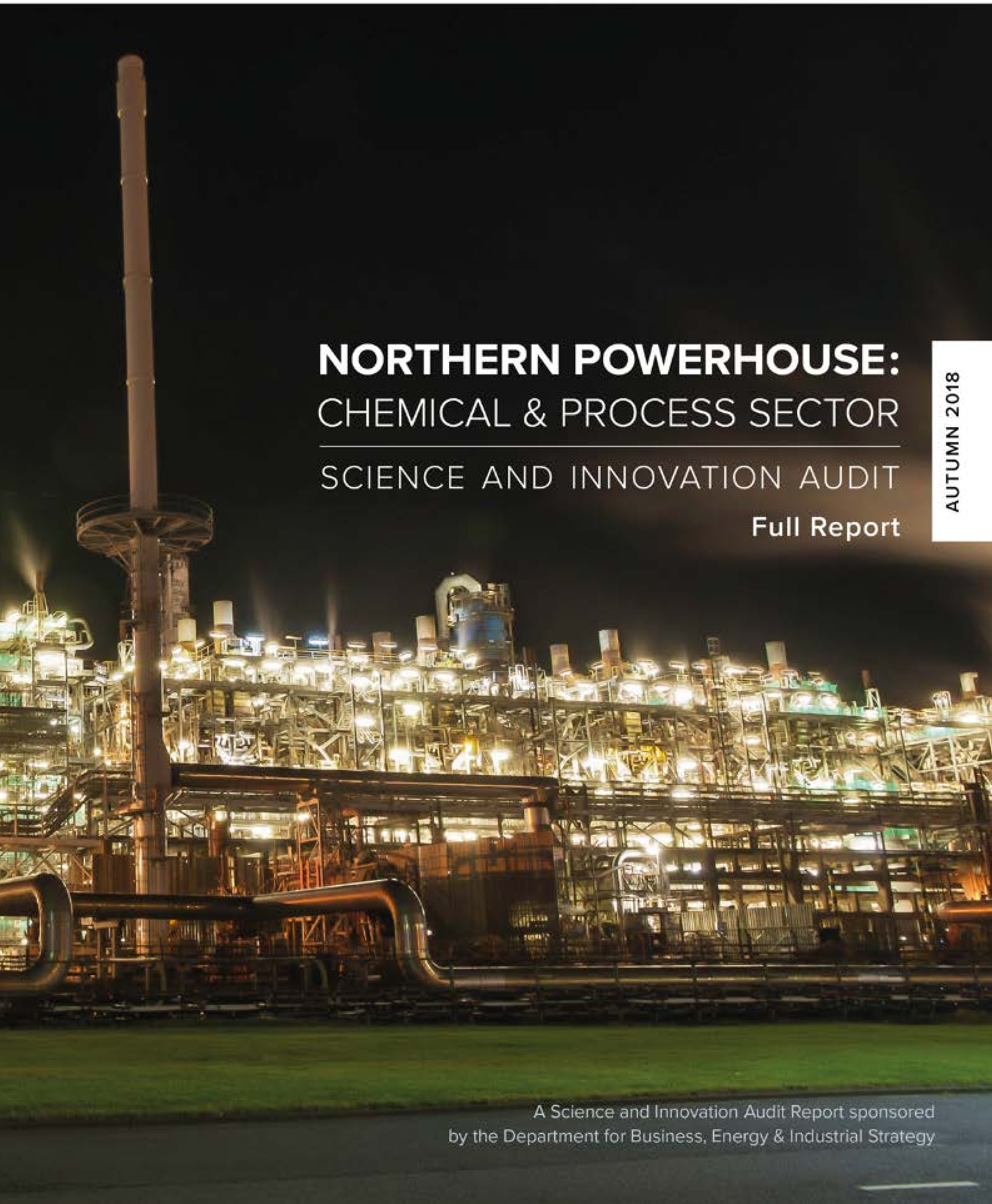
NORTHERN POWERHOUSE
HM Government

Department for
Business, Energy
& Industrial Strategy



NORTHERN POWERHOUSE:
CHEMICAL & PROCESS SECTOR

SCIENCE AND INNOVATION AUDIT

Full Report

AUTUMN 2018

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

Acknowledgements

This Science and Innovation Audit would not have been possible without the work of the following:

Writing and Editorial Team

Tim Hammond, Durham University

Keith Wilson, Tees Valley Combined Authority

Contributors

Geoff Archer, Teesside University

Sarah Bowman, Tees Valley Combined Authority

Ross Burton, Smart Specialisation Hub

Steve Elliot, Chemical Industries Association

Steve Fletcher, Knowledge Transfer Network

Will Haywood, Tees Valley Combined Authority

Beth Kazmierski, Durham University

Chris McDonald, Materials Processing Institute

Chris McNally, McKinsey and Company

Greg Oxley, Durham University

Xavier Potau, Technopolis

Cristina Rosemberg, Technopolis

Steering Group

Paul Booth, Tees Valley Combined Authority (Chair)

Philip Aldridge, NEPIC

Geoff Archer, Teesside University

Chris Beck, TWI

David Brown, Technopolis

Linda Edworthy, Tees Valley Combined Authority

Malcolm Hannaby, Innovate UK

Graham Hillier, CPI

Gareth Fletcher, Materials Processing Institute

Mark Lewis, Tees Valley Combined Authority

Chris Oswin, Materials Processing Institute

Sarah Tennison, Tees Valley Combined Authority

Laura Woods, Teesside University

Iain Wright, NEPIC

Special Thanks

Special thanks to our interviewees and plenary session participants, whose contributions in formulating the key messages of this report were both insightful and immensely useful.

Table of Contents

Northern Powerhouse Chemicals and Process Sector

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

Executive Summary

0.1 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 Northern Powerhouse a consortium was formed in 2017 to focus on our strength in the chemicals and process sector. This report presents the results which includes a broad-ranging analysis of the Northern Powerhouse's chemicals and process sector's capabilities and the challenges and the substantial opportunities for future economic growth. The vision for the study is:

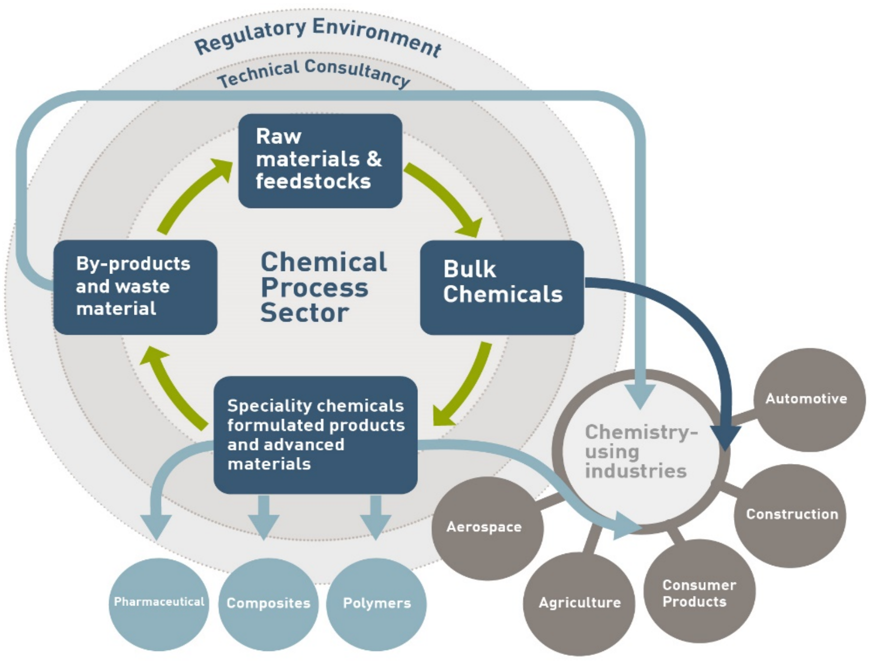
''To ensure that the Northern Powerhouse contributes to the successful delivery of the Strategy for Chemistry fuelled growth that by 2030, chemistry using industries will increase their contribution to the UK economy from £195 billion to £300 billion''.

0.2 This audit will test the hypothesis that the Northern Powerhouse chemicals and process sector continues to be globally competitive with a particular focus on the region's innovation ecosystem.

Sectoral Definition

0.3 For the purposes of this audit, the chemical and process sector encompasses the range of industries in which raw materials are processed through chemical conversions to give finished products, where the products and raw materials differ from one another as a result of undergoing one or more chemical reactions during the manufacturing process. It is differentiated from the broader manufacturing sector which predominantly makes physical conversions to materials **[1]**. Figure 1 provides a schematic exemplifying the interaction between the chemical process sector and chemical using industries:

Figure 1: Sectoral Definition



Sector in context of UK Economy

0.4 Table 1 provides a high-level summary of the chemical and process sector's contribution to the UK economy, based on initial analysis developed to support the Chemical Growth Strategy's 2030 Vision:

Table 1: Sectoral Contribution to the UK Economy [3]:

Sector	SIC Code	Baseline as per CGS Vision [2] (£bn)	Approx UK GVA (£bn) 2010	Approx UK GVA (£bn) 2016
Chemical manufacturing	20	10	10.3	9
Pharmaceutical manufacturing	21	9	9.6	8.9
Automotive	29	11	10	17.1
Aerospace	30.3	7	5.8	6.5
Construction	43.2, 43.3	23	25.5	32.1
Extraction of oil and gas	6	24	22.2	8.1
Provision of electricity	35.11	6	4.5	6.9
Sub-total		**90**	**87.9**	**88.6**
Consumer products and other	10,16-19, 22-28, 71.12	105	105.8	123.7
Grand total		**195**	**193.7**	**212.3**

0.5 The UK's chemistry-reliant industries can be split into two categories: the 'upstream' consisting of chemical producing industries and 'downstream', chemical using industries. The chemicals and process sector is an enabling industry, helping provide technological solutions to many challenges faced by other parts of the economy – it underpins sustainability in downstream industries such as healthcare, electronics, automotive and textiles among others.

Comparative Performance of the Chemicals Sector

0.6 Table 2 compares Gross Value Add (GVA) (output), employment and the GVA per employee (productivity) for the key UK manufacturing sectors:

Table 2: Comparative GVA and employment across the UK manufacturing sector [3]

Sector	SIC code	UK GVA	UK Employment	GVA per employee
Chemicals and Process Sector	**20-22**	**£20,135m**	**140,000**	**£144,000**
Chemical Manufacturing	20	£8,957m	100,000	£90,000
Pharmaceutical manufacturing	21	£8,885m	40,000	£222,000
Automotive	29	£17,120m	159,000	£108,000
Aerospace	30.3	£6,490m	100,000	£65,000
Construction	43.2 & 43.3	£32,064m	600,000	£53,000
Extraction of oil and gas	6	£8,128m	16,000	£508,000
Production of electricity	35.11	£6,885m	28,000	£246,000
Consumer products and other	10,16-19, 22-28, 71.12	£123,700m	2,041,000	£61,000

0.7 Whilst the upstream chemicals sector accounts for c£20bn (9.5%) of manufacturing output, it has a downstream impact on c£212bn or 90% of the UK manufacturing sector. The sector accounts for 140,000 employees (6% of UK manufacturing workforce), however it has a GVA per employee of £144,000, which is significantly higher than the GVA of both the aerospace (£65,000) and automotive (£108,000) sectors.

Contribution to International Trade

0.8 The UK continues to be a significant player in the global chemicals market, however it is important to place the value of the sector relative to other worldwide markets. Table 3 summarises comparative sales of chemicals amongst the leading markets using data sourced from CEFIC Facts and Figures 2017 of the European Chemical Industry **[4]**, CEFIC Landscape of the European Chemicals Industry (2018) **[5]** and Worldometers.info world population estimates by country **[6]**.

Table 3: Comparative sales of chemicals amongst the leading markets (2017 data)

Country	Sales (Billion €)	Population (Million)	Sales per head of population (€)
China	1,331	1,415	941
USA	476	326	1,460
Germany	185	82	2,256
Japan	140	127	1,102
South Korea	113	51	2,216
India	76	1,354	56
France	70	65	1,077
Taiwan	63	23	2,739
Spain	63	46	1370
UK	**60**	**66**	**909**
Brazil	59	210	281
Netherlands	55	17	3235
Italy	52	59	881

0.9 The most significant growth has been in the emerging markets such as China, India and Brazil. The global market is expected to grow by a further 3% in the next 20 years as the Asian industry and industry in the Middle East continue to grow. By 2030, Asia is expected to account for almost two thirds of the global chemical industry market **[4]**.

0.10 Demand for chemicals, particularly intermediate and finished goods continues to expand both in Britain and globally. However, what is in question is the UK's ability to meet both indigenous and export demand, as increasing competition from both East (e.g. China) and West (e.g. USA) is driving down revenues and making it harder for UK-based firms to compete in the global marketplace.

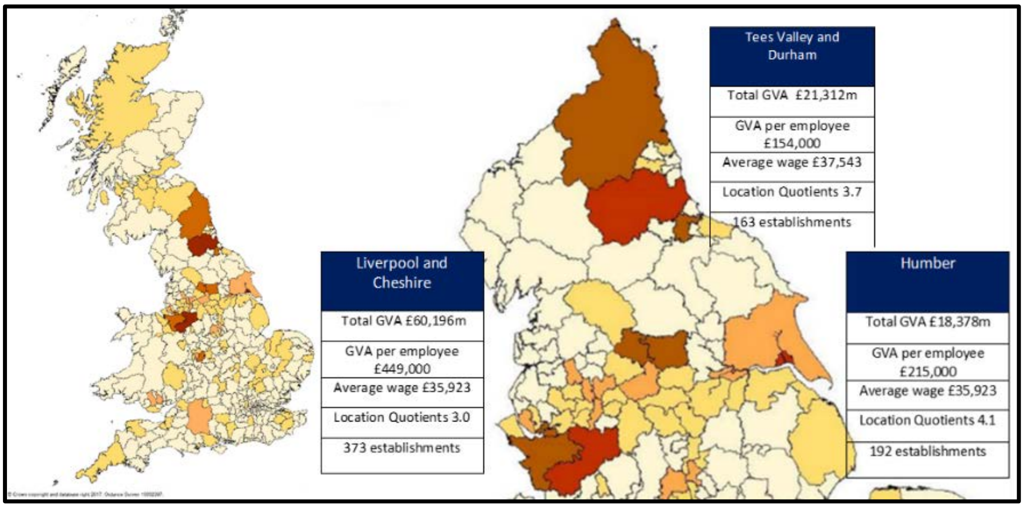
The Northern Powerhouse (NPH)

0.11 The Science and Innovation Audit (SIA) geography is the Northern Powerhouse area, covering the 11 North of England LEP areas and it has the following profile:

- Total GVA: £325bn (UK total £1,651bn);
- Working Age population: 9.89m (UK total 41.4m);
- Productivity per head: £21k (UK: £28.2k);
- Number of active companies: 546,360 (UK: 2.83m);
- Business density 30.85 per 1,000 (UK 36.95); and
- Percentage in employment with NVQ4+: 37.9% (UK 43.5%)

0.12 The NPH has by far and away the most significant impact on the sector GVA. The UK chemical and process sector has a GVA of £28.04bn representing 15.8% of the UK manufacturing sector. Of this, The NPH chemical sector represents £13.40bn GVA, 48% of the UK sector total. The sector represents 26.5% of all NPH manufacturing GVA, compared with the UK average of 21.2%

Figure 2: The Northern chemicals cluster, where the sector works



0.13 The Northern Powerhouse chemicals proposition is based on three strong clusters interlinked by strong East- West supply chains:

- Tees Valley and County Durham;
- Humber LEP area; and
- A combination of Cheshire and Warrington and Liverpool City Region LEP (Cheshire and Merseyside).

0.14 As noted in Figure 2, the variation in GVA across these 3 clusters must be considered in the context of the scale of enterprise and the particular sub-sector it is operating in:

- Humber and Tees Valley have high location quotients in manufacture of fertilisers and nitrogen, manufacture of organic chemicals and manufacture of dyes and pigments;
- Liverpool and Cheshire have high location quotients in manufacture of inorganic basic chemicals and manufacture of pharmaceutical preparations and also have the largest companies by scale (and consequently a greater number of higher value adding functions).

0.15 The significant variance between the regional clusters is largely attributable to the scale of enterprise and the particular sub-sector they are operating in, rather than a difference in productivity. However, it does clearly demonstrate the need to provide more value adding operations both in terms of activity (RD&i) and a move up the value chain (i.e. not merely the manufacture of basic chemicals, but the development of intermediate goods and more integrated supply chains).

Industrial Profile of the Sector

0.16 The chemical sector across the UK and particularly in the NPH is mature, both in the technology being used and also the sectoral age profile. There are few new business start-ups and a relatively low churn (i.e. few company closures). In addition, the sector has a high proportion of middle and large-scale companies, with the former generally delivering intermediate goods to the latter for subsequent exporting. Most middle tier companies are indigenously owned and generally compete in terms of price, whilst the large companies are mostly 'branch plants' of international concerns with overseas headquarter and research functions.

