healthcare, health services and policy from the broadest possible range of clinical, economic and social perspectives. ScHARR comprises four sections: Health Services Research, Health Economics and Decision Science, Public Health and Design, Trials and Statistics, plus the Clinical Trials Research Unit, the hub of the NIHR Research Design Service for Yorkshire and the Humber, the core of the NICE Decision Support Unit, the leadership of the Collaboration for Leadership in Applied Health Research and Care for Yorkshire and Humber and the directorate of the National Institute for Health Research (NIHR) School for Public Health Research.

Lancaster University's Centre for Global Eco-Innovation (CGE) provides in-depth R&D support to help SMEs develop new eco-innovative products, processes and services for global markets, with a strong focus on advanced manufacturing. CGE's first £10m support programme, part-funded by ERDF, was delivered in partnership with Liverpool University and was awarded the 2016 RCUK-PRAXIS 'Outstanding Knowledge Exchange Initiative' award.



Detail of the North West Advanced Manufacturing Innovation District, Lancashire LEP region

Over three years it delivered 300 SME R&D collaborations (resulting in the development of over 120 new products and services and the creation of over 260 jobs), generated over £4m inward investment and made significant environmental impacts. CGE has now developed partnerships with 4 further Northwest HEIs and the centre is rolling out new SME support programmes worth over £20m across the region, as well as exploring new international partnerships and projects.

The Collaborative Technology Access Programme (cTAP) is an £11.4m capital investment that has been part funded by almost £9m from the North West Operational Programme for the European Regional Development Fund (ERDF) and will provide industry with managed access to state of the art technology facilities and expertise commercially unavailable elsewhere. The funding has provided a 1000m2 three-storey building (extending the Chemistry Department) in addition to a range of equipment worth almost £7M.

The National Centre of Excellence for Food Engineering *(£6.9m HEFCE, £4m Innovate UK)* supports the food and drink manufacturing sector (including the Food and Drink Federation (FDF), Nestle, Mondelez, Premier Foods, Greencore, Warburtons, Rockwell Automation, McCains and Spirax-Sarco Engineering plc, Foss UK, First Milk, William Jackson, Greencore, Arla, Quorn, Samworh Brothers and Imperial College) by providing innovative engineering solutions for food and drink manufacturers, alongside equipping future engineers with the leading edge skills and knowledge that food and drink manufacturers need in the 21st century, mindful of key issues over the next decade of healthy products and a healthy diet and agile capability to deliver required products closer to demand utilising Industry 4.0

The Advanced Wellbeing Research Centre focuses on translating research to address the UK's health challenges, refocusing priorities from illness to wellness and empowering behavioural change within communities. The AWRC will provide an outstanding research environment, mirroring the health pathways with a scanning and diagnostics floor, technology driven clinical rooms, a public engagement hub, a knowledge transfer floor, inspiring seminar space, a large rooftop garden, testing laboratories and flexible workspaces for 70 researchers. Partners include Toshiba Medical Systems (CT, MRI and ultrasound); Westfield Health (corporate wellness and innovation fund); and Parkrun (measuring the impact on health for its 1 million UK runners). The AWRC will adopt the successful model of the AMRC with Tier 1 and Tier 2 partners, commercial partners for consultancy and contract research, applied academic researchers and business support for emerging companies in this area.

The £41m Lancaster Health and Innovation Campus University will build on Lancaster University's already strong reputation for research into health and ageing through its Centre for Ageing Research, International Observatory on End of Life Care, Centre for Disability Research, Centre for Research in Human Development and Learning and the Lancaster Health Hub, to provide an integrated approach to healthcare and services for people who are growing older. The campus is a response to a genuine need from industry and will bring together innovators, academics, entrepreneurs, the business community and health care providers, to make advances in products, services and technologies for the health sector. An independent economic impact assessment has found that when the campus is fully operational the project will have the capability to create more than 2,000 jobs and an annual economic impact of £99.8m. Work is anticipated to start later this year on the £41m Phase 1 of the facility, which is expected to open in 2019.

The EPSRC National Centre for III–V Technologies plays a central role in enabling world class research in UK universities. It has wide ranging capabilities in epitaxy (MBE and MOCVD) and device fabrication. As well as supporting UK university research the centre plays an equally significant role in enabling developments in UK industry.

5 *Industry consultation*

To build on existing analyses of industrial capacity in the audit areas, and to identify key opportunities and growth points, a consultation of key industry representatives was commissioned. The consultation, carried out by SQW, involved representatives of key companies active in the region in high value manufacturing, across a number of different sectors and of sizes varying from large multinationals to SMEs.

Questions that the consultation addressed included:

- Distinctive specialisms across SCR and Lancashire's advanced manufacturing sector, including capabilities and processes across the advanced manufacturing innovation ecosystems
- International activity, including internationally significant assets, exports and imports
- Actual interactions that exist between advanced manufacturing assets (including research excellence), the business base and supply chains, with a focus on collaborations in relation to innovation and science
- Key opportunities to develop the competitiveness of SCR and Lancashire's advanced manufacturing supply chains and foster increased levels of collaboration and more open innovation.

The synthesis report from this consultation is provided next, in full.

The Sheffield City Region and Lancashire Science and Innovation Audit

'Deep Dive' Research into International Activity, Collaborations and Supply Chains across the Advanced Manufacturing Sector – Synthesis of key findings

24 August 2016

SQW

Contents

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Approved by:	Luke Delahunty Director	Date:	24/08/16

1. Introduction

1.1 Together, the Sheffield City Region (SCR) and Lancashire were selected as one of five areas to prepare a Science and Innovation Audit (SIA) for Government by September 2016. The main purpose of the SIA is to:

- demonstrate the distinctive and nationally significant sectoral strengths of SCR and Lancashire;
- explore how these (and relevant supporting capabilities) could be developed further in the future so as to help drive productivity growth in a rapidly changing and increasingly competitive global market;
- identify gaps or weaknesses within the innovation ecosystems that exist currently across the SIA geography;
- explore what new action areas and investments could be progressed in order to maximise the economic growth for UK PLC through the SIA priority sectors and technology areas.

1.2 The underpinning logic and rationale of the joint SCR-Lancashire SIA bid rests upon a shared heritage and strength in **high value manufacturing.** More specifically**,** the SIA process has identified a specific focus on the area's distinctive capabilities around **aerospace, energy (especially nuclear), healthcare technologies and transport (especially rail)**.