0.17 The sector has relatively few new business start-ups, this is largely attributable to the maturity of the technology (no immediate disruptor technologies) and high start-up costs (as the sector is capital intensive).

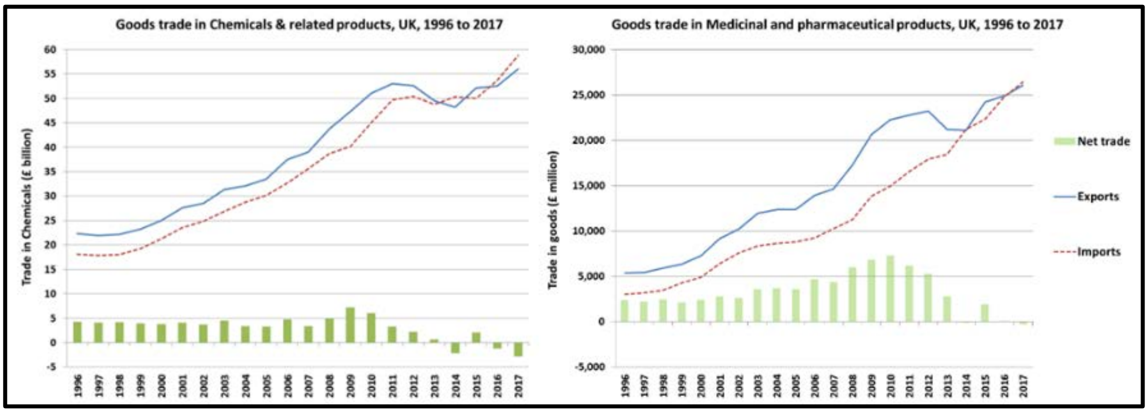
0.18 Unlike other sectors of a similar level of maturity, chemicals and process companies are becoming more fragmented at the same time as having a significantly higher proportion of (largely family owned) middle tier companies. Much of this fragmentation is the result of overseas buy out, designed to increase market control and secure supply chains.

0.19 The chemicals industry within the Northern Powerhouse has traditionally had a very strong export orientation. Trade, both in terms of imports and exports of chemicals has more than doubled in the last twenty years, which is in line with the overall economy, however the significance of the chemicals sector to Britain's overall trade figures continues to increase, but at a declining rate, in particular:

- Chemicals exports have risen from circa £23bn in 1996 to £56bn in 2016 with a more significant rise in imports from a baseline of circa £18bn in 1996 to £58bn in 2016 (overall exports have risen from £167bn in 1996 to £306bn with imports rising from £180bn to £462bn in 2016); and
- In proportionate terms, the importance of the chemical sector has increased from 14% to 18% for overall exports and 10% to 12% in terms of imports.

0.20 Figure 3 shows that 2013 was the first unfavourable imbalance in trade for the chemicals and related products sector. This fall mirrors that in the pharmaceutical products sub-sector which represent nearly 50% of export trade and can largely be attributed to a number of Astra Zeneca products going off patent in 2011/12 (see details in Chapter 6). However, the increase in imports for the NPH is at a faster rate than growth in the sector as a whole, indicating that imports are substituting domestic production and in increasingly higher value-added elements such as medical & pharmaceutical products, i.e. 19 times the value in 2016 compared to 1996. This sub-sector accounted for £3.5bn (42%) of the total increase of the whole Chemicals sector.

Figure 3: Net Trade for the Chemicals and related products 1996-2017



0.21 The reduction in exports has been across the board including price sensitive sub sectors like manufacture of organic chemicals and fertilisers and nitrogen, but also in high value products such as pharmaceuticals.

0.22 In short, the Northern Powerhouse is losing its competitiveness, access to supply chains and export orientation across the full range of products, at the same time as a proportionate decline in export activity across most chemical sub-sectors. This decline in export orientation may have a causal effect on the level of innovation activity undertaken.

0.23 As noted above, the sector is dominated by large overseas controlled companies and circa 500 middle tier companies who largely compete on price in established supply chains. This has manifested itself in two ways:

- A useful proxy for business expenditure on research and development is tax credits. Of the total claims 20.5% were from the NPH region (business base of region is 23%), accounting for 11.4% of the total amount claimed and 9.6% of the total expenditure. These figures suggest the NPH region could be doing more to invest in R&D; and

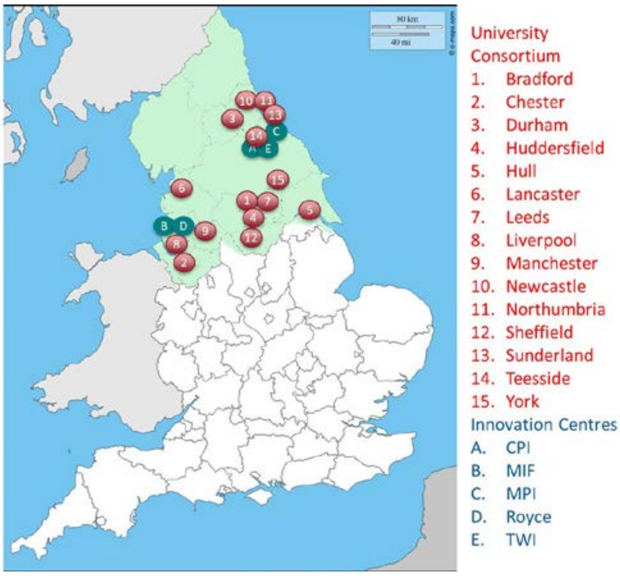
- Location information based on where R&D is actually performed rather than the location of the head office shows a disproportionately large amount being spent on R&D in the South East and East of England, with under-representation within the Northern Powerhouse.

0.24 There is a need to curb the loss of market share/reduced export orientation and this may be largely mitigated through investment in innovation. The development of and investment in the circular economy and resource efficiency represents a significant opportunity for the chemical and process sector to re-shore activity and build new product bases. The use, re-use and remanufacture of raw materials and products aligned with further resource efficiency has the potential to address many of the present sector asks. In addition, industrial digitisation and particularly mass machine learning has the potential to mitigate sectoral fragmentation and address the coordination market failure which usually impedes the roll out of circular economy solutions at the industrial level.

Innovation Ecosystem

0.25 The Innovation ecosystem of the UK and the NPH was assessed from the perspective of academic research quality, University engagement with industrial base, business R&D spend, Government innovation support, IP filed and Research and Technology Organisations' (RTO) activity. The UK research base in the selected sectors continues to be globally competitive, particularly in terms of quality of research. This theme of international competitiveness is reflected within the NPH region, which although it is a comparatively small region, the NPH has a number of individual institutions which have international status and continues to attract significant UK and foreign research investment.

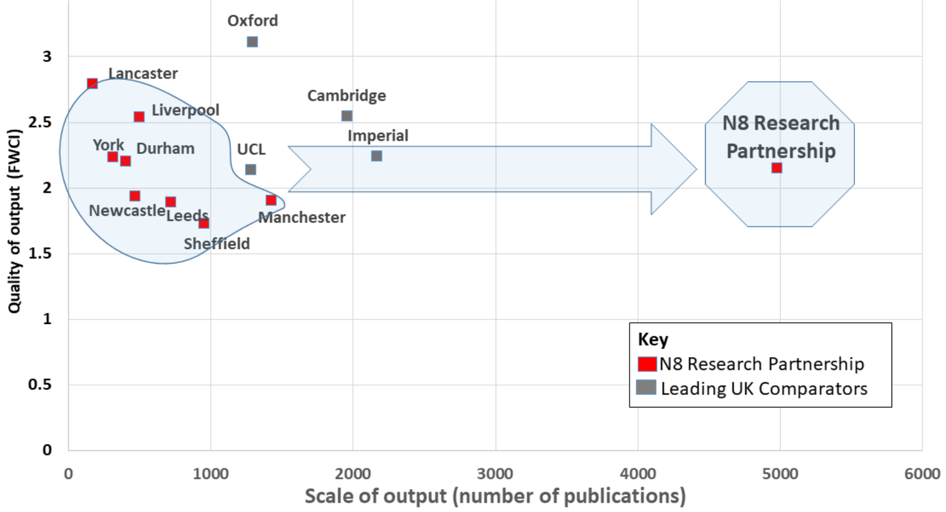
Figure 4: Innovation ecosystem



0.26 The leading research institutions within the SIA area demonstrate strong research quality across the academic disciplines related to the chemical and process industry. Particular strengths were highlighted in materials sciences, chemical synthesis, chemical measurement, atmospheric physics and chemistry. This high-quality research on an individual institutional level indicates that there is strength in depth across the chemical process sector within the SIA area that could be utilised to deliver innovation and enhance the region.

0.27 Figure 5 presents the amalgamation of an analysis of research quality (as measured by the field weighted citation index) across the key innovation needs identified across all six chemical and process sub-sectors against publication quantity for the Universities within the SIA. The combined scale and quality of research outputs if deployed collaboratively and collectively would outstrip larger national comparator institutions several-fold. There is therefore potential for more collaborative working between disciplines and across institutions.

Figure 5: Scale and quality of research, the potential impact of collective R&D delivery



0.28 It is not surprising, considering the geographical strength of this sector that there is a northern cluster of internationally and nationally important Catapults and other National Innovation Centres that support the chemicals and process sector. The consortium includes the Centre for Process Innovation (CPI), the Materials Processing Institute, TWI, the Royce Centre and Materials Innovation Factory. These innovation centres work closely with academia and industry to foster and encourage innovation in key areas.

0.29 Analysis of Business R&D spend within the sector has shown that there is evidence of disconnect between where the products are manufactured within the SIA area and company research, where a significant proportion is outside of the NPH. As would be expected, pharmaceuticals research is by far the largest focus followed by chemical manufacturing and speciality chemicals. Relatively little is spent on R&D in plastics, polymers and materials.

Innovation Coordination

0.30 Innovation coordination has been a common theme across all Wave 2 and Wave 3 SIAs and of particular importance is Coordinated Innovation and Business support; Strategic Investment and access to finance; and recognition of sector identity through a single body. These closely align with the conclusions arising from this SIA and are explored more fully in Chapter 9.

0.31 There are very clear technological linkages in particular with the work of the Applied Digital SIA in the application of digitisation to the chemicals and process sector and both working groups have closely collaborated in developing their audits and actions. Further facilitation of adoption of digital technologies is needed to drive general economic benefits to the process industries from reduced operational costs, lower maintenance costs and improved decision making. McKinsey & Company estimates that "Digital can drive significant productivity improvements to the order of 30 – 40% EBITDA increase across the industry" **[7]**.

0.32 The SIA has identified the Circular Economy and resource efficiency as a strong enabler that runs across the key sub-sectors as a means of reshoring activity and driving growth. This is showing close alignment with messaging on the importance of eco-innovation and clean growth within the NW Coastal Arc Clean Growth SIA. Both groups have been in preliminary discussions and will seek to continue dialogue on coordinated and collaborative interventions post completion of the audit phase.

0.33 A very clear message emerging from the study is that there could be more collaboration with a focus on industry challenges which will underpin competitiveness and future growth of the sector. This is reflected in some fragmentation in the present innovation ecosystem, both between Universities and the National Innovation Centres, and gaps in ability to respond to the company needs. In this context, a model that spans the working principles of two best practice exemplars, the Northern Sustainable Chemistry (NORSC) consortium and the Knowledge Centre for Materials Chemistry (KCMC) should be considered as a mechanism to address industry challenges in simpler ways and ultimately expand R&D investment in the region.

0.34 Additional process support investment is needed to reflect the relative maturity of the sector with large capital requirements for "traditional" plant. The development of more flexible, smaller scale processes through increasing personalisation and customisation provides good opportunity for growth.

0.35 Alignment of the chemical and process sector supply chains to key applications that have been prioritised for chemical using industries within the UK Industrial Strategy will be critical. A detailed mapping of future needs aligned to the present base will lead to opportunities to: strengthen existing supply chains by reintegrating them using next generation technology.

Growing Importance of Place

0.36 Unlike other sectors, it is our contention that even though ownership is becoming increasingly fragmented, technological advancement such as industrial digitisation and the circular economy may facilitate more integration. In addition, industry is becoming increasingly clustered in fewer but more globally competitive locations which have the essential prerequisites to compete. Table 4 prioritises the key components of regional and sectoral growth and identifies mechanisms for its further enhancement within the Northern Powerhouse:

Table 4: Priorities of the key components of regional and sectoral growth

Priority	Description of Activity
1) Access / Cost of Feedstocks	The availability of inexpensive natural gas in the Gulf Coast has been the key to its success as the gas is used as a feedstock in the production of various chemical commodities. This in turn has brought significant investment to the region in what is called the 'shale gas boom'. The local sourcing of affordable resources, will not only permit import substitution, but will also be a prime motivator for the reshoring of further production methods. The price of feedstocks was judged to be the most important factor in support of inward investment.
2) Access to transport / location of main markets	The Catalisti cluster was set up to capitalise on access to transport, encourage more co-location at transport hubs, create supply chain solution and address any constraints through the development of cross sectoral partnerships between small and large companies, research institutions and government organisations.
3) Application of emergent technologies	Digitisation of chemicals manufacturing is the cornerstone of the Industry Transformation Map for the energy and chemical sector in Singapore. It is anticipated that it will support productivity through automated measurement using advanced manufacturing sensor technology, sophisticated data analytics and visualisation will enable improved manufacturing efficiency while connectivity across the supply chain will streamline the sector as a whole. There will be implications too for the safety of people and assets, as well as cybersecurity.
4) Skilled labour force	The Economic Development Board for Singapore have supported consultants, Accenture in mapping digital skills needed including data and trend analysis, automation management, cybersecurity, big data management, modelling and simulation and user interface design.
5) Innovation Ecosystem	The Chemelot Innovation campus model provides a creative ground for innovation and for new company formation. Key impacts include: higher rates of business start-up; and enhanced translational research, through the co-location of research facilities and provision of on-site knowledge transfer partnerships.

Conclusions and Recommendations

0.37 In assessing the ability of the Northern Powerhouse to successfully deliver the Strategy for Chemistry Fuelled Growth the Table 5 SWOT analysis noted the following:

Table 5: SWOT Analysis of the Northern Powerhouse Chemicals and Process Sector

Strengths	Weaknesses
• Individual institutions with world class research; • Strong national innovation centre presence; • Strong geographic clusters in Tees Valley, Humberside and Merseyside; • Highly integrated supply chains; and • Recent upturn of investment/buy outs of and by indigenous companies.	• Business R,D&I conducted outside the region; • Disconnect between research base and technology translation functions; • Lack of recognition of the critical mass across the Northern Powerhouse • Mature sector with high costs of entry to new starts; and • Limited investment in research and development, particularly amongst mid-tier domestically owned companies.
Opportunities	**Threats**
• Increase in demand in global markets for intermediate and higher value adding goods; • Use of nascent technologies and new energy feedstocks; • Increased demand for reshoring and use of circular economy solutions; • Opportunities for use of industrial digitisation; • Opportunities to utilise sectoral free trade zones in conjunction with blockchain solutions • Opportunities to use Northern Powerhouse Diaspora/Develop the brand; • New models for commercialising technologies: public/private partnerships and associated financing mechanisms; and • Significant opportunities for scale and growth particularly in mid-sized companies.	• Consolidation into a small number of globally competitive clusters; • Increased costs related to feedstocks; • Increased price sensitivity and competition for intermediate goods; • 'Greying workforce' with fewer high skilled opportunities; and • Supply chain integration through buy out and further denudation of higher value added functions.

0.38 In response the following actions have been developed:

- Develop a unique selling point for the Northern Powerhouse in conjunction with associated mechanisms and institutions to promote the region and ensure global competitiveness Including Sectoral Free Trade Zone Proposition);
- Masterplan for Northern Powerhouse development, building the capabilities and skills to deploy the following supports:
  - o Development of new feedstocks;

- Impact of industrial Digitisation/Sectoral Free Trade Blockchain Solution;
- Supply chain consolidation and diversification;
- Impact of the circular economy; and
- Development of programme of support for leadership training/talent attraction and retention.

0.39 Building upon our original hypotheses, our vision, therefore, is that over the next 12 years, the NPH chemicals and process sector will:

- Be the most competitive location, by building upon its existing highly efficient bulk chemicals infrastructure, further driving down costs through accessing (existing and emerging) affordable feedstocks and utilising nascent technologies;
- Regain lost export markets and re-shore the production of high value intermediary goods and R&Di functions of locally based global concerns;
- Diversify into new geographic and sectoral supply chains;
- Deliver more knowledge transfer between industry of all size and ownership structure and the regional innovation ecosystem to enhance productivity and ensure global competitiveness;
- Be a globally recognised centre for the application and testing of industrial digitisation and circular economy solutions to the chemicals and process sector; and
- Lead the adoption of bio-processing solutions for chemicals production.

Table 6 below uses international benchmarks to develop a robust action plan to create a step change to the region.

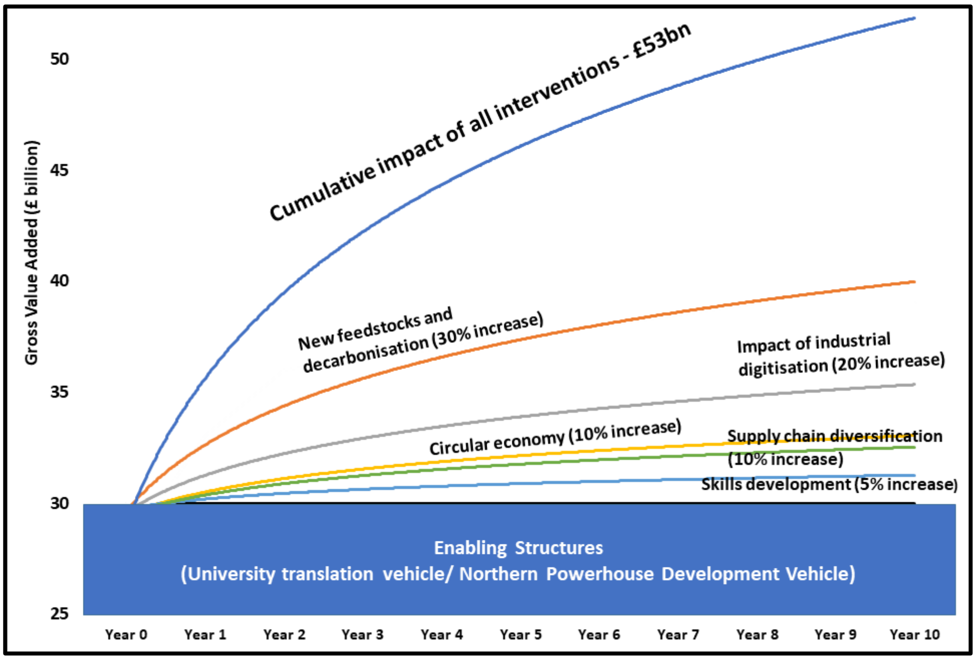
Table 6: Proposed Action Plan

Intervention	Implementation
Acting at Global scale	**NPH Chemicals and Process Sector Development Vehicle:** Augmenting existing sectoral representative bodies, it will be tasked with delivering an enhanced business support function, including but not limited to: supply chain /export diversification and foreign direct investment. Success will be enhanced added value being delivered within the NPH.
Unifying the innovation ecosystem	**Technology translation:** Creation of an innovation delivery system to valorise the academic research base and maximise the economic impact on the sector. Establish an integrated science and technology innovation network (a 'knowledge-based growth hub') integrating with the innovation scale-up of CPI and the other specialist Research Organisations in the NPH. This to provide a strong, agile translational interface accelerating the translation of University research into Industry, closely coordinating with the N11 local enterprise partnerships and science/business parks to drive infrastructure provision in support of relevant inward investment. **Accelerate Technology Commercialisation:** This would require new venture capital funding to commercialise research and provide finance for emerging companies and initiatives to promote clustering and sharing between the public and private sectors.
Increasing productivity through new feedstocks, the use of nascent technologies and decarbonisation	**Resource Efficiency: Develop new feedstock base for chemical industry:** Consider the options that (existing and emerging) affordable feedstocks (e.g. hydrogen, carbon dioxide, shale gas) may give the North. Recognise the opportunities that the bio-economy presents to feedstock development and the strength of industrial players in the NPH. This would require feasibility studies and a roadmap for industry development, as well as aligning the different stakeholder interests.

	Accelerate the move towards industrial digitisation. Northern chemicals sites could provide testbeds for the trialling of industrial digitisation and 5G solutions to address issues related to fragmentation. **Develop the circular economy proposition to mitigate feedstock concerns.** Northern chemicals sites could provide a base for new industries. This would require active engagement with the players developing these industries, as well as the development of a number of pilot / demonstrator projects.
Intervention	**Implementation**
Consolidating and diversifying supply chains	**Programme of support aimed primarily at mid-sized chemical companies**, including provision of skills, innovation and networking support for diversifying supply chains.
Delivering skills to meet sector ambition	**Programme of support to develop talent across the NPH.** Development of an integrated training and skills programme, primarily focused on the coordinated delivery of apprenticeships, including: recruitment, training and placement across the region. This will be primarily aimed at mid-sized businesses across the region. In addition, work with existing knowledge providers to impart specialist leadership and technical training driven by industry. This will in large part be driven by emerging technological absorptive incapacity in, for example the circular economy and industrial digitisation. The integrated model would address the issue of emerging fragmentation across the sector and will therefore significantly benefit both business and individuals if cross-company apprenticeships could be supported.

0.40 Synthesising the findings of the benchmarking study aligned to the key innovation recommendationtions, Figure 6 illustrates the projected impact of the proposed action plan and wider technological changes on the sector:

Figure 6: Growth trajectories of interventions based on international benchmarks



The above figure reflects the following key assumptions based on the findings of international benchmarking:

- 30% increase in output, reflects the catalytic impact on new investment as a result of reduced feedstock costs experienced in the Gulf Coast;
- 20% increase in output, reflects what was experienced as a result of investment in Singapore and sense checked to impact assumptions developed by McKinsey Consultants;
- 10% increase in output as a result of addressing gaps in the existing supply chain. This is benchmarked to the pre-2012 situation, where a number of these activities were previously delivered indigenously;
- 10% increase in output as a result of investment in circular economy solutions. Given the nature of the technology, this estimate relates to high level analysis developed by the Ellen McArthur Foundation and emerging impact associated with investment experienced in Singapore and Belgium/Northern Germany; and
- 5% increase in output is related to the increases in management efficiency and the subsequent attraction of higher value adding functions related to research and development.

1 Introduction

Background

1.1 In autumn 2015, the United Kingdom (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 identifying mechanisms to realise their potential.

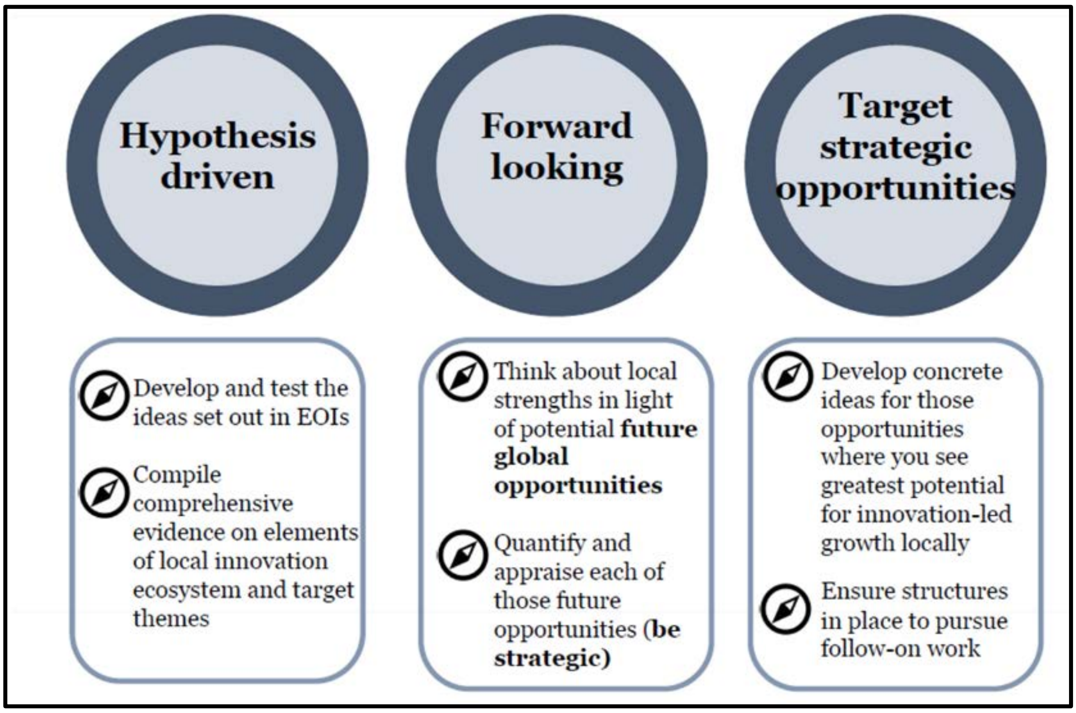
1.2 The SIA specific objectives, which were set out in the call for Expressions of Interest (EoI) are to:

- Identify and validate areas of potential global competitive advantage across the UK;
- Inform the development of the Government's Industrial Strategy;
- Provide an evidence base for strategic decision making on local innovation priorities;
- Strengthen future bids for local investment, e.g. science capital bids, private sector and other related funding; and
- Foster collaboration between universities and local businesses, local authorities and Local Enterprise Partnerships (LEPs) or their equivalents in the Devolved Administrations.

1.3 It is intended that the SIA reports will also support the delivery of England's Smart Specialisation Strategy.

1.4 Figure 1.1 illustrates the approved approach to delivering the SIA:

Figure 1.1: Technopolis Guide for Wave 3 Consortia (November 2017)



1.5 In response to the 2017 call for Expressions of Interest a consortium assessed regional strengths and opportunities in the chemicals and process sector. The consortium includes:

- All Northern Powerhouse Local Enterprise Partnerships and Universities;
- North East Process Industries Consortium (NEPIC);
- Materials Processing Institute;
- Centre for Process Innovation (CPI); and
- TWI.

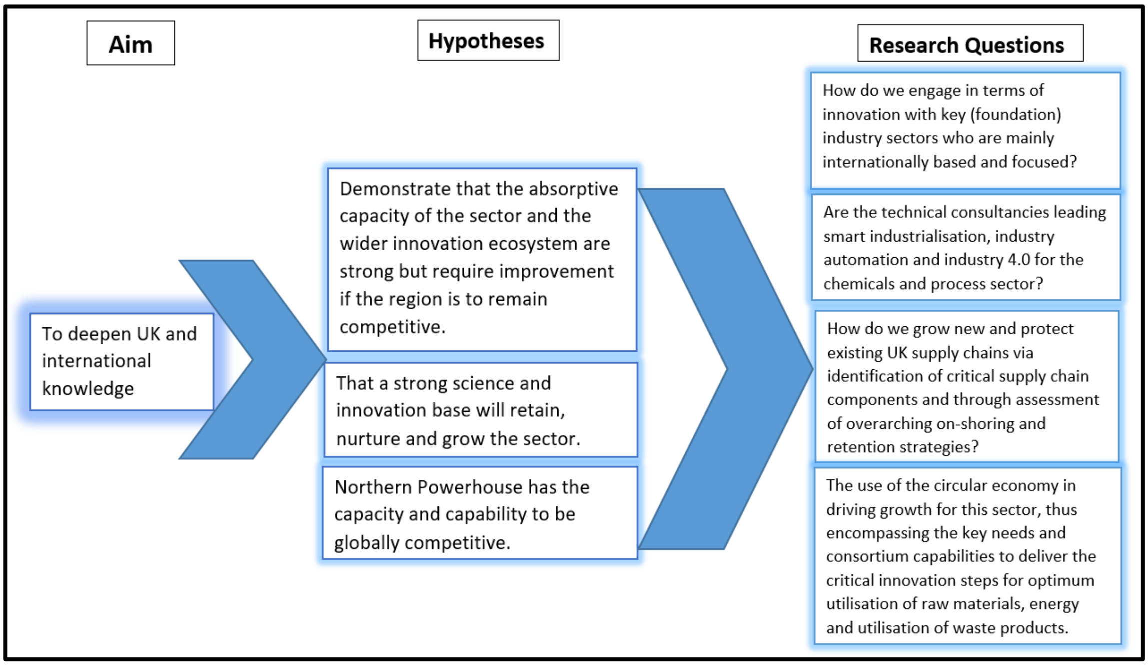
1.6 This audit will test the hypothesis that the Northern Powerhouse chemicals and processing sector continues to be globally competitive with a particular focus on the region's innovation ecosystem.

1.7 The vision for the study is:
''To ensure that the Northern Powerhouse contributes to the successful delivery of the Strategy for Chemistry fuelled growth that by 2030, chemistry using industries will increase their contribution to the UK economy from £195 billion to £300 billion''.

1.8 Our overall aim is to:
''Deepen international knowledge networks as a mechanism:
- *For domestic diffusion of innovation and enhanced sectoral productivity; and*
- *In the longer term, for the development of an internationally competitive knowledge base".*

1.9 The audit will therefore identify the networks, skills, capabilities and facilities needed to ensure continued global competitiveness and necessary mitigating activities. Our audit is based on the three sub-hypotheses presented in figure 1.2 below. Research questions link to the hypotheses by showing the practical steps taken to achieve the broad aims of the SIA, on a very realistic, achievable and measurable basis.

Figure 1.2: Aim, hypotheses and research questions of this Science and Innovation Audit



1.10 Having been selected to progress the audit as part of the national wave 3 process, our SIA has utilised the following methodology as set out in Table 1.1:

1.11 The first 4 chapters of the report are the result of desk-based research undertaken by the consortium. However, the desk-based review of secondary research identified a number of gaps in existing knowledge of the sector within the Northern Powerhouse, which in line with the original hypotheses, necessitated extensive primary research including:

- Stakeholder Interviews;
- International benchmarking against six comparator national and sub-national entities; and
- 3 Stakeholder workshops.

Table 1.1: SIA Methodology

Desk-based research
Review of economic data. • Review of academic capability and sector roadmaps. • Analysis of implications of digitisation and circular economy. • International benchmarking / analysis of nascent technology / materials.
Primary research
• Interviews with Universities and wider research base. • Interviews with LEPs and sector representative bodies. • Interviews with 40 companies.
Reporting and write-up
• Plenary session 1: analysis of emerging findings from primary and secondary research stages. • Plenary session 2: action planning event. • Development of conclusions and recommendations.

1.12 The results of this primary research have been written up as three themes and several key conclusions.

2 The Chemical & Process Sector - Key Trends / Drivers

Key Messages
• International demand for chemicals continues to increase, however industrial capacity, particularly in the Far East is growing at a faster rate; • The relative importance of the UK market is diminishing in global terms, however with the use of digitisation and the circular economy there is a significant opportunity to 'reshore' activity and further integrate supply chains; • The expertise and knowledge within the chemical and process sector is essential to informing innovation in chemical using industries such as healthcare, electronics, automotive and aeronautical; and • Clear linkages can be seen for the chemicals and process sector to engage and help to address the UK Industrial Strategy Grand Challenges (e.g. Clean Growth and ageing population).

Introduction

2.1 The chemical and process sector can appear to be very complex to the lay person. One of the main reasons for this, is that people do not come across raw chemicals in their normal everyday lives, as the outputs of the sector are largely intermediate goods for other sectors. A further complicating factor which inhibits the non-chemist from acquiring an understanding of the chemical industry is its lack of homogeneity. It varies hugely in its scale, its nature, the processes employed and equipment used.

2.2 As a result of this scale and impact on finished products, the importance of the chemical and process sector in underpinning the UK manufacturing base cannot be over-emphasised.

Purpose

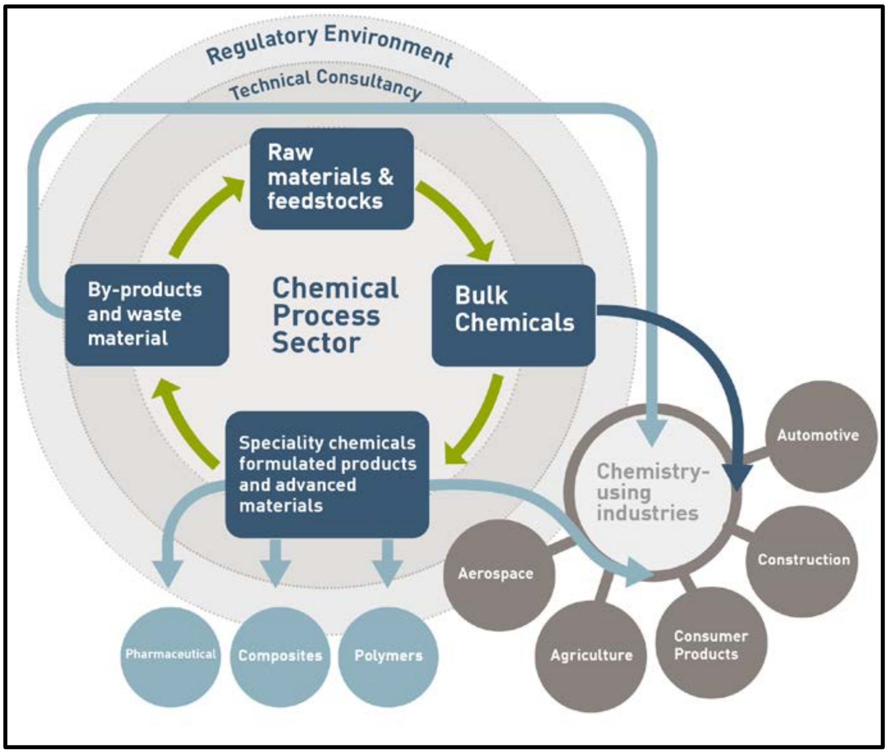
2.3 To provide transparency regarding the scope and scale of the chemicals and process sector, this chapter of the audit will provide the following:

- A detailed sectoral definition;
- An understanding of the scope and scale of the agreed sector both nationally and internationally; and
- A summary of the high-level trends and drivers affecting the sector and its sub sectors.