1.3 The EoI for the SIA set out the following hypotheses, which are developed further in the full Audit:

- High value manufacturing activity in the future will be increasingly digitised, reconfigurable, customisable and will capture more of the value chain. This has led to the development and growing prominence globally of the 'Industry 4.0' concept. McKinsey has defined this as

  'the next phase in the digitisation of the manufacturing sector, driven by four disruptions: the astonishing rise in data volumes, computational power, and connectivity, especially new low-power wide-area networks; the emergence of analytics and business-intelligence capabilities; new forms of human-machine interaction such as touch interfaces and augmented-reality systems; and improvements in transferring digital instructions to the physical world, such as advanced robotics and 3-D printing'[1]

- This will be driven and supported by technological innovation in data analytics, robotics, automation, new business models, new advanced materials and processes
- The Sheffield and Lancashire SIA region has a strong scientific research and industrial innovation offer in relation to Industry 4.0 capabilities as well as new and

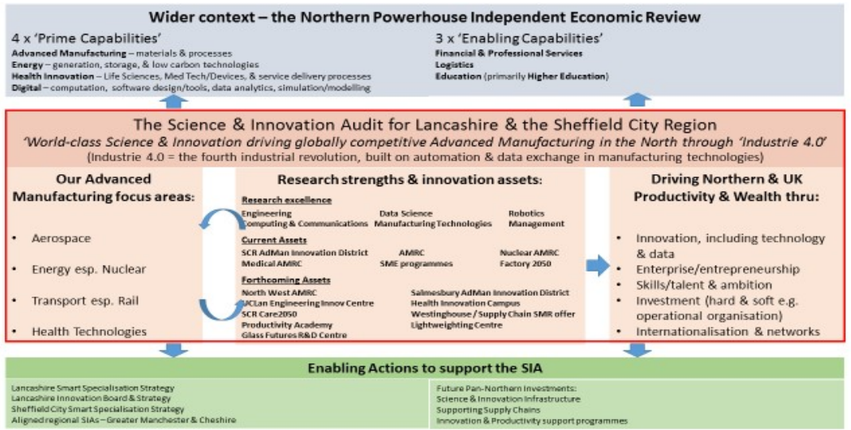
[1] Manufacturing's next act, Cornelius Baur and Dominik Wee, McKinsey (June 2015) available at: http://www.mckinsey.com/business-functions/operations/our-insights/manufacturings-next-act

uniquely successful types of translational research institutions which support commercialisation and skills development

- As a result, further investment to enable greater innovation will drive productivity growth in high value manufacturing in the SIA region, in the North more widely and across the UK.

1.4 The focus of the SCR and Lancashire SIA fits well strategically with the wider Northern Powerhouse agenda, as illustrated below. In the recent Independent Economic Review for the Northern Powerhouse, four 'prime capabilities' were identified for the economy of the North. These were assessed as being differentiated and distinctive at a pan-Northern level, highly productive and areas where the North is well-positioned to compete internationally. The prime capabilities identified were: advanced manufacturing (with a focus on materials and processes); energy (including nuclear); health innovation (including medical technologies and devices); and digital (with a focus on data analytics, simulation, and high performance computing) – all of which map closely onto the priority sectors in the SCR and Lancashire SIA.

Figure 1-1: The SCR-Lancashire SIA and how it sits within the wider economic context



Source: SQW with Lancashire LEP and the University of Sheffield

This assignment

1.5 In this context, SQW was commissioned at the end of June 2016 to undertake **qualitative 'deep dive' research** into:

- **distinctive specialisms** across SCR and Lancashire's advanced manufacturing sector, including capabilities and processes across the advanced manufacturing innovation ecosystem(s)
- **international activity**, including internationally significant assets, exports and imports

- actual **interactions** that exist between advanced manufacturing assets (including research excellence), the business base and supply chains, with a focus on collaborations in relation to innovation and science
- **key opportunities** to develop the competitiveness of SCR and Lancashire's advanced manufacturing supply chains and foster increased levels of collaboration and more open innovation.

1.6 As agreed with the University of Sheffield, this assignment was not intended to be a comprehensive mapping exercise of the advanced manufacturing sector and its supply chains (this was not possible in the timeframe available), nor was it focused on the analysis of secondary data (which was being covered elsewhere by the SIA team). Rather, it sought to **provide 'showcase examples' and illustrations** of the different types of international engagement, collaborations involving local, national and international partners, and supply chain interactions across some of SCR and Lancashire's key businesses in the advanced manufacturing sector. The resulting material was collated in a way so that the company 'cameos' would help to inform and shape the SIA document.

1.7 A longlist of potential companies was identified by the client group for consultation, with coverage across the aerospace, nuclear, healthcare technologies and rail sub-sectors. Introductory emails were issued by respective clients in the SCR and Lancashire, and SQW followed up with all companies who were willing and able to participate in the timeframe available for the work. In-depth consultations were held with 19 businesses/organisations in total, and all but two of these were held face-to-face. The companies and organisations consulted are listed below, and we would like to thank them for their contribution to this work. In addition, SQW undertook a headline review of key documents relating to the SCR and Lancashire's specialisms in relation to advanced manufacturing, which was used to inform the consultation process.

Table 1-1: Companies and organisations consulted for this study

Sector	Company / organisation name
General advanced manufacturing	Nikken Kosakusho Europe Magnomatics Siemens Footprint tools Precision Polymer Engineering BAE Systems (Maritime)
Aerospace	Boeing BAE Systems (Military Air and Information) NWAA
Medical Technologies	JRI Orthopaedics Sheffield Precision Medical B Braun Panaz
Nuclear	Forgemasters Westinghouse Electric Company UK Limited
Rail	Volker Rail Unipart

Sector	Company / organisation name
	Schwihag
	Alstom

Source: SQW 2016

1.8 This synthesis paper provides a summary of the overarching messages from the research, as well as sector-specific details and illustrations. The material provided here draws entirely on the consultations completed above, and therefore presents a picture of the area's strengths, opportunities and interactions from the perspective of those consulted.

1.9 The key feedback messages and research findings are structured as follows:

- Section 1 provides a **summary of the distinctive strengths and capabilities** on offer across the SCR and Lancashire advanced manufacturing sector
- Section 2 presents an overview of **international links and wider activity** taking place within the businesses consulted
- Section 3 presents key messages around **collaborations and interactions between businesses, supply chains and supporting research/innovation assets**
- Section 4 draws together common (and sector-specific) **growth opportunities** for the SCR and Lancashire advanced manufacturing sector, **barriers** to further interaction, collaboration and innovation, and **priorities** for future action in order to address these.

1.10 This paper is supported by stand-alone case study reports for each business consulted. These are provided separately.

2. Summary of findings

2.1 In this Chapter, we provide a summary of key findings under the four research topics set out above. For each one, we draw out common themes that span across the consultee discussions and then provide sector-specific pictures for general advanced manufacturing, aerospace, nuclear, medical technologies and rail in the shaded message boxes.