Sectoral Definition

2.4 For the purposes of this audit, the chemical and process sector encompasses the range of industries in which raw materials are processed through chemical conversions to give finished products, where the products and raw materials differ from one another as a result of undergoing one or more chemical reactions during the manufacturing process **[1]**. It is differentiated from the broader manufacturing sector which predominantly makes physical conversions to materials **[1]**. Figure 2.1 summarises the interaction between the chemical process sector and chemical using provides a schematic illustrating how the chemical and process sector is an integral component impacting upon the chemical using industries.

Figure 2.1: The Chemical and Process Sector



The chemical and process sector contribution to chemistry using industries

2.5 The Chemistry Growth Strategy (CGS) found the total GVA contribution of the chemistry-using industries in the UK to be £176bn, as summarised in figure 2.2.

Figure 2.2: The Contribution of the Chemistry Using Industries to the UK Economy [2]

2.6 The SIA has reworked the CGS analysis with the most recent data available as outlined in Table 2.1. Calculated using data from the Office for National Statistics (ONS) Annual Business Survey

2010 and 2016 (Provisional) Results. This analysis suggests relatively static growth against the 2010 baseline.

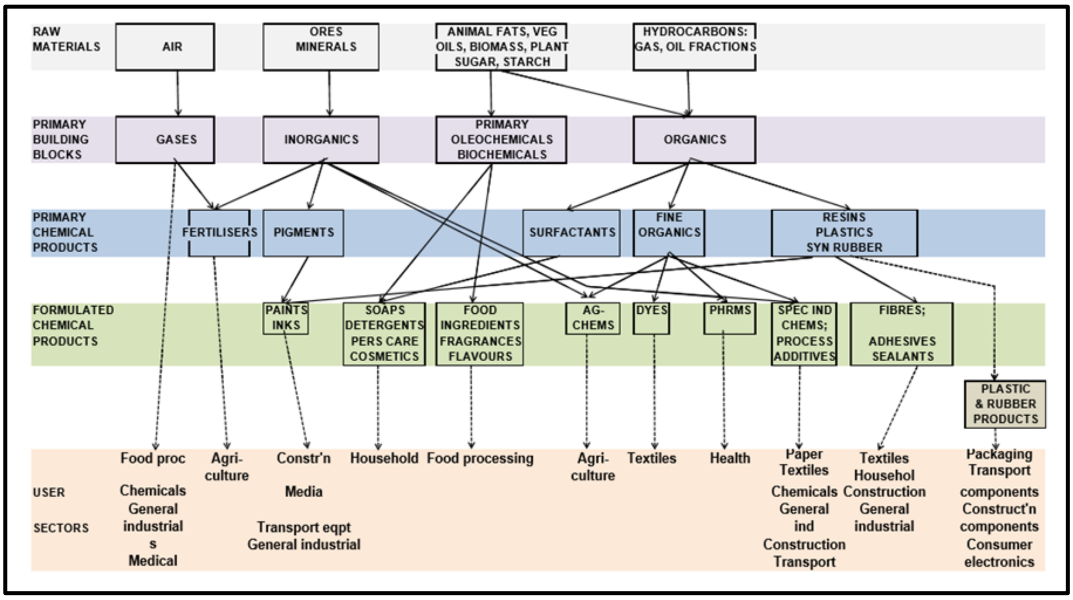
Table 2.1: Approximate GVA of the Chemical Using Industries [3]

Sector	SIC Code	Baseline as per CGS Vision [2] (£bn)	Approx UK GVA (£bn) 2010	Approx UK GVA (£bn) 2016
Chemical manufacturing	20	10	10.3	9
Pharmaceutical manufacturing	21	9	9.6	8.9
Automotive	29	11	10	17.1
Aerospace	30.3	7	5.8	6.5
Construction	43.2 and 43.3	23	25.5	32.1
Extraction of oil and gas	6	24	22.2	8.1
Provision of electricity	35.11	6	4.5	6.9
Sub-total		**90**	**87.9**	**88.6**
Consumer products and other	10,16-19, 22-28, 71.12	105	105.8	123.7
Grand total		**195**	**193.7**	**212.3**

2.7 The UK's chemistry-reliant industries can be split into two categories: the **'upstream'** consisting of chemical producing industries and '**downstream',** chemical using industries. The upstream chemicals and process sector is an enabling industry, helping provide technological solutions to many challenges faced by other parts of the economy – it underpins sustainability in downstream industries such as healthcare, electronics, automotive and textiles among others.

2.8 The critical relationship between the chemical and process sector and chemistry using industries is the result of a variety of supporting roles within the sector. Most obviously, the chemical and process sector provides the raw materials, feedstocks and intermediates for the chemistry-using industries that allow them to manufacture products. Alongside this however, the expertise and knowledge within the chemical and process sector is essential in informing and expanding the chemistry-using industries. One example of the expertise necessary for the chemistry-using industries is the knowledge of paints/coatings and surface technology essential to the automotive and aerospace industries. The following figure illustrates how the outputs from the chemicals sector fit with wider supply chains across the British economy:

Figure 2.3: Examples of Supply Chain Links associated with the UK Chemical Industry [2]



2.9 Without the activities of the UK chemical and process sector, all of the related downstream industries would not function as effectively within the UK, by becoming more reliant on importing of goods. Therefore, they are a key component of national and Northern Powerhouse supply chains.

2.10 In delivering support to chemistry-using industries the chemical and process sector can be categorised into a number of supporting sub-sectors, detailed in Appendix 1. Table 2.2 shows the GVA by sub-sector (2016) **[8]**.

Table 2.2: Comparative GVA (2016) by sub-sector [8]

Sub-sector	SIC Code	SIC Code Descriptor	Total GVA (2016) (£m)
Bulk chemicals	20.12	Manufacture of dyes and pigments	86
	20.13	Manufacture of other inorganic basic chemicals	792
	20.14	Manufacture of other organic basic chemicals	854
	20.15	Manufacture of fertilisers and nitrogen compounds	25
	20.59	Manufacture of other chemical products n.e.c	1,672
Total			**3,429**
Specialty chemicals	20.2	Manufacture of pesticides and other agrochemical products	420
	20.3	Manufacture of paints, varnishes and similar coatings, printing ink and mastics	880
	20.4	Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	1,530
	20.51	Manufacture of explosives	58
	20.52	Manufacture of glues	173
	20.53	Manufacture of essential oils	260
	21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	8,885
Total			**12,186**
Polymers and plastics	20.16	Manufacture of plastics in primary forms	1,058
	22.2	Manufacture of plastic products	7,796
Total			**8,854**
Materials	20.6	Manufacture of man-made fibres	46
	22.1	Manufacture of rubber products	1,260
	23	Manufacture of other non-metallic mineral products	5,655
Total			**6,961**
Grand Total			**31,450**

2.11 Table 2.3 compares GVA, employment and the gross value added (GVA) per employee for the key UK manufacturing sectors. The key conclusions from this are:

- Whilst the upstream chemicals sector accounts for c£20bn (9.5%) GVA, it has a downstream impact on c£212bn or 95% of the UK manufacturing sector.
- The sector accounts for 140,000 employees (6% of UK manufacturing workforce), however it has a GVA per employee of £144,000, which is significantly higher than the GVA of both the aerospace (£65,000) and automotive (£108,000) sectors.

Table 2.3: Comparative GVA and employment across the UK manufacturing sector [3]

Sector	SIC code	UK GVA	UK Employment	GVA per employee
Chemicals and Process Sector	**20-22**	**£20,135m**	**140,000**	**£144,000**
Chemical Manufacturing	20	£8,957m	100,000	£90,000
Pharmaceutical manufacturing	21	£8,885m	40,000	£222,000
Automotive	29	£17,120m	159,000	£108,000
Aerospace	30.3	£6,490m	100,000	£65,000
Construction	43.2 & 43.3	£32,064m	600,000	£53,000
Extraction of oil and gas	6	£8,128m	16,000	£508,000
Production of electricity	35.11	£6,885m	28,000	£246,000
Consumer products and other	10,16-19, 22-28, 71.12	£123,700m	2,041,000	£61,000

Global Context

2.12 The UK continues to be a significant player in the global chemicals sector, however it is important to place the value of the sector relative to other worldwide markets.

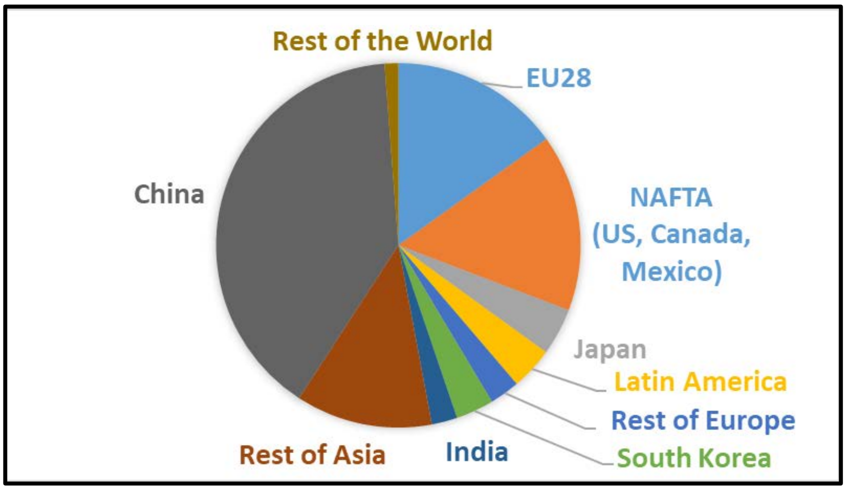
2.13 Table 2.4 summarises comparative sales of chemicals amongst the leading markets using data sourced from CEFIC Facts and Figures 2017 of the European Chemical Industry **[9]**, CEFIC Landscape of the European Chemicals Industry (2018) **[5]** and Worldometers.info world population estimates by country **[6]**.

Table 2.4: Comparative sales of chemicals amongst the leading markets

Country	Sales (Billion €)	Population (Million)	Sales per head of population (€)
China	1,331	1,415	941
US	476	326	1,460
Germany	185	82	2,256
Japan	140	127	1,102
South Korea	113	51	2,216
India	76	1,354	56
France	70	65	1,077
Taiwan	63	23	2,739
Spain	63	46	1,370
UK	**60**	**66**	**909**
Brazil	59	210	281
Netherlands	55	17	3,235
Italy	52	59	881

2.14 Figure 2.4 summarises the comparative size of key chemical markets. The most significant growth has been in the emerging markets such as China, India and Brazil. The global market is expected to grow by a further 3% in the next 20 years as the Asian industry and industry in the Middle East continue to grow. By 2030, Asia is expected to account for almost two thirds of the global chemical industry market **[9]**.

Figure 2.4: International Chemical markets 2017 [9]



2.15 Demand for chemicals, particularly intermediate and finished goods continues to expand both in Britain and globally. However, what is in question is the country's **ability to meet both indigenous and export demand**, as increasing competition from both East (e.g. China) and West (e.g. USA) is driving down revenues and making it harder for UK-based firms to compete in the global marketplace.

Key Drivers for the sector

2.16 In an ever-changing world, it is important that the UK does not lose its competitive edge. It therefore needs to build upon any continuing/emerging advantage in the global market in order to deliver further growth and business opportunities. The following PESTLE analysis identifies those key drivers of global change and how they will impact on the chemicals sector in the UK:

Table 2.5: PESTLE analysis: Impact of Global drivers on the Chemicals and Processing Sector

Heading	Analysis
Political [2] [10] [11] [12] [13] [14] [15]	**Brexit:** The UK chemical sector has an annual turnover of £60 billion and employs 144, 000 people. With an annual trade surplus, the chemical and chemistry-using industries are the UK's biggest contributor to the national balance of payments **[2]**. In an uncertain economic climate with the implications of Brexit still unclear, it is therefore essential that the UK's chemical & process sector cements its position as an internationally competitive industry. Whilst the UK and EU share of the global market has shrunk in recent years, the UK chemicals sector has continued to grow with an increase of 3.6% in 2016. Chemicals and chemical products account for 6.8% of UK manufacturing GVA **[10]**. **Relationship with the EU:** The implications of Brexit are still unclear, especially with the lack of certainty around possible trade deals and the likelihood of the UK remaining within the single market. The UK exported €19.3bn of chemicals to the rest of the EU in 2016, accounting for approximately 7% of total EU sales, and imported approximately €22.6bn of chemicals from the EU, accounting for around 4.5% of EU27 sales **[15]**. Based on total EU sales figures, approximately 75% of all chemical imports to the UK arrive through the EU **[11]**. Many chemical and chemistry-using industries face supply chains being disrupted and extra tariffs on imports and exports being imposed. The UK's established growth sectors (aerospace, agri-tech, automotive and life sciences) all rely on chemical process industries for raw materials, expertise and facilities. Industry therefore needs to build on the infrastructure which already exists within the UK by re-

Heading	Analysis
	building UK supply chains in order to remain globally competitive **[12]**. Brexit will also have implications for companies that rely on the global mobility of employees and industries that want to bring people in from overseas. **Industrial Strategy Grand Challenges:** The BEIS Industrial Strategy was launched in November 2017 **[13]**. This has significant linkages with the chemicals and process sector and presents huge opportunities in terms of addressing the four 'Grand Challenges', relating to artificial intelligence and data, ageing society, the future of mobility and clean growth **[14]**.
Economic [9] [16] [17] [18]	**Global growth:** The total revenue of the global chemical industry in 2016 was £3.8 trillion **[16]**. The global industry has grown over the last 30 years, mostly due to growth in Asia which now accounts for over half of all global chemical sales (figure 2.4) **[9]**. The global market is expected to grow a further 3% in the next 20 years as the Asian industry and industry in the Middle East continue to grow. By 2030, Asia is expected to account for two thirds of the global chemical industry market **[17]**. Chemical sales in the EU have grown over the last 30 years but their market share has declined due to dilution effects from expanding markets in other countries **[17]**. The EU now has a 15.1% share in global chemical sales with the UK representing a 7% share in EU sales which therefore equates to a 1.1% share of the global market. In order for EU and UK markets to remain competitive on a global scale, they need to focus on innovative solutions to the current gaps in the chemical & process sector whilst maintaining their strength in the saturated markets they are traditionally strong in **[9]**. **Remaining globally competitive:** Alongside Brexit there is increasing competition from global chemical process industries, especially from Asia and the Middle East. Increased productivity from these countries is driving prices down as supply begins to outstrip demand. To remain competitive against big industries in countries such as China, the UK needs to once again ensure its own supply chains are secure with a move towards internalising them **[18]**. As with Brexit, it is also important for the UK to shift focus towards innovation and developing new technologies that address global issues and are unique to the UK, so marking the UK as globally important (and necessary) in the chemical process sector.
Social [14] [19] [20] [21] [22]	**Expanding global population and urbanisation:** It is predicted that by 2030 the world population will reach 8.5 billion people, of these, 60% will be living in urban areas **[22]**. There will be an estimated 2 billion cars on the roads by 2030 **[19]** and the amount of global energy usage will have doubled by 2050 **[20]**. Chemistry will be an essential component in meeting the challenges associated with the extra demands on the planet, the chemical & process sector will therefore be key in helping the world to continue developing (such as developments in mobility **[14]**) whilst preserving the limited natural resources available. **Demographics:** The UK currently has an ageing workforce, especially in sectors like bulk manufacturing, with a shortage of people coming through to fill the gaps. There is also a skills gap in general within the chemical and process sector due to fewer people specialising in STEM subjects than necessary to maintain the workforce **[21]**. A problem more specific to the Northern Powerhouse is attracting people to work in the north. The skills gaps within the sector extend through the entire supply chain and are not specific to the defined sub-sectors. The skills gap increases the importance of attracting students to universities

Heading	Analysis
	within the Northern Powerhouse to increase the chances of them remaining in the region post-graduation.
Technological [7] [14] [23] [24]	**Digitisation:** As industries become increasingly interconnected, networking and digitisation is becoming an essential component of all industrial processes and the chemical and process sector is not exempt from this. The development of the internet of things is forcing industries to maintain an online presence in order to remain competitive. As digitisation becomes increasingly and inevitably important, the importance of technical consultancies will become greater and their use by the chemical and process sector will expand **[7] [23]**. The importance of digitisation is also recognised as part of the artificial intelligence and data Grand Challenge **[14]**. **Onshoring / Reshoring:** Reshoring is increasing in UK manufacturing, driven by shifting consumer preferences; a reduction of the wage gap with emerging economics; volatile international transport costs, and a desire by management to better control quality and supply chain risks. **Maximising use of limited resources:** Pressures created by limited natural resources and the drive towards a low carbon economy will require the securing of UK supply chains and local feedstocks, alongside new innovations to reduce reliance on fossil fuels and drive low-carbon technologies forward. A more circular economy to reduce waste will also be essential to this **[24]**. [A Circular Economy is a deviation from the more traditional linear economy whereby products are made, used and then disposed of. In a circular economy, resources are kept in use for as long as possible and the maximum value is extracted from them.]
Legal [25]	The EU has adopted several pieces of legislation on chemicals, which are primarily 'trade regulations' harmonising the conditions under which chemicals can be placed on the market. The aim of REACH **[25]** is to protect human health and the environment. REACH shifts the responsibility from public authorities to industry with regards to assessing and managing the risks posed by chemicals and providing appropriate safety information for their users. REACH is constantly evolving, having been amended 38 times since it was enacted in 2006. REACH is enforced by the European Chemicals Agency (ECHA) and relatively little of its regulation has been transposed into UK law. For the UK to continue to trade with the EU there may be a need to adopt REACH regulations, which may be increasingly expensive.
Environmental [14]	**Climate change:** The drive towards low-carbon technologies and a need to preserve the natural environment has created a need for new technologies to be developed in order to allow production methods to be altered in a way that allows them to be economically viable, whilst having as small an impact on the environment as possible. **Maximising use of limited resources**: A key problem with the move towards internalising supply chains and a circular economy is that all industries naturally want to look after their own interests. This means industries tend to pull in different directions, and any requirement to work together to form a circular economy will involve a shift in base-level thinking. Both issues of climate change and utilising limited resources are brought into even sharper focus for the sector by the clean growth Grand Challenge **[14]**.