The SCR and Lancashire's distinctive strengths and capabilities in advanced manufacturing

2.2 A number of key capabilities are evident across the advanced manufacturing sectors in the SCR and Lancashire:

- A **critical mass of business and research assets, and world class skills**, that can provide **advanced manufacturing expertise and capability throughout the whole process** of designing, developing and manufacturing products. This includes early-stage R&D, rapid prototyping and testing, sourcing materials, high quality precision manufacturing of finished products, and taking new products to market.
- A reputation for **high quality and precision manufacturing/materials**, which is essential in structural and safety critical sectors such as nuclear, medical technologies, as well as aerospace (military)
- The prevalence of **collaborative applied research** which is directly involving and influencing businesses and has strong links to local universities and research assets (covered more detail in the sections below), all of whom have a strong 'can do' attitude
- The ability to find **clever ways to exploit new products, materials and processes and emerging technologies across a broad range of niche sectors,** including within and across the aerospace, energy and medical technologies sectors, which gives the sector real resilience
- Strengths around **advanced digital design, testing and manufacturing techniques**, which are core components of 'Industry 4.0', including computer-controlled design, testing, simulation and visualisation, and manufacturing, computer-modelled quality assurance, and digital print manufacturing of materials.

2.3 The table below details the distinctive capabilities, assets and strengths in each of the SIA's four priority sectors, according to the views of consultees.

Figure 2-1: Key messages by sub-sector

Aerospace consultees	Medical technologies consultees
• The aerospace offer in the SCR and Lancashire sub-regions is complementary, but somewhat different too. • In Lancashire, key capabilities include the **design, testing, manufacture and assembly of aerospace components**, with large employers (e.g. BAE at Samlesbury and Warton, plus Rolls Royce at Barnoldswick etc.) and a tightly integrated supply chain feeding into those larger companies. These companies make a significant contribution to sub-regional GVA and employment. They invest huge sums into their R&D and broader innovation activities in order to remain globally competitive. The sector is a real success story for Lancashire and the North more widely, but key market and technology drivers of change are giving rise to new threats (and opportunities), both for the Tier 1 firms and their local supply chains, which are critical in terms of manufacturing component parts and/or sub-systems. • In the SCR, there are real strengths in the **application of advanced manufacturing R&D, especially in terms of the development of new products and processes within the aerospace sector** (and other sectors). This builds on the critical mass of globally leading R&D that is relevant to the aerospace sector centred around the Advanced Manufacturing Park, which includes the AMRC, Sheffield's Universities and industry (including Boeing). • The prevalence of **collaborative applied research** which is **directly influencing** aerospace businesses and their supply chains is seen as a distinctive strength for both areas.	• The SCR has a '**critical mass'** of medical technology companies that is considered to be **nationally significant and distinctive**, including the sector's 'big names' as well as many smaller specialist firms. A key asset is the Medical AMRC, which offers specialist capabilities in mechanical and electrical design, prototyping, design for manufacture and visualisation. • A key strength of the SCR's sector is its ability to provide **expertise throughout the whole process of designing, developing and manufacturing medical implants and instruments**. This includes early-stage R&D, prototyping and testing, sourcing materials, high quality precision manufacturing, and taking new products to market. The SCR's reputation for **high quality precision manufacturing** of safety critical components is particularly important for the medical devices sector, which is highly regulated. • Many of the companies employ **advanced digital production techniques**, including computer-controlled manufacturing, computer-modelled quality assurance, and digital print manufacturing of materials. • Evidence on Lancashire's medical technologies is more limited – there are evident strengths in **innovative materials for the medical sector** (such as anti-microbial treatments and intelligent textiles), which has clear complementarities with the SCR offer.
Nuclear consultees	**Rail consultees**
• The SCR has specific expertise in **designing, testing and manufacturing internationally unique and often very technically challenging components for the nuclear sector**. • The SCR's strengths draw on the area's wider advanced manufacturing capabilities in metal forming, machining and processing. It is the combination of **cutting edge R&D** and facilities to **test and manufacture at scale** that sets the SCR apart, as well as its reputation for **high quality manufacturing** which is essential in structural and safety critical components for the nuclear sector.	• When combined, the SCR and Lancashire SIA area is seen as having a **relatively strong offer** in terms of the rail sector. • The area is home to **some key rail businesses and many smaller-scale specialised manufacturing companies** who supply products and services to the larger firms. • There are mixed views on whether the SCR/Lancashire offer is preeminent nationally – it competes with the likes of York and Derby – but existing offer is seen as nationally significant (if not unique) and the forthcoming **National College for High Speed Rail** will provide the area with a key nationally (and potentially internationally) significant asset.

• The SCR has some key businesses engaged in R&D and manufacturing for the nuclear sector, which involves **new material development and process improvements**, drawing on **computer modelling capabilities.** • Through Westinghouse's large Springfield nuclear licensed site in Lancashire (the first plant in the world to produce fuel for a commercial nuclear power station), the area has the capability to **manufacture fuel for all major designs of nuclear reactors**. • In addition, the SCR is home to the Nuclear AMRC, providing links to academic expertise and large-scale testing facilities.	• Key capabilities include the **production and repair of rail equipment** – drawing on the area's reputation for the manufacture of high tech products, processes and materials that can be applied to the rail industry – as well as **expertise in technical support, and the design and management of infrastructure schemes**. • The AMRC provides links to high quality R&D facilities for regional rail businesses

Source: SQW summary of consultation feedback

International activity

2.4 **Many of the SCR and Lancashire's advanced manufacturing companies operate globally** (e.g. BAE Systems, Nikken, Magnomatics and Unipart), although some (e.g. Volker Rail, Alstrom and B Braun) are UK subsidiaries of foreign-owned firms which are designed to primarily serve the UK market (such as Network Rail and the NHS). The **reach and strength of international relationships varied considerably** across the businesses consulted. Some, for example, are well established in European and US markets and have recently expanded in South Africa, Australasia, Russia, and the Middle East; for others, the Middle East is their core market for exports. In addition to manufacturing fuel, Westinghouse's Springfields operations also provide conversion services for intermediate products such as uranium dioxide powder for overseas customers in Europe, Korea and Japan.

2.5 Where companies are exporting, this can include advanced manufacturing products and services, but a number of consultees are experiencing **considerable export growth in expertise, knowledge and the demand for increasingly customised products**. For example, Forgemasters are observing increased demand for plant and equipment design expertise from countries such as India and China; most of Magnomatics' international work involves collaboration to develop bespoke magnetic gearing products with large-scale international clients; and Nikken is finding more international clients are looking for bespoke tool holding solutions, rather than off-the-shelf products.