Emerging Trends by Key Sub Sectors

2.17 Table 2.6 provides a summary of the key trends and drivers affecting each of the sub sectors identified in Table 2.1, before assessing them against immediacy and scale of impact:

Table 2.6: Trends and drivers by sub-sector, rated for impact and immediacy

Sub- Sector	Trend/Driver	Scale of Impact	Likelihood (i.e. risk assessment)	Risk rating (likelihood x impact)
Chemical manufacturing (Bulk Chemicals) [2] [10] [15] [18] [26] [27] [28] [29] [30] [31] [32]	High energy costs of production (relative to competitor economies)	H	H	H
	Increasing regulations on chemical production and use	H	H	H
	Need to maintain environmental water and air quality during production	H	H	H
	Sustainable resourcing / production	M	M	M
	Reducing input costs driven by competition for resources	H	H	H
	Potential impact of changing regulation through trade deals	H	M	H
	Climate change driving low-carbon alternatives	H	M	H
	Growth of overseas markets increasing competition	M	M	M
	Brexit: need for security and need to build up existing infrastructure	M	M	M
	Use of water within the sector, almost as important as fossil fuels and has demands on quality, waste and cost	M	L	M
	Fossil fuels are necessary for feedstocks and as a source of energy, doubling their importance. With the USA now providing cheap shale gas it is hard for local supplies to compete	M	M	M
Speciality chemicals [2] [10] [27] [28] [32] [33] [34] [35] [36]	Consumer preference for 'natural' products	M	M	M
	New functionality	M	M	M
	Ageing population, meeting the medical and practical demands	M	M	M
	Demand for low carbon technologies	M	M	M
	Urbanisation	M	L	M
	Increase in prevalence of disease	M	L	M
	Greater production of APIs	M	M	M
	Demand for specialised healthcare	M	L	M

Sub- Sector	Trend/Driver	Scale of Impact	Likelihood (i.e. risk assessment)	Risk rating (likelihood x impact)
Polymers and plastics [27] [28] [37] [38] [39] [40] [41]	Increased demand for bio-based polymers, films and plastics	M	M	M
	Growing consumerism	M	M	M
	Growth in end-use markets	M	M	M
	Pressure on reduction in plastic usage	M	M	M
	Understanding the full life cycle of plastics	M	H	M
Materials [2] [27] [28] [40] [42] [43]	Demand for energy-efficient materials in automotive, aerospace, construction, etc.	M	M	M
	Increased demand for bio-based and renewable raw materials	M	M	M
	Growing consumer demand	M	M	M
	Use and sourcing of 'natural' products	M	L	M
	New functionality demands	M	L	M
	Increasing population demands	M	L	M
	Increased proportion of people living in urban areas	M	L	M
	More cars etc. in use	M	L	M
	Drive towards new technologies to face challenges and meet consumer demand	M	L	L
	Demand for low-carbon technologies	M	M	M
Technical consultancies [7] [44]	Digital transformation	M	M	M
	Need for more defence systems against cyber-attacks etc.	M	M	M
	Focus on developing SMEs over large corporations	M	M	M
	Focus on specialisation	M	M	M
	Implementation of AI	M	M	M
	Automation and robotics	M	M	M
	Internet of things	H	M	H
	Digital transactions → how you transfer smarter etc.	H	M	H
Wider supply chain [2] [10] [15] [24] [27] [28] [29] [30] [42] [45] [46] [47] [48]	Ethical and environmental policies from fast-moving consumer goods companies diffusing throughout their supply chains	L	L	L
	Reliance on imported materials	M	M	M
	Increased raw materials and energy prices	H	H	H
	Sustainable supplies of raw materials and energy	H	H	H

Sub- Sector	Trend/Driver	Scale of Impact	Likelihood (i.e. risk assessment)	Risk rating (likelihood x impact)
	Diversification of input raw materials	H	H	H
	Reduced dependency on fossil fuels	H	H	H
	Increased primary energy usage	H	H	H
	Limited natural resources	H	H	H
	Move towards a more circular economy	M	M	M
	Energy price fluctuation	H	H	H
	Need to re-build UK supply chains	H	H	H
	Big companies can drain talent from their own supply chains	H	H	H
	Suppliers may have an over-reliance on one customer	H	H	H

Key:
Scale of Impact: Degree of impact and scale of coverage: High (H) implies that either at least 50% of the sector or output will be impacted. Medium (M) implies circa 25% - 50% of the sector or output will be impacted and Low (L) implies less than 25% of the sector or output will be impacted
Likelihood: High (H): 75% or above certainty rate of event occurring, Medium (M) 50-75% likelihood, Low (L): Below 50%.

2.18 Table 2.6 clearly demonstrates a number of trends which are both immediate and high impacting, including:

- Overall growing demand for chemicals globally at the same time as increasing concerns about finite resources;
- Need to sustain/rebuild local supply chains, particularly in light of Brexit and need to reduce transport costs;
- Need to address the high costs of energy and raw materials and begin to utilise low carbon solutions;
- The growing importance of digitisation, particularly in relation to integrating supply chains; and
- The growing importance of the circular economy as a mechanism for not only enhancing productivity by mitigating the high costs of energy and raw materials, but also for reshoring of activity.

2.19 However, the table does not prioritise the relative importance of each of the sub-sectors to the UK and Global economy. This theme will be picked up in later chapters.

3 SIA Geography and Specialisation

''The Northern Powerhouse is a vision for joining up the North's great towns, cities and counties, pooling their strengths and tackling major barriers to productivity to unleash the full economic potential of the North.'' Northern Powerhouse Strategy: November 2016.

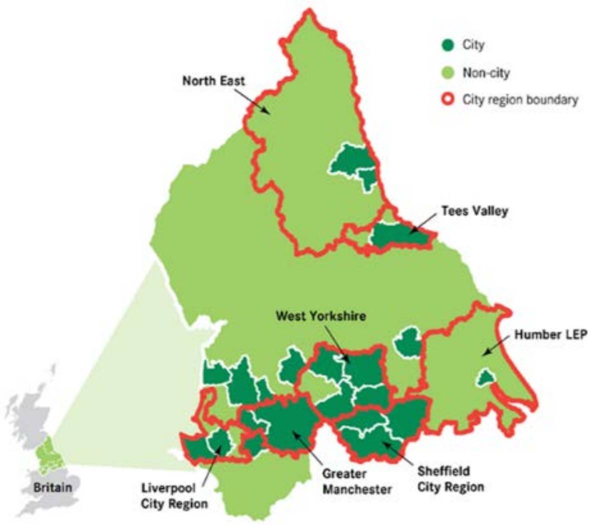
Key Messages

- The UK and the Northern Powerhouse in particular, is facing a growing trade deficit in what was historically a positive sector for UK exports. To prevent this leading to a wider trade deficit it will be necessary to increase onshore production;
- Re-building UK supply chains will also be essential to ensuring the security of supply chains within the chemical process sector going forwards as global primary resource prices are increasing in volatility. With the building of supply chains and the need to internalise resources, a more circular approach to the economy will be essential in ensuring longevity;
- Re-building UK supply chains is likely to be reliant on reshoring previously lost production capacity related to lower valued intermediary goods;
- Chapter 6 will provide more detailed analysis of which sub sectors are most at risk and the necessary mitigating activities.

The Northern Powerhouse in Summary

3.1 The SIA geography for the Northern Powerhouse covers all 11 North of England LEP areas. Allowing for overlap of these areas means the effective SIA geographic areas comprises the three North of England regions (North East, North West and Yorkshire and Humber) plus the Sheffield LEP districts that lie within the East Midlands regions and although they do not form a distinct geography they are interlinked through established supply chains. Table 3.1 below provides a high-level summary of the SIA area:

Figure 3.1: Map and high-level analysis of Northern Powerhouse



Key

Economic Data [49]:

- Total GVA: £325bn (UK total £1,651bn);
- Working Age population: 9.89m (UK total 41.4m);
- Productivity per head: £21k (UK: £28.2k);
- Number of active companies: 546,360 (UK: 2.83m);
- Business density 30.85 per 1,000 (UK 36.95); and
- Percentage in employment with NVQ4+: 37.9% (UK 43.5%)

3.2 GVA data analysis for the chemicals and process sector in 2016 is summarised in Appendix 2 **[50]**. The summary headlines are:

- The manufacturing sector represents 10.1% of the UK economy, and 15.4% of the economic activity in the NPH

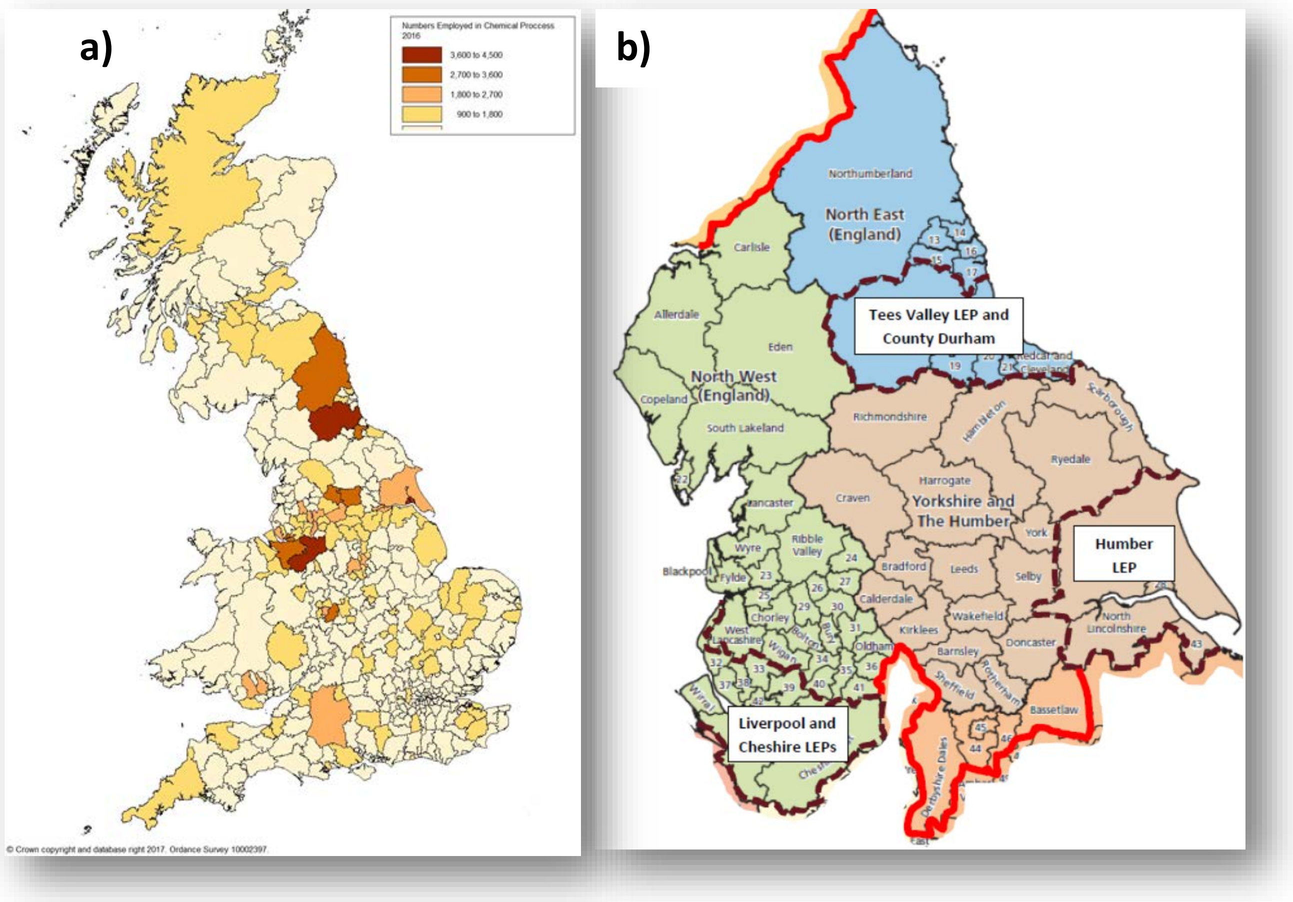
- The chemical sector has a GVA of £28.04bn representing 15.8% of the UK manufacturing sector
- The NPH has by far and away the most significant impact on the sector GVA, representing £13.40bn GVA, **48% of the UK sector total**.
- This represents 26.5% of all NPH manufacturing GVA, compared with the UK average of 21.2%

3.3 Considering the chemistry-using industries defined by the CGS, the Northern Powerhouse contributes 29,000 full time employees compared to 132,000 for Great Britain, giving a location quotient for employment of 2.1 for the Northern Powerhouse versus the rest of Britain **[51]**.

Sub Regional Clusters

3.4 Figure 3.2 a) presents an analysis of ONS chemical and process employment in 2016 **[52]**. The predominance of employment in the Northern Powerhouse SIA area is clearly emphasised with the identification of three distinct chemical process sector concentrations: including Tees Valley and County Durham, Humber LEP area and a combination of Cheshire and Warrington and Liverpool City Region LEP (Cheshire and Merseyside) areas (see Figure 3.2b). These clusters are connected through a series of integrated supply chains spanning the Northern Powerhouse (NPH) region with a particularly strong manufacturing belt running along the M62 corridor.

Figure 3.2: a) UK chemicals and process sector employment 2016, [52] b) SIA Area



3.5 Tables 3.1 and 3.2 provide a snapshot of the characteristics of each of the three Northern Powerhouse clusters in relation to the following sectors: chemical manufacturing, speciality chemicals, polymers, plastics and materials and pharmaceuticals:

Table 3.1: Scale of key clusters [8]

	Humber	Liverpool and Cheshire	Tees Valley and Durham
Total GVA	£18,378m	£60,196m	£21,312m
GVA per employee	£215,000	£449,000	£154,000
Average wage	£35,923	£35,923	£37,543
Location Quotients	4.1	3.0	3.7
Number of Establishments	192	373	163

Table 3.2: Employment numbers by sector [8]

	Humber	Liverpool and Cheshire	Tees Valley and Durham
Chemical Manufacturing	2,729	2,149	3,912
Speciality chemicals	1,085	1,429	2,863
Polymers, plastics and materials	3,172	4,656	4,891
Pharmaceuticals	1,412	1,882	4,810

3.6 Both tables must be considered in the context of the scale of enterprise and the particular sub-sector it is operating in:

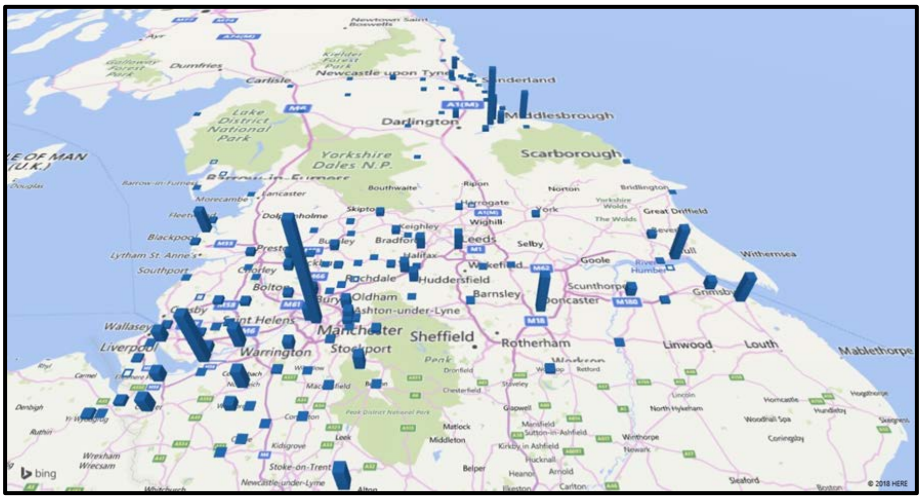
- Humber and Tees Valley have high location quotients in manufacture of fertilisers and nitrogen, manufacture of organic chemicals and manufacture of dyes and pigments;
- Liverpool and Cheshire have high location quotients in manufacture of inorganic basic chemicals and manufacture of pharmaceutical preparations and also have the largest companies by scale (and consequently a greater number of higher value adding functions).

3.7 In summary, the significant variance between the regional clusters is largely attributable to the scale of enterprise and the particular sub-sector they are operating in, rather than a difference in productivity. However, it does clearly demonstrate the need to provide more added value operations both in terms of activity (RD&i) and a move up the value chain (i.e. not merely the manufacture of basic chemicals, but the development of intermediate goods).

3.8 The specific characteristics of these chemical clusters has been recognised by two recent cluster reports; for Humberside which sets out an energy intensive industries decarbonisation vision **[53]** and for the Tees Valley Process Industries that defines short medium and long-term product opportunities **[54]**

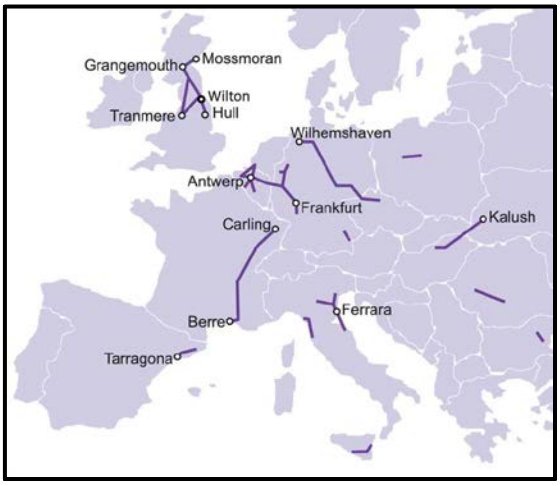
3.9 Appendix 3 provides insights on company location by company size and turnover as exemplified by Figure 3.3 which maps 2018 Companies House data for companies within the sector that are registered within the NPH.

Figure 3.3: Turnover by location – Northern Powerhouse (total= £26,968m)



3.10 Figure 3.4 provides an illustrative example of the interconnections with respect to the supply of ethylene (ethene) between the three Northern Powerhouse clusters. Ethylene is the most important organic chemical, by tonnage and is the building block for a vast range of chemicals from plastics to antifreeze solutions and solvents, all of which are manufactured in the region.

Figure 3.4: Distribution of Ethylene by pipeline across Europe [55]

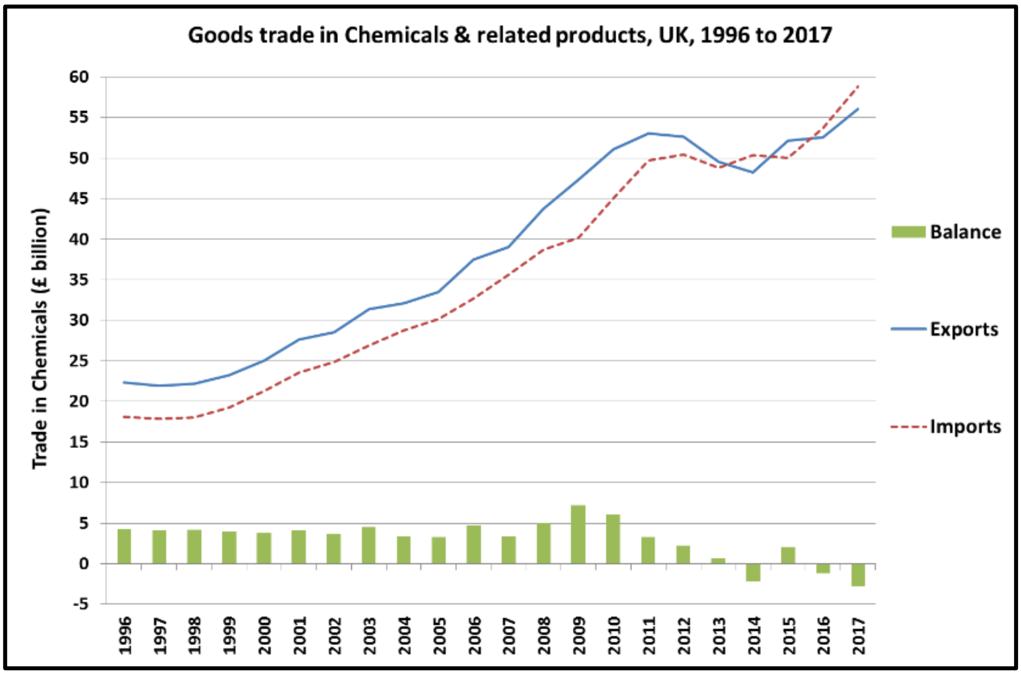


Contribution to Global Competitiveness

3.11 Section 2 provided a high-level assessment of the comparative size of the UK chemicals market. In this section, that market assessment is further broken down into the relative importance of import/export activity.

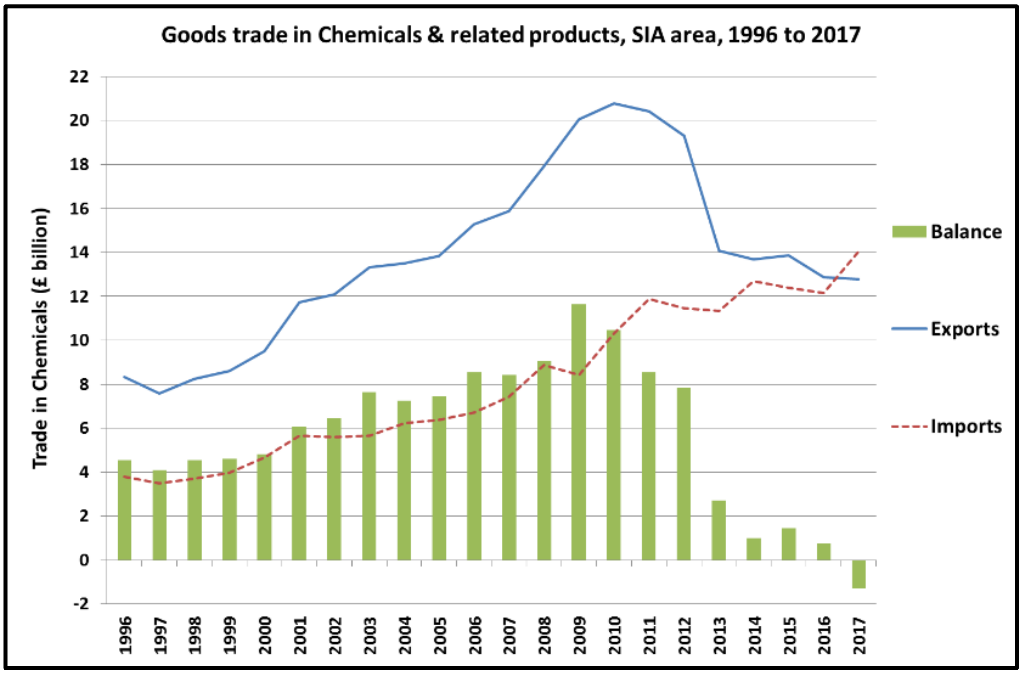
3.12 Figure 3.5: provides more granularity as regards the overall UK chemicals trade balance. Further detailed analysis is provided in Chapter 6 and associated Appendix 14:

Figure 3.5: UK Chemical sector trade balance Source: HMRC UK Trade Information 2017 [56]



3.13 Figure 3.6 provides more granularity as regards the chemicals trade balance, focusing as it does on solely the Northern Powerhouse and is therefore disproportionately impacted by localised changes in the trading environment.

Figure 3.6: Northern Powerhouse chemical sector trade balance [56]



3.14 The following points should be noted:

- There has been a significant reduction in export activity, whilst at the same time an increase in imports. This is even more noticeable within the Northern Powerhouse;
- The increase in imports is at a faster rate than growth in the sector as a whole, indicating imports are substituting domestic production;
- Imports within the Northern Powerhouse have mostly been in higher added value elements such as Medical & pharmaceutical products and are 19 times the value in 2016

compared to 1996. This sub-sector accounted for £3.5bn (42%) of the total increase of the whole Chemicals sector; and

- The reduction in exports has been in the more price sensitive subsectors including manufacture of organic chemicals and fertilisers and nitrogen, which are predominantly in the east of the Northern Powerhouse.

4 Regional Academic Strengths in Science and Innovation

Key Messages

- The UK research base in the selected sectors continues to be globally competitive, particularly in terms of quality of research;
- Although the Northern Powerhouse is a comparatively small region it has a number of individual institutions which have international status and continue to attract significant UK and foreign research investment;
- The leading research institutions within the SIA area demonstrate strong research quality across all six sub-sectors of the chemical and process industry. Particular strengths were highlighted in materials sciences, chemical synthesis, chemical measurement, atmospheric physics and chemistry;
- High-quality research on an individual institutional level indicates that there is strength in depth across the chemical process sector within the SIA area that could be utilised to drive innovation and enhance the region;
- The combined scale and quality of research outputs if deployed collaboratively and collectively would outstrip larger National comparator institutions by several fold. There is therefore potential for more coordinated collaborative working between disciplines and across institutions; and
- There is evidence of fragmentation in the present innovation ecosystem, both between Universities and the National Innovation Centres, and gaps in ability to respond to the needs of companies. In this context, a model that spans the working principles of two best practice exemplars, the Northern Sustainable Chemistry (NORSC) consortium and the Knowledge Centre for Materials Chemistry (KCMC) principles should be considered as a mechanism to address industry challenges in simpler ways and ultimately expand R&D investment in the region.

4.1 A key hypothesis within this audit is that a strong science and innovation base will retain, nurture and grow the sector. This is achieved through a strong research base aligned to an excellent innovation translation network. This section assesses the strength of the research ecosystem through the following variables:

- Research Quality, including Research Excellence Framework and Publications and Citation Analysis;
- Share of UK Science Base; and
- Share of UK International Income.

4.2 This section focusses on academic research strengths. Section 5 provides further detail of the research, development and innovation capabilities within the private sector and intermediate bodies.

Research Quality

4.3 The Northern Powerhouse region contains 32 higher education institutions (see Appendix 4b) collectively with 522,000 students **[57]**, amounting to 23% of all students nationally **[58]**. The consortium comprises 15 Universities. This includes the N8 research partnership of eight research intensive Universities within the Northern Powerhouse (Durham, Lancaster, Leeds, Liverpool, Manchester, Newcastle**,** Sheffield and York). The N8 works together with the aim of promoting collaboration, driving economic growth and driving innovation on an international level. The N8 are responsible for **[59]**:

- £1.2bn annual research income;
- £12.2bn annual regional economic impact;

- 190,000 registered students; and
- 119,000 FTE direct, indirect and induced jobs.

4.4 The consortium also includes seven key additional Northern Powerhouse Universities with strong links to the chemicals and process sector including Teesside, Bradford, Chester, Huddersfield, Hull, and Northumbria and Sunderland. The relevant strengths of the 15 universities that are part of this consortium are given in Appendix 4.

Research Excellence Framework (REF)

4.5 In 2014, UK universities undertook a comprehensive review of their research as part of the Research Excellence Framework (REF 2014). In the three most relevant areas to this SIA (detailed below), the region submitted a total of 3,296 outputs from 897.24 FTE researchers. The number of outputs submitted by the UK as a whole in these areas was 12,866 from 3,451.89 FTE researchers. The region therefore accounted for 26% of submitted outputs in the relevant research areas as outlined below **[60]**:

- Chemistry: Of the universities in the region, 10 submitted studies in the subject area of chemistry out of a total of 37 for the UK as a whole. Liverpool, Durham and Manchester were all in the top quartile in the overall ratings. Liverpool was ranked second in terms of output with Lancaster also featuring in the upper quartile. Durham was ranked first for impact in chemistry and Liverpool was ranked 4th. Manchester and Leeds featured in the upper quartile in terms of impact and Liverpool and Manchester both featured in the upper quartile for environment. In terms of research power, Manchester and York were in the upper quartile.
- Aeronautical, Mechanical, Chemical and Manufacturing Engineering: 7 institutions in the region submitted outputs but Manchester and Sheffield both submitted under 2 separate departments, giving 9 submissions out of a total of 25. In terms of overall ratings, both Manchester departments featured in the top quartile. Newcastle was 3rd for output with Leeds also in the upper quartile and Leeds was 3rd for impact with both Manchester departments in the upper quartile. Manchester Chemical Engineering was also in the upper quartile for environment.
- Electrical and Electronic Engineering, Metallurgy and Materials: 10 institutions from the region submitted outputs but once again Manchester and Sheffield submitted under 2 departments each, giving 12 submissions out of a total of 37. Manchester Metallurgy and Materials and Leeds were both in the upper quartile in the overall rankings and Leeds was 3rd for output with Sheffield Materials Science and Engineering in the top quartile. Both Manchester departments and Leeds were in the top quartile for impact, Manchester Metallurgy and Materials was in the top quartile for environment and both Manchester departments were in the top quartile for research power.

REF performance of institutions in the top quartile is summarised in Table 4.1.

Table 4.1: Institutions with top quartile rankings in 2014

(Key: **D**urham, **La**ncaster, **Le**eds, **Li**verpool, **M**anchester, **N**ewcastle, **S**heffield, **Y**ork)

Unit of Assessment	Overall	Impact	Environment	Output	Research Power
Chemistry (/37)	Li (2nd), D, M	D (1st), Li (4th),	Li, M	Li (2nd), La	M, Y
Aeronautical, Mechanical,	Le (3rd), M	Le (3rd) M	M	N(3rd) Le	-
Electrical and Electronic Eng.,	M, Le	M, Le	M (4th)	Le (3rd),S	M (4th)

Publications and Citation Analysis

4.6 Scopus was used to carry out an analysis on the amount and quality of research being published in areas relevant to the key challenges faced by the chemical and process sector across the UK and internationally. Details of the methodology and key words used in the citation analysis are provided in Appendix 5a).

International Performance

4.7 Annex 3b) provides a comparison between the UK research base with international comparator nations China, US, Netherlands, France, Denmark and Germany, in each of the six sub-sectors defined in Section 2.

4.8 China and the US have produced the largest number of publications across all subsectors, with the least active countries being the Netherlands and Denmark. The UK, France and Germany all lie somewhere in between the two extremes, though they all produce significantly fewer papers than the US and China across all sub-sectors. It is unsurprising that the US and China lead the world in terms of the number of publications produced as the size of the countries, number of research institutions and volume of academic staff engaged in research are all significantly higher in the US and China than across the rest of the world.

4.9 When considering the quality of publications produced (estimated by the average number of citations per paper in each sub-sector) China fares relatively poorly compared to the number of papers it produces, suggesting China produces large volumes of papers that are not of great quality. The exception here is in materials. The UK fares very well in terms of publication quality, second only to the US in most cases, showing that whilst a relatively small number of publications are produced in the UK, they are of good quality and confirming many previous reports that state the UK is second only to the US in terms of top quality scientific research. Across the six sub-sectors, the UK, US and Netherlands perform best in terms of publication quality with France, Germany and Denmark lagging behind slightly behind.