2.6 A number of factors that have enabled the SCR and Lancashire's businesses to access international markets. Given the growth in demand for customised products, the **R&D capabilities** of many businesses has been critically important. Linked to this, the ability of these businesses to demonstrate access to world-leading research assets, alongside a breadth and depth of expertise in the area, to design and develop solutions for their clients is vital. In this context, consultees raised the following issues:

- The AMRC, which is seen as an internationally significant and distinctive asset and the "best in the world" at what it does – and, for example, it is the only place that Boeing engages with this kind of activity. The Medical AMRC is also seen as an internationally significant asset for medical technology businesses in the SCR. Companies have taken foreign clients there to demonstrate cutting edge techniques,

such as 3D modelling, and one consultee believed that engaging with the Medical AMRC helps to secure the confidence of global clients that the quality, depth and breadth of expertise in the area to provide solutions.

- Following on from the above, BAE Systems highlighted their strong support for the development of the proposed NWAMRC facility at Salmesbury, stating that they felt this could also develop into an asset of international significance. Similarly, BAE Systems and Siemens both highlighted that the Lancaster University Management School was "world class" and that it could play a key role in ensuring that the advanced manufacturing sector had access to leaders and managers who were equipped to innovate.

- The forthcoming National College for High Speed Rail in SCR will also provide the area with a potentially internationally significant asset, both in terms of attracting foreign students to study at the College and exporting knowledge and expertise developed there.

2.7 The reputation and ability of businesses in the area to manufacture products at the **highest quality possible** has also been critical in accessing international markets. This is particularly important in safety critical products such as medical implants and the highly regulated healthcare sector, and components for the nuclear sector.

2.8 The table below provides examples of international activity from each sector.

Figure 2-2: Company illustrations of international activity

General advanced manufacturing consultees
• Nikken Kosakusho Europe Limited is a specialist in high precision tool holding solutions for advanced machining processes in the SCR. **Its 'Innovation Centre for Europe' on the Advanced Manufacturing Park is Nikken's European Headquarters**, and provides the company's central location for R&D and testing capabilities – customers from across Europe regularly visit the centre to develop bespoke solutions at Nikken's facilities (and often linking across to the AMRC). The company **generates around 60% of its turnover (by value) through exports, and the share is even higher (at 75-80%) by volume of products**. The majority of Nikken's exported goods and services are to Europe, and this accounts for 50% of the company's turnover. Key markets include Germany, France, Italy, Spain, Scandinavia and Eastern Europe. More recently, the business has expanded into South Africa, Australasia, Russia and the Middle East. A growing share of international (and UK) customers are looking for bespoke and tailored tool holding solutions, rather than off-the-shelf products – and Nikken are seeking to build on this, **moving more towards selling 'solutions', adding greater value to the activities that take place in the SCR**.
• Magnomatics, a company in the SCR which designs, develops and tests magnetic gear technologies, generates **two-thirds of its revenue from international work**, equating to around £1.5m each year. This often comes from **long-term collaborative work to design and develop magnetic gearing products with large-scale clients** (with turnovers in excess of £5bn) in a range of sectors. Examples include working with automotive manufacturers in Sweden, India, the US and China, rail and aerospace firms in the US, and a number of EU companies in the renewable energy sector.

Aerospace consultees	Medical technologies consultees
• BAE operates in a global market in terms of customers, competitors and collaborators. **Exports are therefore a key part of the UK operations of BAE and represent 46% of total UK sales revenues.** The Middle East is the most important export market, accounting for 69% of all exports in 2013, whilst the US also accounts for a significant share at 15%. The rest of Europe is of lesser importance, with 4% of exports, and the remaining 12% go to other countries across the world.	• **Exports account for around 50-60% of Sheffield Precision Medical (SPM)'s turnover at present**, which equates to around £1.5m, and this has grown rapidly since 2010. Key markets include the US, Europe and Japan. • JRI Orthopaedics operates in a global market. Exports have grown significantly over the last 30 years, and **now 25% of turnover comes from exported products and services.** The EU is a major market for the company, but more recently exports have grown to Australasia and South Africa (aided by similar medical education and a common language) and Brazil. China is making huge investments into health care and is seen a key future export market.
Nuclear consultees	**Rail consultees**
• Forgemasters, based in Sheffield, generates **around 50% of its turnover through exports,** of which a large proportion comes from the oil and gas sector (42%), followed by processing (22%), steel plants (14%) and nuclear (10%) sectors. Europe and the US are key markets for Forgemasters. The company exports both products and services, and is **experiencing increased demand for plant/equipment design expertise** from countries such as India and China.	• All of the rail companies consulted are part of **global companies**. For two, their operations in the UK primarily serve UK markets. Yet Schwihag, for example, does export to Canada, France, Germany and Hong Kong. However, currently it is experiencing such strong growth in the UK market that there is limited incentive or capacity to focus on overseas markets.

Source: SQW 2016

Collaborations and interactions between businesses, supply chains and research assets

Collaborations

2.9 Many of the SCR and Lancashire's businesses are engaged in collaborative activities, both through **working directly with clients to develop bespoke solutions** to meet their needs, as part of **R&D-led projects** to develop and design completely new (and adapt existing) products, processes and materials, or through the use of 'neutral' innovation spaces such as the AMRC where companies are able to showcase their new technologies to existing or potential clients. There is a **strong innovation culture** already embedded in these businesses, who recognise the need to be agile and able to adapt to change and new opportunities. The **scale of investment in innovative activities can be very significant** – Forgemasters, for example invests around 5-10% of its turnover in R&D, which equates to around £10m+ per annum.

2.10 **Many of the collaborations embrace Industry 4.0 principles**, with businesses seeking to move towards more customised processes and products through the use of digital technologies in data analytics, automation, and new materials and techniques, thereby capturing more of the value chain. For example, many of the collaborations that Siemens is engaged in focus on Industry 4.0, driven by the need to accelerate the speed of innovation with shorter product introduction timescales and the need to respond to changing customer demand and expectations (e.g. mass customisation etc.). This includes technologies which

incorporate internet connectivity, the use of visualisation and virtual prototyping, and innovative manufacturing techniques such as additive manufacturing (3D printing). The 'servicisation' of the advanced manufacturing sector is also helping to drive new collaborations, as firms (and customers) work together on issues such as whole-life asset optimisation and through life management. See Figure 2-3 for further examples.

2.11 **Businesses in the SCR and Lancashire are collaborating with universities, research centres and their supply chains locally, and together across the Pennines**. For example,

- Precision Polymer Engineering in Lancashire encourages its own suppliers to work closely with the company, challenging them to share in 'next product' development and innovation, and to 'stay ahead of the game'. This includes building relationships with its local suppliers, gaining and utilising knowledge of their capabilities, and encouraging them to work with the company to solve practical problems.
- The University of Sheffield is a global principal partner university for Siemens, and hosts the Siemens Wind Power Research Centre.
- Westinghouse has been collaborating with AMRC on several fronts, including a recent study on the manufacturability of the W-SMR Reactor Pressure Vessel (RPV). This study identified several advanced manufacturing techniques which could be explored should the Westinghouse design be selected by the Government in the current SMR competition.
- Working with the Management School at Lancaster University, Siemens and BAE Systems have run a joint programme of workshops for SMEs aimed at developing leadership and management skills in relation to innovation activity. The SMEs were encouraged to visit the manufacturing facilities of both Siemens and BAE to see how innovative technology is being used in the production process.
- Schwihag UK's predecessor company, Ambagarth Holdings, collaborated with the AMRC to develop a new coating for rail plates. Schwihag (the parent company) were so impressed by the new technology that they bought out Ambagarth.