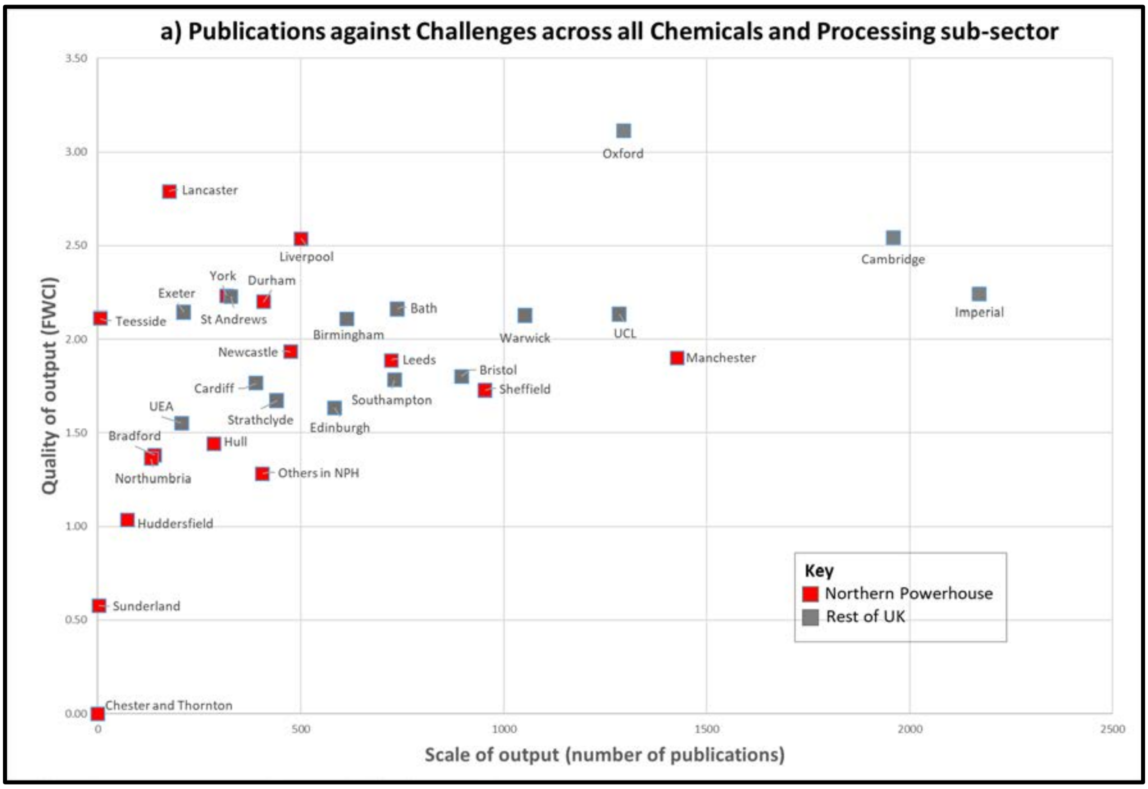
Comparisons across the UK research base

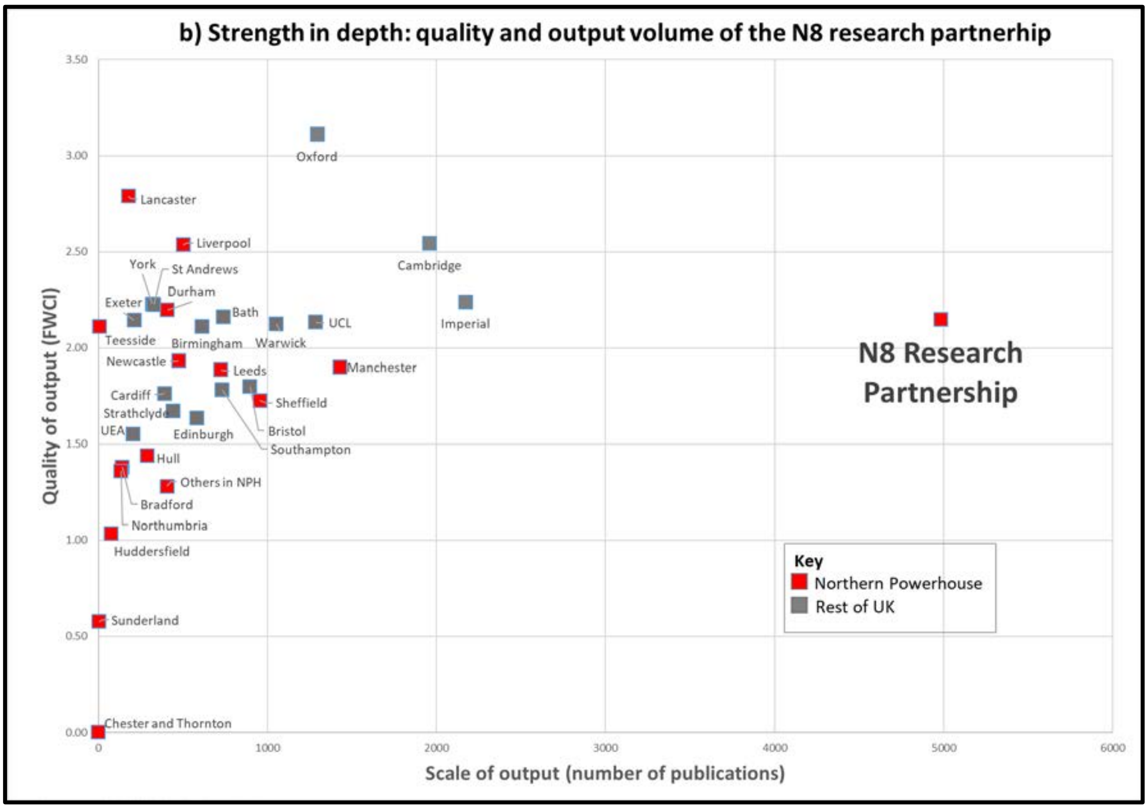
4.10 Appendix 5c) details the outputs from a publications and citations analysis based upon a key word search derived from the key trends and drivers identified in Section 2 for each of six chemical sub-sectors. Comparator institutions outside of the SIA area were chosen as they were amongst the top performers in the relevant REF 2014 areas. Figure 4.1 provides an amalgamated analysis across all the sub-sectors and plots the scale of publications output on the x axis against a measure of the quality of outputs as measured by the Field Weighted Citation Index (FWCI) on the y axis. The FWCI was calculated as the ratio of the total number of citations actually received by the individual institutions outputs, and the total citations that would be expected based on the average of the subject field.

4.11 Whilst the quantity of output is not as great as some of the larger research institutions, in the UK, leading research institutions within the SIA area compare favourably in terms of quality as measured by the FWCI. The scale of publication output is not unsurprising as institutions within the SIA area are generally smaller and less well funded than their comparison institutions such as Oxford, Cambridge, Imperial and UCL (for example, Oxford's research income is 8-9 times that of Durham or Lancaster).

4.12 The leading research institutions within the SIA area demonstrate strong research quality across all six sub-sectors of the chemical and process industry. This high-quality research on an individual institutional level indicates there is strength in depth across the chemical process sector within the SIA area that could be utilised to drive innovation and enhance the region.

Figure 4.1: a) Research output versus research quality. Publications responding to the key challenges to the Chemical and Process sector for the period, 2013-17

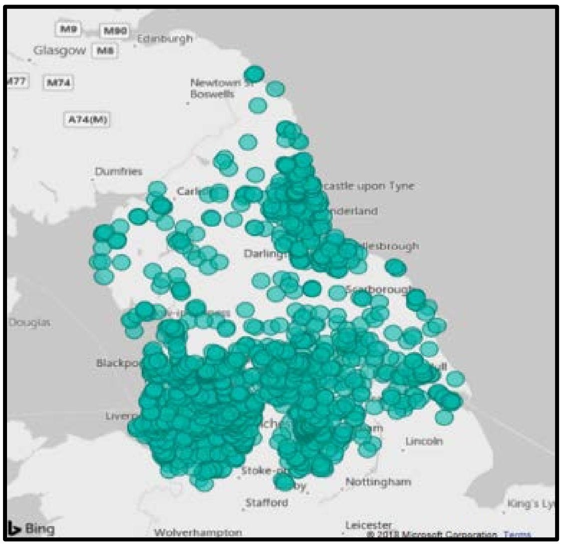




Share of UK science base: UK Research Income

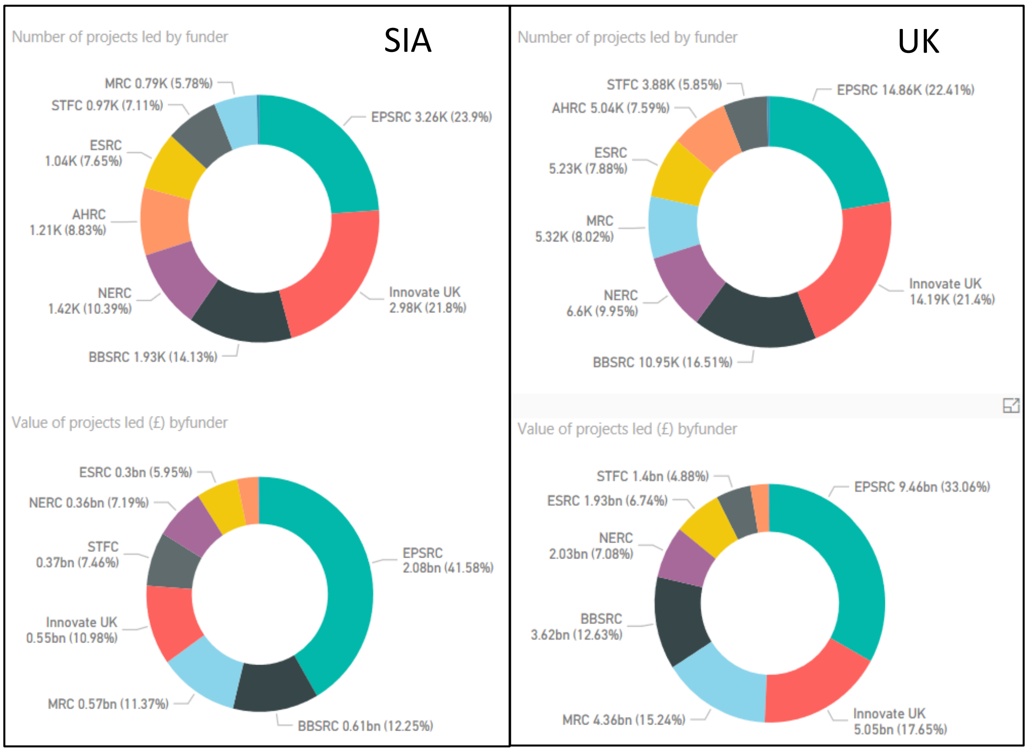
4.13 The Northern Powerhouse share of UK publicly funded research spend within the aforementioned disciplines is set out below. In relation to publicly funded projects, 3,444 unique participants (organisations) were involved in projects between 2007 and 2017, accounting for 14.72% of unique participants in the UK. The locations of research organisations in the region are shown in figure 4.2 **[61]**.

Figure 4.2: Location of organisations receiving UK research funding [49]



4.14 The Northern Powerhouse region accounted for 20.41% of UK publicly funded projects between 2007 and 2017, and 17.35 % of the total funding (Figure 4.3) **[61]**. Of the total projects for the region, almost half were funded through EPSRC and Innovate UK. The region has a relatively high proportion of EPSRC funding (22%) and a smaller proportion of Innovate UK funding (11%) than the UK as a whole. Further evaluation of Business research spend is detailed in Chapter 5.

Figure 4.3: UK Research Funding: Number and value of projects led by funder 2007-17 [49]



4.14 In terms of the number of Innovate UK projects awarded to universities, Sheffield was 2nd and Manchester 3rd out of a total of 173 institutions. Newcastle, Leeds, Liverpool, Sheffield Hallam, York, Durham, Huddersfield, Manchester Metropolitan and Northumbria all featured in the upper quartile. When considering the value of grants awarded by Innovate UK, Sheffield was once again 2nd. Manchester, Newcastle, Leeds, Liverpool, York, Sheffield Hallam, Bradford and Durham all featured in the upper quartile.

4.15 The key funding areas, proportion of UK funding the region had in this area, and level of specialisation are shown below in Table 4.2. A specialisation value of over 1 suggests the share of funding in the specific subject area for the region is greater than its share of UK funding as a whole **[61].** Particular strengths can be seen in materials science, chemical synthesis, chemical measurement, atmospheric physics and chemistry and materials processing.

Table 4.2: Northern Powerhouse research specialisation [61]

Sector	Share of UK total funding (%)	Specialisation
Materials sciences	27.56	1.67
Chemical synthesis	20.89	1.27
Chemical measurement	20.07	1.22
Atmospheric physics and chemistry	30.48	1.85
Catalysis and surfaces	17.34	1.05
Materials processing	24.84	1.51

Share of UK International Income (Non UK funding)

4.16 Table 4.3 shows the percentage of UK funding and specialisation that the region achieved in each of the three most relevant REF areas over the period 2008 to 2012 **[60]**. Strong performance is seen across all three areas.

Table 4.3: Northern Powerhouse University share of UK International income [49]

Unit of Assessment	Share of UK's International Research Income/ %	Income Specialisation
Chemistry	29.72	1.15
Aeronautical, Mechanical, Chemical and Manufacturing Engineering	41.45	1.50
Electrical and Electronic Engineering, Metallurgy and Materials	28.82	1.17

Horizon 2020

4.17 Horizon 2020 is the largest EU research and innovation program, designed to encourage private investment as well as encourage breakthroughs and discoveries in scientific research **[62]**. As of September 2017: 49 Universities across the UK had received Horizon 2020 funding, 9 of which are located within the Northern Powerhouse. These 9 institutions received 15.6% of the UK's Horizon 2020 funding and were involved in 17.8% of the total participations for the UK. Across all participations and funding provided by Horizon 2020, broader than the Universities alone, the Northern Powerhouse accounted for 16.0% of participations and 14.7% of funding **[49]**.

Multidisciplinary Strengths in Working with Industry

4.18 A particular feature of the Northern Powerhouse University ecosystem is the strength of both chemistry and chemical engineering disciplines and what appears to be a very strong willingness and ease in collaboration inter institutionally. Within the 15 University SIA consortium there were 12 Universities with formal Chemistry Departments with a further 2 with strong chemistry functions within other departments. This aligns with 6 formal chemical engineering departments plus 5 strong chemical engineering functions within other departments. Where Universities don't have Chemical Engineering functions, close collaborations are developed with other institutions.

4.19 Centres for Doctoral training (CDTs) represent strong vehicles for engagement with industry and also train postgraduates as future employees within the sector. There are presently 9 Centres for Doctoral Training (CDTs) in support of the sector with a further 6 under application as summarised below.

Table 4.4: EPSRC CDT partner networks (including * which are presently at full proposal stage)
(Key: Durham, Lancaster, Leeds, Liverpool, Manchester, Newcastle, Sheffield, York)

Technical area	CDT partner networks
Formulated organics	**S**-'Polymers, Soft Matter and Colloids'; **D**/**L**-'Soft Matter and Functional Interfaces' and SOFI2*, **Le**-'Molecules to Product'*; **M**-'Next Generation Mathematics for Materials Modelling'* & **M**-'Smart Manufacturing with Industry 4.0 Compliance
Digitisation	**3 Le**-'Fluid Dynamics'; **Le**-'Complex Particulate Products and Processes'; **La**/**Le**-'Statistics and Operational Research in Partnership with Industry', **S**-Digital Manufacturing'*
Formulated inorganics	**Li/S**-'New and Sustainable Photovoltaics'; **Li**-'Next Generation Materials Chemistry'*; **M**-'Materials for Demanding Environments' & 'Integrated Catalysis'*; **La/ Ma**-'Science and Applications of Graphene and Related Nanomaterials'

4.20 Appendix 4 summarises the University key centres and areas of activity. All the Universities have strong examples of multidisciplinary working with industry. Some (non-exhaustive) examples include:

- Durham's strategic relationship with Procter and Gamble. Multidisciplinary project working across over 50 projects to date involving chemistry, biosciences, physics, engineering and computer science, psychology and the business school. Working pan institutionally and cross-sectors with non-competing industrial partners as exemplified by a recent major EPSRC award **[63]** on molecular migration with partners Durham, Sheffield, York and Birmingham Universities and P&G, Akzo and Mondelez.
- Hull's partnership with CATCH, the employer organisation representing the Humber's £6billion chemicals and process industries
- Lancaster's strong SME engagement with the NW chemical sector through its Collaborative Technology Access programme (cTAP) An 11.4m ERDF supported capital build that has engaged with over 300 companies, creating over 260 new jobs, over 120 new products and services and secured over £4m towards inward investment
- Leeds Institute of Process Research and Development engaging strongly with dozens of companies in the chemical, polymer and pharmaceutical sectors through EU (H2020, ERDF, ~£28m), Innovate UK (8 projects ~£8M), UKRI (~£10M), Industry (~£2M) projects including strategic relationships with AstraZeneca and P&G.
- Liverpool's close partnership with Unilever in the £68m Materials Innovation Factory, providing open access to a materials science automation robotics and automated materials discovery expertise. Croda International joined the Factory in November 2017.
- The Manchester led Process Integration Research Consortium is formed by 26 major companies representing the process and utility industries. The application of Centre for Process Integration technology has led to significant reductions in both energy costs and

emissions of greenhouse gases. Since 2008 ca. US$350m of savings have been realised through the exploitation of CPI technology with US$1.4m generated from software sales [64]

- Sheffield's Polymer Centre is the UK's largest single-university academic network in the field, collaborating with a variety of industrial partners such as Unilever, BP, Syngenta, P&G, AkzoNobel, Lubrizol, BASF and Croda. Located across the Faculties of Science, Engineering and Medicine, this network of 55 academics and ~120 post-docs and PhD's covers all areas of polymer science and technology.
- Teesside, Hull and York (lead) £5m connected capability Fund project THYME growing the productivity of Yorkshire, Humberside and the Tees Valley bioeconomy as a whole by bringing together research and commercialisation within the three universities.
- York led RenewChem is an industrial focused membership group leading the transition to green manufacturing and circular economy in the chemical industries. RenewChem includes a Centre for Graduate Training (CGT) in Sustainable Chemical Manufacturing and industry access to innovative research specialisms, facilities, early sight of new results and results of long term, high quality research project. Current members of RenewChem include Croda, Unilever, GSK, Circa, Merck, Nestle and Brocklesby.
- Redbrick Molecular- a spin-out from the Universities of Sheffield and Leeds works closely with partner universities, licensing intellectual property from academia to industry in order to produce key chemicals which are used early in the drug discovery process. The company utilised start up loans from the University of Sheffield and Leeds and uses a unique business model where all profits from sales are used to support UK academic chemistry research.
- Appendix 4c) provides a comprehensive summary with further specific examples related to application of digitisation solutions provided in Chapter 7.