2.12 **Collaboration is also taking place with wider partners across the North**, including on innovations within and across the Northern Powerhouse's 'prime capabilities'. For example, BAE Systems has partnered with the Hartree Centre at Sci-Tech Daresbury in the Liverpool City Region on augmented reality, and JRI Orthopaedics in the SCR has collaborated with the University of Liverpool to develop a novel approach to joint surface regeneration, and with the University of Manchester to assess the residual stress profile of a new orthopaedic implant at its synchrotron particle accelerator.

2.13 Looking to the future, at the point when nuclear SMRs are ready for deployment in the UK and globally, **Westinghouse in Lancashire will have established a UK nuclear supply chain in support of the new build Moorside nuclear power station project at West Cumbria**. This will be leveraged for the UK SMR deployment and will also support the development of new skills in the UK and the creation of sustainable new jobs throughout the nuclear supply chain. Westinghouse's aspiration is that most of the procurement of the Westinghouse SMR would be sourced in the UK together with the basic design, detailed design and licensing. **The Northern Powerhouse, including both the SCR and Lancashire, is ideally located to take advantage of this**. **Westinghouse has identified several specific suppliers in the Northern Powerhouse that would be well positioned to exploit this growth opportunity**. The deployment of Westinghouse SMR in the UK is also intended to create an export SMR market, which these organisations would then be in a prime position to supply, thus supporting further growth and innovation across the SIA geography.

2.14 Businesses in the SCR and Lancashire also **draw in wider expertise in the UK and internationally**. For example,

- As well as collaborating with the AMRC and Lancaster University, BAE also partners with both the Manufacturing Technology Centre in Coventry and Cranfield University on additive manufacture, the University of Nottingham on robotics, and the National Composites Centre in Bristol on composites.
- Westinghouse is supporting an Accident Tolerant Fuel programme in collaboration with NNL and various UK universities who are providing technical consultation (Imperial, Cambridge and Manchester).
- At both a European level and in the UK, Alstom works closely with rail industry operators and the regulators who set safety standards, and with supply partners on systems development, assessment and testing – including in relation to high tech control and diagnosis systems, using algorithms and 'big data' in measuring and predicting wear. International partners include the German companies Voith and Knorr-Bremse and the French-controlled Faiveley Transport.
- Both Panaz in Lancashire and JRI Orthopaedics in the SCR have been involved in (separate) pan-European research projects. For example, JRI was part of an international consortium that secured FP7 funding to develop new bioceramic products for orthopaedic applications, and Panaz was one of three commercial partners in a pan-European research project focused on fluorocarbons (PFCs) which sought to reduce the number of carbon molecules in 'next generation' flame-retardant fabric.
- Schwihag UK undertook a joint venture with a Chinese company that had expertise in bonding rubber to metal in order to develop a rubber 'boot' for its rail plates. London Underground required this modification to the standard rail plates because Underground lines differ slightly from 'outside' railway lines.

2.15 There are a number of examples where collaborations are seen as **nationally and internationally significant,** where local capabilities come together to do something really quite distinctive in the advanced manufacturing field. See Figure 2-3 for further details on this.

2.16 The collaborations discussed with consultees were instigated in a variety of ways, from formal EU and Government funded research projects through to informal networking. **A number of factors have played an important role in enabling collaborations to work effectively** – including the involvement of "very outward looking" and internationally

credible Universities across the SCR and Lancashire, the scale of expertise on offer (which spans the advanced manufacturing process), and access to state of the art R&D facilities in relevant fields. Also, in many cases, well-established relationships, trust and proximity between partners has been critical – many have worked together on other projects previously, and the ability to interact quickly face-to-face matters. In the SCR, the AMRC was noted as playing an important role in encouraging collaboration around common technologies and techniques which apply across the SIA's priority sectors. Three factors are important here: it is seen as 'neutral ground', which encourages increased sharing of ideas and co-operation to solve common problems; it acts as an independent hub for research expertise, businesses and supply chains to interact; and its facilities promote the migration of technologies and innovation between and across different industries.

2.17 As a result of the new technologies, processes and products developed through collaborations, companies in the SCR and Lancashire have been able to access international markets and raise the profile of the area's expertise on a global platform, access larger contracts with knock-on benefits for their local supply chains, improve the efficiency and productivity of their operations, and encourage further investment. For example:

- JRI Orthopaedics' collaboration with Newcastle and Nottingham Universities to develop a novel shoulder implant system has enabled the company to boost exports. By 2013, the product was generating annual revenue of over £1m for JRI, of which, 50% came from international customers.
- VolkerRail's innovative approach to collaborative alliances - the first rail company in the UK to be involved in alliances of this kind - has enabled them to deliver large-scale infrastructure contracts in the rail sector, which has given the company more confidence in investing in its own company, and has knock-on benefits for the supply chain.

2.18 In the box below we highlight some of the more innovative collaborations across the SCR and Lancashire that are nationally and internationally significant, focusing on those that demonstrate interactions between research assets, key businesses and the supply chain. More detail on each collaboration is provided in the stand-alone case study reports for each company.

The Sheffield City Region and Lancashire Science and Innovation Audit
'Deep Dive' Research into International Activity, Collaborations and Supply Chains across the Advanced Manufacturing Sector – Synthesis of key findings [DRAFT]

Figure 2-3: Examples of collaborations

General advanced manufacturing consultees

- **Collaboration with the SCR's R&D expertise and businesses to innovate in the machining processes of aerospace components**: Rolls Royce approached Nikken five years ago with a challenge to produce titanium fan disks more quickly and effectively, and eliminate the risk associated with cutting tools failing and damaging highly expensive aerospace components in the process. Through informal networking at the AMP, Rolls Royce approached Nikken, a specialist in high precision tool holding solutions, for support in addressing the issue. Nikken worked in collaboration with the AMRC and Technicut (a Sheffield-based cutting tool manufacturer) to develop a solution. Nikken's holding technology meant that any failure of the cutting tools would not damage the titanium component, giving Rolls Royce 'complete process security'. As a result of this collaboration, Rolls Royce saw a 50% reduction in the cost of processing titanium fan disks, a 50% reduction in the number of tools required in the process, and reduction in the processing time from 34 to 10 hours. Nikken has since presented the technology developed here at international conferences and increasingly, through this kind of collaborative activity, Nikken is seen as an innovative global brand.
- **Collaboration between Siemens and two large aerospace companies at Factory 2050**: The AMRC Factory 2050 is the UK's first fully reconfigurable assembly and component manufacturing facility for collaborative research, capable of rapidly switching production between different high-value components and one-off parts. Factory 2050 therefore provides an environment where Siemens can come together with customers to use its technology to support their innovation. For example, Siemens is currently working with two large aerospace companies to develop the most accurate industrial robot in the UK. Accuracy is crucial in the aerospace industry and this joint project aims to develop a robot which will be accurate to within a couple of hundred nanometres, rather than the current level of accuracy which is measured in millimetres.
- **Collaboration in the Chinese automotive sector**: Magnomatics is currently collaborating with Changan, China's third largest manufacturer of cars, to develop novel hybrid gearbox technologies. The collaboration is part funded by a £1.9m grant from Innovate UK, and will cost £2.8m in total over a five-year period. It began in July 2016, and involves Changan (providing the customer perspective), Magnomatics (who will provide the novel gearbox technology), the University of Sheffield (with expertise in control systems engineering), Romax in Nottingham (who provide expertise in the virtual design of gearboxes) and a Cambridge-based company specialising in the modelling of internal combustion engines. It is hoped that the collaboration will bring a number of high value and highly technical design jobs to the SCR.

Aerospace consultees	Medical technologies consultees
• **Collaboration and innovation in Lancashire's aerospace supply chain:** Hurst Green Plastics ('HGP'), based in the Ribble Valley, designs and manufactures storage equipment for use on industrial production lines. Close co-operation with BAE led to the development of the TwinBin Kanban storage system. This inventory control management system for small components such as rivets and fasteners won the Queen's Award for Innovation in 2012. It is now used by BAE in the production of the Eurofighter Typhoon at Samlesbury and is also in use at BAE sites across the UK and overseas. • **Collaboration with AMRC, Boeing and the supply chain**: Messier-Bugatti-Dowty, a Gloucestershire-based supplier of landing gear for the aerospace sector, sought to reduce the weight of its products using titanium. Messier worked with the AMRC on its titanium machining capabilities, Boeing provided guidance and technical direction on the project, and two Sheffield-based companies (Nikken and Technicut) provided cutting and tool holder solutions. The end result enabled Messier to secure a £7bn order with Boeing to supply landing gear for the 787. For Boeing, the knowledge that the AMRC was involved gave it confidence they were procuring the very best landing gear.	• **Collaboration between JRI, Sheffield Hallam University and the University of Manchester:** JRI wanted to improve the durability of its orthopaedic implants, and so worked with Hallam University to utilise expertise in 3D modelling and stress testing of implants, and drew upon expertise at Manchester University to assess the residual stress profile at its synchrotron particle accelerator. This was the first time globally that an orthopaedic implant had been tested in this way. It enabled JRI to refine their manufacturing processes to maximise the durability of their implants, which has helped to maintain JRI's reputation of quality and integrity, and has improved its international competitiveness. • **Collaboration to develop novel knee ligament implant:** Sheffield Precision Medical (SPM) collaborated with a start-up business in Huddersfield, the AMRC and surgeons to develop and produce a new design of knee ligament implant using Computer Numerical Control equipment. The AMRC and SPM played a central role in designing and developing a new implant using 3D printing and testing, designing cost-effective manufacturing processes, and – crucially – the capability to work with surgeons to translate ideas and concepts into product solutions. The product is now being manufactured ready for market.
Nuclear consultees	**Rail consultees**
• **Forgemasters is currently involved in an R&D collaboration to develop more effective welding and advanced metal forming techniques**, which will involve an investment of £5m (part-funded by Innovate UK and DECC) between July 2015 and early 2018. The collaboration involves a number of SCR-based partners, including the AMRC (which is providing machining expertise and testing capabilities), Rolls Royce (who are contributing IP to deploy the techniques on an industrial scale), the University of Sheffield (bringing metallurgy expertise), and Sheffield Hallam University (with their expertise in fracture mechanics). TWI inputs have also been provided from across the UK in welding and non-destructive testing. Once completed, it is hoped the research will be of national and international significance, as it has the scope to change the way in which welding and advanced metal forming techniques can be undertaken.	• **Unipart Group has collaborated with Rolls Royce to create a new advanced manufacturing facility** "MetLase" on the Advanced Manufacturing Park, which opened in 2016. This joint venture focuses on the development and delivery of manufacturing solutions for advanced fixtures and products for use in contexts where precision and speed of deployment are critical. The joint venture will utilise advanced software and laser cutting technologies to reduce the time taken to design and manufacture specialist prototypes and products, ultimately improving customers' productivity. It will draw on Rolls Royce's patented software, and Unipart's routes to market. The joint venture will initially focus on the aerospace, automotive, motorsport and the medical technologies sectors, but the products could be applied across a range of sectors in the UK and globally. The facility was designed to provide SMEs from the neighbouring Advanced Manufacturing Park Technology Centre the opportunity to expand into larger premises for this kind of activity, as well as attracting high technology companies from elsewhere. It is now home to more than 50 high growth companies.

Source: SQW 2016

Supply chains

2.19 **Some of the companies are very focused on design and testing, and therefore the supply of inputs can be relatively small in volume**. That said, for example in the case of Magnomatics, the majority of components (around 60% by value) are sourced from businesses in the SCR, mostly from small, independent suppliers, and manufacturing services, specifically related to specialist advice on manufacturing processes, are provided by the AMRC. **For other companies, especially those which are part of international groups, a large proportion of inputs can be imported**. For example, B Braun imports c.99% of the products it sells from aboard (and most of these come from its Group network); and Nikken imports 80% of its inputs from its parent company in Japan. However, again, **where inputs are sourced in the UK, a large proportion of these are sourced locally**. B Braun works with local firms to manufacture very specialised medical equipment under the B Braun brand, and has utilised local firms for very specialised services, and for Nikken, the majority of inputs sourced from the UK come from the SCR.

2.20 **Where inputs are sourced from the UK, there is evidence of strong local supply chain relationships**. In part, the sector depends on high quality inputs and processes for products that are used in safety critical sectors – two consultees noted that trust and performance of suppliers is therefore paramount, and the ability to communicate face-to-face regularly and check performance with suppliers located close by is very important.

2.21 Examples of tightly integrated local supply chain ecosystems are presented below.

Figure 2-4: Examples of strong supply chain interactions

Aerospace consultees

- Reflecting the complexity of the aerospace industry, BAE has a national and international supply chain supported by a local ecosystem of suppliers based in and around Lancashire. BAE's average procurement spend for the Eurofighter Typhoon in the North West is almost £25m, and spending in Preston by all of BAE's business units was £165m in 2013. Key suppliers include:
  - Kaman Composites UK (based in Lancashire) who design and build components/structures with particular expertise in composites
  - The Hyde Group (headquartered in Greater Manchester) who provide machining solutions
  - Magellan Aerospace (in Blackpool, Lancashire) which specialises in components and assemblies for aero-structures and landing gear.
- For Boeing, a number of UK capabilities support the development of the 787, some of which are sourced from suppliers in the SCR (e.g. Rolls Royce provides engines, AMRC provides research in manufacturing). In addition, some of Boeing's top UK suppliers sub-contract activity to SCR-based businesses: e.g. Rolls Royce and Messier sub-contract inputs from AML Sheffield (which provides expertise in machining technology) and Alcoa Sheffield (which provides forging and extrusion expertise), and UTC Aerospace Systems in Wolverhampton sub-contracts to AML Sheffield.

Medical technologies consultees

- JRI's supply chain is tightly integrated in the SCR. Most of its raw materials are sourced from the area – its three largest suppliers are Sheffield-based businesses:
  - Symmetry Medical (manufacturer of surgical instrument, orthopaedic implant, and sterilization case and tray markets)
  - Orchid (offering design, forging, casting, machining, plastics technologies and implant bone in-growth coatings)
  - Sheffield Precision Medical (which manufactures medical instruments).

Nuclear consultees

- Most of Forgemasters' inputs are sourced from within the SCR
- In 2014/15, the Westinghouse Springfields site spent over £100m with some 800 suppliers. In terms of future growth opportunities, SMR could be very significant for the firm and the UK's wider nuclear supply chain. Westinghouse's own analysis has concluded that most of their SMR supply chain is accessible to the UK. A study by the AMRC on the Reactor Pressure Vessel indicated that whilst the UK had the capability (e.g. large forgings, advanced manufacturing techniques), supplier capacity could be the limiting factor if several reactors were to be ordered simultaneously.

Rail consultees

- Alstom's Preston site sources directly, usually within the UK, to deliver long-term service contracts. Its key suppliers include William Cook, a specialist supplier of steel castings to the rail and other industries, based in Sheffield and Leeds. Other products which are regularly bought-in by the Preston site include circuit boards, rewound motors and sheet metals.
- The majority of Schwihag UK's suppliers are based in the SCR or the Midlands. For example, it sources steel from Scunthorpe and gets the casts for its rail plates from foundries in Sheffield and Nottingham.

Source: SQW 2016

The Sheffield City Region and Lancashire Science and Innovation Audit
'Deep Dive' Research into International Activity, Collaborations and Supply Chains across the Advanced Manufacturing Sector – Synthesis of key findings [DRAFT]

Growth opportunities, barriers and priority actions

2.22 Whilst there is some variation in the exact nature of future growth opportunities and barriers in each of the priority sub-sectors that the SIA is focusing on (e.g. SMRs in nuclear and continued participation on the F-35 programme in aerospace etc.), **there are a number of common themes that span across the sectors.** Specifically, consultees argued that the SCR and Lancashire are well placed to take advantage of:

- growing demand for high quality products at low cost, drawing on the area's expertise in advanced manufacturing processes and materials
- increased demand for "whole system solutions", building on the area's critical mass of businesses, research assets and world class skills that can provide advanced manufacturing expertise and capability throughout the whole process of designing, developing and manufacturing products
- the opportunity to adapt existing capabilities in high precision processes and high performance materials for different sectors and contexts, such as hostile or difficult environments, where extreme stress endurance is critical
- Industry 4.0, especially in its ability to drive continuous improvement and ultimately business productivity.

2.23 There are also, however, **common threats and barriers that apply across the advanced manufacturing sub-sectors** that will need to be addressed in order for the SCR and Lancashire sub-regions to realise these growth opportunities fully:

- skills gaps – this includes engineers with the right skills to work in an Industry 4.0 setting (i.e. with digitals skills such as visualisation), commercialisation skills and market understanding, leadership and management skills, and a combination of engineering *and* language skills (to access export markets)
- a need for greater collaboration in order to develop "whole system solutions", and transfer existing capabilities into new sectors/contexts
- the long tail of businesses who are not engaged in innovative thinking or activities, and who struggle to find the capacity (time and finance) and/or capability to engage effectively in innovative collaborations.

2.24 Consultees suggested a number of actions that could help to address the challenges outlined above, including:

- access to finance (especially for prototyping)
- access to state of the art R&D facilities (and their research) – the NWAMRC was mentioned in this context
- access to high quality and flexible physical workspace for innovative start-ups in the sector

- support to improve leadership and management skills and innovation cultures across the wider business base, for example through the proposed Productivity Academy
- actions to encourage more/better interaction and collaboration, including mentoring, networking events which are joined up and specifically tailored for the advanced manufacturing sector, continuing to promote assets such as the AMRC to provide 'hubs' for collaboration (and ensuring that the supply chain links to these)
- better collective marketing of the SCR and Lancashire's – and the wider North's – complementary capabilities in advanced manufacturing.

Figure 2-5: Sector-specific opportunities, barriers and priority actions

General advanced manufacturing consultees

- Opportunities include:
  - The ability to **adapt high precision processes and high performance materials in different sectors and contexts**, such as hostile or difficult environments where extreme stress endurance is critical
  - Linked to the above, the concept of a **catapult style 'Glass Futures' initiative** is still in its early days, but is beginning to build momentum and is supported by major firms including Siemens as well as the University of Sheffield and Sheffield Hallam University. The proposed facility would provide an environment in which the glass industry in the SCR-Lancashire sub-regions (and elsewhere in the Northern Powerhouse and beyond) can collaborate at a site near to the existing AMRC. "*The facility will be modelled on the existing Catapult Technology Centres, **designed to deliver innovation into the UK glass manufacturing industry**, co-create and retain intellectual property in the UK generated from research into the multiple applications of glass and glassy material in the spheres of industry, photonics, computing and bio-medicine and in the process create a palette of new materials."*
  - **Industry 4.0 is a key growth opportunity for the future**, particularly around cyber-physical systems and their inclusion of a feedback loop allowing physical processes to affect computations, and computations to affect physical processes. This has the potential to lead to machine self-learning and drive continuous improvement. Greater adoption of automation and robotic systems could also make a significant difference to business productivity[2]
- Key threats/barriers/actions identified by consultees included:
  - the lack of suitable skills. The SCR and Lancashire need to **ensure that the engineers of the future are equipped fully with the right skills to work in an Industry 4.0 setting**. This will include increased training for engineering students in digital skills such as visualisation, but also promoting this emerging side of the engineering industry to digital graduates who would otherwise go down the more established pathway of using their skills in the games sector etc. Other skills issues include difficulties in finding individuals with language *and* engineering skills, and engineers with marketing skills.
  - a concern around the **long-term funding of the major research assets**, such as the AMRC, and the risk that as assets broaden their membership to become more financially sustainable, it may compromise **their ability to remain at the forefront of innovation**
  - a **lack of confidence to invest following the Brexit** Referendum, particularly for businesses whose UK sites act as EU headquarters for global brands
  - **failure of localised supply chains in the SCR and Lancashire to respond effectively to the new drivers of change** within advanced manufacturing markets and for these firms to **lose their global competitiveness**.
  - a **long tail of (often very small) businesses in the supply chains who are not engaged in innovative thinking or activities.** If more of these businesses could be encouraged to get involved, productivity of the region as a whole would benefit. Suggested actions included improved **access to finance**, **mentoring**, **networking and showcasing events**, **ensuring that R&D disseminated from research assets is 'accessible'** for the wider business base, and providing **physical space** for innovative start-ups in the advanced manufacturing sector. This would also ensure that supply chain activity is not lost to new emerging clusters abroad.

[2] According to one consultee, a study by Copenhagen Business School found that if the UK and Ireland were to adopt automation and robotic systems to the same extent as leading countries (such as Germany and Japan) productivity could rise by up to 22%, and long-term employment by 7%, representing a major growth opportunity for SCR and Lancashire (and the UK as a whole).

Aerospace consultees

- Opportunities include:
  - The aerospace market continues to grow, driven by increasing demand for air travel and the need for modern aircraft in both civilian and military defence markets. As a result, opportunities lie in the **processing of inputs, advanced / lightweight / high integrity materials, and expertise in how best to exploit these** in aerospace (and other) applications. This really plays to the SCR and Lancashire's strengths.
- Key threats/barriers/actions identified by consultees included:
  - Customers are demanding **ever greater levels of efficiency and quality**, which will demand improvements not just from the primes, but also from their supply chains
  - **International customers are demanding that more production processes happen in their country** in order to develop localised high tech clusters. Companies in Lancashire and the SCR must embed more innovation activity locally (e.g. by enhancing local links with key innovation partners and universities) in order to preserve their competitive advantage.
  - A concern that the supply chain is failing to meet changing demand, and is **struggling to raise its productivity** to match international competition
  - **Inertia** is an issue for a large proportion of businesses. Engaging these in the work and knowledge transfer activities of research assets (such as the AMRC) is important
  - **Capacity** is an issue, in the ability of businesses – especially smaller ones in the supply chain - to commit resources to work with research assets and other businesses. Also, they don't always have the capability to operate in the digitally enabled environments needed for the implementation of Industry 4.0.
  - **Difficulties in finding the right type, quality and volume of skills** remains a challenge. There is a need for skills providers and employers to work together to raise the profile of the advanced manufacturing sector to change perceptions, and the curriculum must also be redesigned to reflect the changing needs of employers in this sector. There is also concern about **gaps in leadership and management** in the sector, to enable businesses to complete in international market places.

Medical technologies consultees

- Opportunities include:
  - **Developing high quality medical instruments at lowest possible cost**, which requires innovation in automated / advanced manufacturing technologies
  - the move towards "**whole system solutions"** that provide clients with healthcare products and solutions (i.e. a package of components, tools etc.)
  - huge **international demand for medical equipment and technologies**, particularly in large countries with ageing populations who want to lead longer, more active lives (e.g. China)
  - the **greater use of new materials** (e.g. graphene) in medical devices
- Key threats/barriers/actions identified by consultees included:
  - the **need for greater collaboration** to develop "whole system solutions" and more cost-effective technologies / devices. Assets such as the AMRC are playing an important role as a 'hub' to bring partners together. A comprehensive and freely accessible 'map' of relevant capabilities across the academic and business base would also be helpful to enable networking
  - **a wealth of businesses in the sector who are not regularly innovating**, or doing so in a sustained way, to develop better products and/or export – a key challenge is changing mind-sets, for example, through networking and good practice case studies
  - the need for **better, collective marketing** of the SCR and Lancashire offer and the wider North's capabilities that are relevant to the medical technologies sector on an international scale
  - concern about the **future supply of skills**, especially those with technical experience and knowledge (which have an ageing demographic) to underpin the manufacturing services/support sector. Also, the availability of labour with **technical *and* language skills**, to enable export expansion, and the supply of '**next generation leadership'** in technology know-how and new product and business development
  - **capacity and funding for businesses (especially SMEs) to invest in R&D** and innovative technologies, and specifically to test the commercial viability of novel concepts.

Nuclear consultees

- Opportunities include:
  - Nuclear is a major growth opportunity for the SCR, Lancashire and the North more broadly, especially in the **development of new generation plants (e.g. Moorside) and SMRs to sell to the global market place.** Westinghouse suggests a UK-based entity that will allow the Government and industry to actively participate as an <u>owner</u> in the design, manufacture, and global deployment of SMRs.
  - The area has the manufacturing and ancillary expertise to be a first mover in SMRs. For example, opportunities exist to significantly reduce manufacturing lead times by using advanced manufacturing techniques such as advanced welding, advanced non-destructive examination, and portable machining for critical safety-related components, powdered metal hot isostatic pressing and various additive manufacturing technologies.
- Key threats/barriers/actions identified by consultees included:
  - In the context of SMRs, a study by NAMRC indicated that whilst the UK had the capability to respond to global opportunities (e.g. large forgings, advanced manufacturing techniques), supplier capacity could be the limiting factor if several reactors were to be ordered simultaneously.
  - The **ability to fund prototyping** is critical to taking advantage of these opportunities. There is considerable uncertainty around future funding post-Brexit
  - **More networking events for the advanced manufacturing sector** would help encourage collaboration to develop new technologies/products for the nuclear sector (events/networks exist, but they are often too generic or not region-specific)
  - **Greater clarity and transparency on the direction of Government policy** would also help to inform businesses' R&D investment plans.

Rail consultees

- Opportunities include:
  - the greater use of **digital platforms and big data** in the rail sector, including to maximise effective utilisation of infrastructure
  - developing **new lightweight materials** (and the processes required to manufacture these) for the rail sector
  - improving **energy consumption and utilisation.**
- Key threats/barriers/actions identified by consultees included:
  - A lack of understanding amongst many businesses about what the market might want in future, and being ahead of this curve.
  - A **shortage of labour with appropriate skills to translate ideas into commercial applications,** and how new products/processes can be taken to market (including exports). More generally, there is concern about the ageing workforce in the rail sector, and the implications for the skills base around replacement demand
  - The **availability of finance and facilities to do prototyping and simulation** to prove new ideas are financially viable/exportable/safe

Source: SQW 2016

This report was produced for the Department for Business, Energy and Industrial Strategy. The consortium overseeing the audit represents the key innovation partners in the Sheffield City Region and Lancashire Local Enterprise Partnership areas.

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