4.21 An example of how multidisciplinary working has been harnessed pan-institutionally is the Northern Sustainable Chemistry (**NORSC)** consortium**.** Initiated by Durham's Centre for Sustainable Chemical Processes (CSCP) in close collaboration with the University of York's Green Chemistry Centre of Excellence, Leeds' Institute of Process Research and Development (iPRD), and catalysis researchers in the Department of Chemistry, Newcastle. Subsequently, the original NORSC group was expanded to include contacts at the Universities of Sheffield, Hull, Huddersfield, Bradford, Manchester and Liverpool. NORSC developed a network that was to become a premier partner for the delivery of green chemistry, catalysis, and sustainable chemical manufacturing research and development, strongly supported by a number of the chemical, pharmaceutical and materials industries located in northern England. The consortium built upon its combined research expertise and potential, through collaboration across different research groups, to deliver research above and beyond the capabilities of the individual departments and to support regional industries to initiate new industry-university joint development and research projects spanning sustainable chemistry and catalysis, acting as a knowledge transfer partner not only to research expertise, but to available infrastructure and specialist equipment.

4.22 An example of industry problem solving building on academic expertise is the 'Knowledge Centre for Materials Chemistry' (**KCMC**), which is an industry-led partnership between industry and academia, dedicated to driving materials chemistry innovation. KCMC is a national centre with a strong base in the Northwest of England, and draws on expertise at the universities of Bolton, Bristol, Liverpool, Manchester and Southampton, and the computational modelling capabilities of the Hartree Centre at Daresbury. The KCMC connects the academic knowledge base in materials chemistry with the innovation needs of companies in multiple industry sectors, and with a particular focus on advanced materials. Since 2017 KCMC has been hosted by the Centre for Process Innovation; prior to that KCMC was hosted by the KTN. The KCMC now works closely with KTN, Innovate UK and the Catapult Centres to help address UK innovation challenges in materials chemistry. Since its foundation in 2009, KCMC has delivered more than £30million collaborative research income, including £9million industry income, and engaged with in excess of 600 companies of which 40% are SME's. An independent evaluation of KCMC carried out by Warwick Economics and Consulting in 2015 **[65]**, identified GVA benefits in excess of £200million.

4.23 Whilst clearly there are good examples of strong business-University interactions, a very clear message emerging from the pan NPH University workshop convened 23 March 2018, was that there is not enough collaboration, and that there needs to be more focus on industry challenges which will underpin competitiveness and future growth of the sector. This is reflected in fragmentation in the present innovation ecosystem, both between Universities and the National Innovation Centres, and gaps in ability to respond to the needs of companies. In this context, a model based upon a restructured and properly resourced NORSC was seen as an attractive option to enable better industry access to knowledge and expertise and drive collaborative working across the priority sector challenges, for example in enabling development of the Circular Economy. Subsequent discussion has suggested that a model than spans the NORSC and the KCMC operating principles should be considered as a mechanism to address industry challenges in simpler ways and ultimately expand R&D investment in the region.

5 Innovation Strengths and Growth Points

Key Messages

- Although there is still significant investment in the innovation ecosystem across the Northern Powerhouse, there is evidence of disconnect with certain sub-sectors and also scales of enterprise and pattern of ownership;
- There is a clear geographic disconnect between where goods are produced and the location of innovation;
- Analysis of business R&D spend within the sector has shown that there is:
  - Evidence of a disconnect between the national innovation ecosystem and actual production; and
  - A contributory factor to the lower GVA per job experienced in the Northern Powerhouse due to the absence of higher value add headquarter and research and development functions;
  - There is greater scope for the NPH innovation base to support the business R&D Headquarters outside of the region but that also there would be benefits in developing business R&D in closer proximity to the research base.
- Comparatively low levels of University spin outs in this sector across the Northern Powerhouse;
- There is a need to address the absorptive capacity of micro and small enterprises, particularly within plastics, polymers and materials; and
- The sector seems to be impacted by two counterbalancing trends, an ageing workforce disproportionately affecting supply of higher technical and managerial skilled individuals, at the same time as the reduction of HQ and R&Di functions is affecting the demand for such functions. However, such a situation will not lead to economic equilibrium, rather unless it is addressed, the sector could face a vicious cycle of perceived declining opportunities.

Introduction

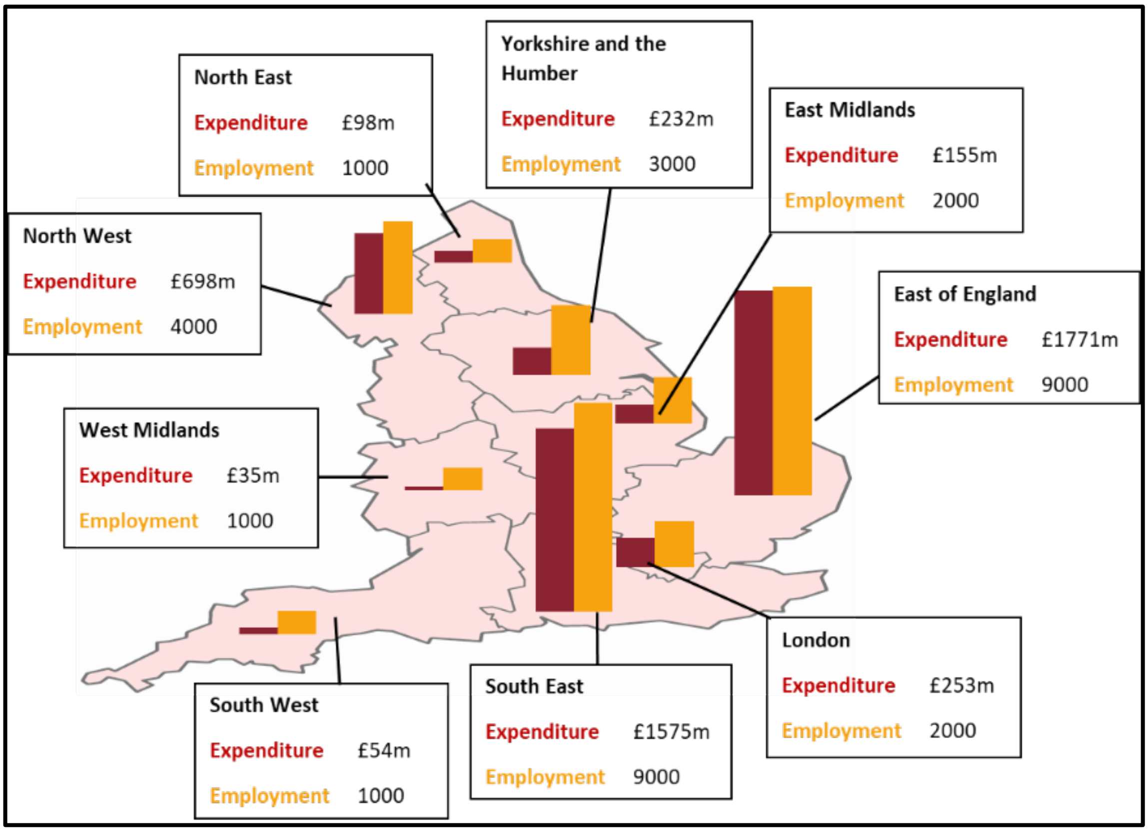
5.1 This section complements previous analysis in section 4 by identifying the innovation strengths of businesses within the sector across the UK and the Northern Powerhouse. The analysis of innovation strength relies on the following proxy variables, including:

- Direct Business Expenditure on R&D;
- Government support to business;
- Catapults and National Innovation Centres and
- Workforce Capability and Skillset.

Direct Business Expenditure on R&D

5.2 The Office for National Statistics (ONS) publishes data on the expenditure and employment within UK businesses on R&D by broad industry group (as opposed to *specifically* the chemicals and process sector, for instance) **[66]**. Appendix 6a details the methodology used. Figure 5.1 shows a summary of the business expenditure on R&D activities within the broad chemical manufacturing product group broken down by region alongside the number of employees employed in R&D roles **[66]**. In the case of this data, location information is based on where the R&D is actually performed rather than the location of the head office. Figure 5.1 shows a disproportionally large amount being spent on R&D in the South East and East of England, with a disproportionally small amount being spent in the North East and North West. The employment data follows the same pattern as the expenditure data. The data further suggests that companies within the Northern Powerhouse region could be doing more in terms of spending on R&D.

Figure 5.1: Business expenditure on R&D activities broken down by region and number of employees in R&D roles



5.3 When viewed against overall employment and production (Section 3 Figure 3.2a), there is a clear disconnect between where products are manufactured and company led R&D activity. There is a disproportionate amount of research activities taking place in the south east and east of England, whereas manufacturing and other lower value adding activities are focused in the Northern Powerhouse. This has two implications:

- Evidence of a disconnect between the national innovation ecosystem and actual production; and
- A contributory factor to the lower GVA per job experienced in the Northern Powerhouse due to the absence of higher value add headquarter and research and development functions.

5.4 Two issues are important here. Firstly ensuring that the UK based R&D headquarters for internationally owned companies remain in the UK. This is against strong competition for siting these internationally and potential concerns post Brexit. The strength of the NPH academic base should be leveraged to support and engage with these key centres. Secondly, whilst we are in the age of internet connectivity, proximity of business based research to the academic and non-academic centres of excellence does matter. This is further emphasised in the International benchmarking study reported in Chapter 7 and Appendix 16 in, for example, the impact of the Chemelot innovation campus in Southern Holland.

5.5 The Bureau van Dijk ORBIS database **[67]** compiles company account information on over 280 million companies worldwide; the information collected includes turnover, employee count, and location (for those who have declared) of R&D expenses. Further data analysis was undertaken on R&D expenditure declared in Company accounts as summarised in Appendix 6b. Figure 5.2 shows the breakdown of R&D expenses by region and sector in the UK including pharmaceuticals and figure 5.3 shows the same information excluding pharmaceuticals.

Figure 5.2: R&D Expenditure (Including Pharmaceuticals) [67]

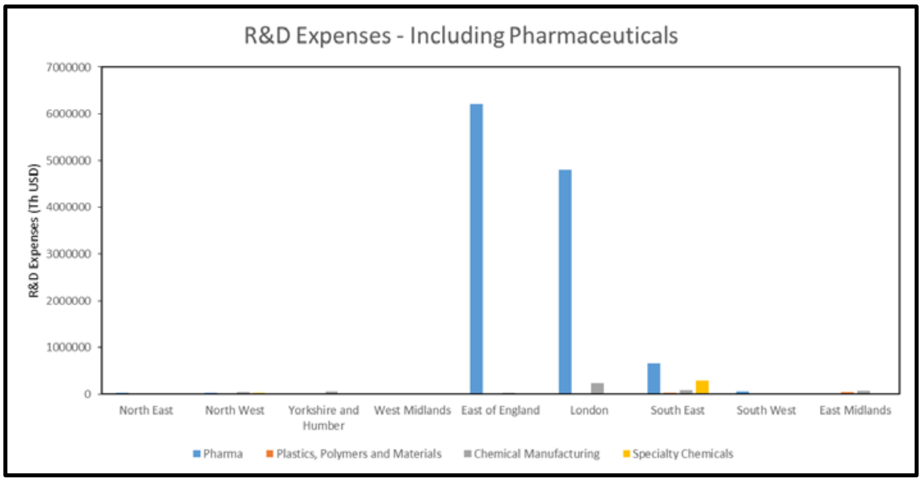
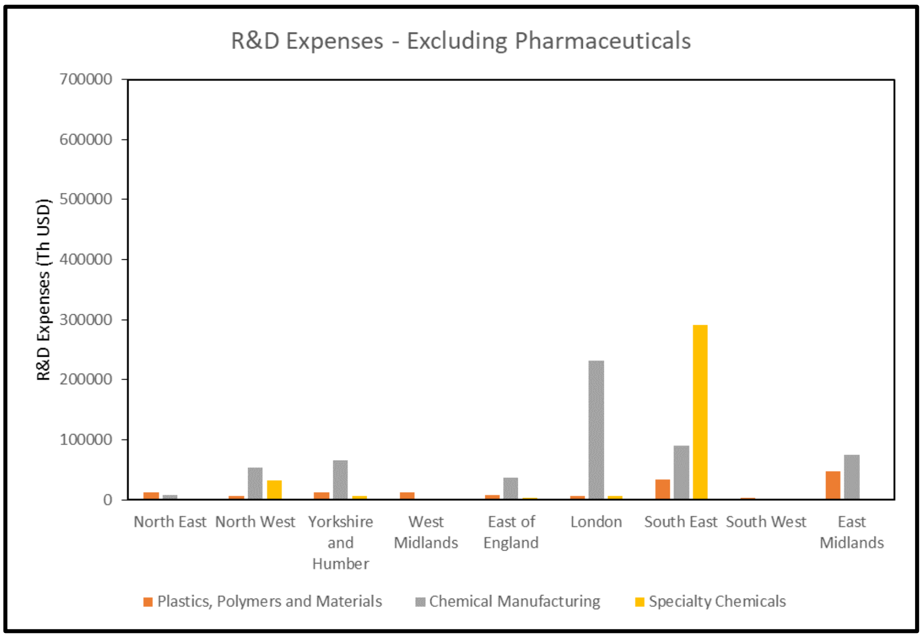


Figure 5.3: R&D Expenditure (Excluding Pharmaceuticals) [67]



5.6 From figures 5.2 and 5.3 we can see that pharmaceuticals account of the vast majority of declared R&D expenses and this spend is concentrated in London and the East of England. The data gathered by ORBIS is however, likely to be skewed by the headquarter effect. When pharmaceuticals are excluded from the data, the concentration of R&D expenses shifts slightly to London and the South East. Most R&D is concentrated on chemical manufacturing though there is also a large concentration of R&D spend on specialty chemicals in the South East. Relatively little is spent on R&D in plastics, polymers and materials. The Northern Powerhouse accounts for a relatively small amount of the R&D spend overall. Appendix 7 shows individual sector breakdowns for each region within the UK.

5.7 A final proxy for level of innovation, is company growth rates. The Beauhurst searchable database **[68]** (outlined in appendix 6c) was used to provide information on the UK's fastest growing companies and the level of Innovate UK funding awarded to both companies and universities. There are currently 279 fast-growth companies located within the Northern Powerhouse region, of which 99 have received grants from UK funding bodies. Those 99 companies have received 219 grants between them to a total of £31,546,815.

5.8 Beauhurst also gives information on the number of spin-out companies from UK universities. Between 2013 and 2017 thirty companies were spun out of universities within the SIA area, these companies between them have received 78 grants to a total of £9,527,657. Spin-out companies from universities are examples of innovation being turned into economic gain for the region.

Government Support to Business: Innovate UK Funding

5.9 Innovate UK postcode data shows where the research is carried out rather than where the company is registered, eliminating the headquarter effect. Table 5.1 analyses Innovate UK awards between 2004 and the beginning of March 2018. Data is presented for all sectors and also for the two classification areas where chemical and process sector research is most likely to be specified. The Methodology is outlined in Appendix 6e.

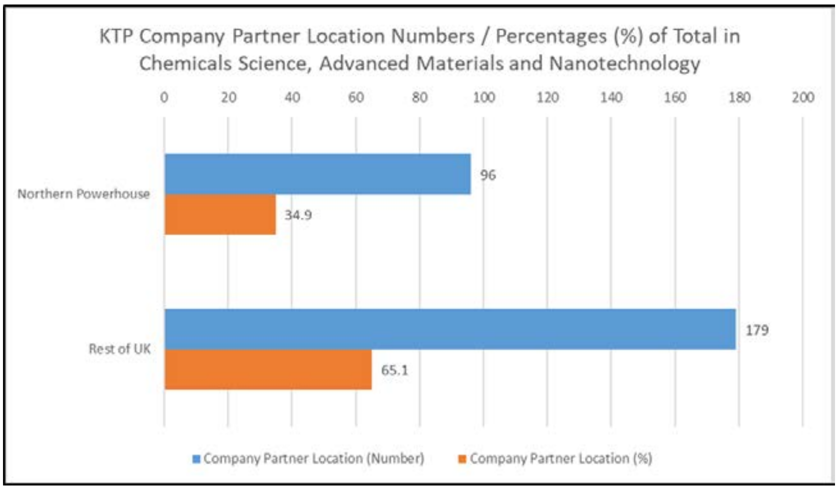
Table 5.1: Innovate UK Awards 2004 to March 2018 [69]

All Awards					Materials and Manufacturing/ Emerging and Enabling				
	Number of Awards	Total Grant/£m	% Value	NPH		Number of Awards	Total Grant/£m	% Value	NPH
North East	814	262	9.5%	23.2%	North East	1,224	48	7.4%	17.8%
North West	2,056	159	5.8%		North West	2,779	26	4.0%	
Yorkshire and Humber	1,501	220	8.0%		Yorkshire and Humber	2,127	41	6.4%	
East Midlands	1,659	151	5.5%		East Midlands	2,426	35	5.5%	
West Midlands	1,815	357	12.9%		West Midlands	2,580	61	9.6%	
East of England	2,206	224	8.1%		East of England	3,575	55	8.6%	
London	3,498	463	16.7%		London	5,328	137	21.3%	
South East	3,454	461	16.7%		South East	5,287	99	15.4%	
South West	1,742	232	8.4%		South West	2,740	82	12.7%	
Northern Ireland	312	34	1.2%		Northern Ireland	465	8	1.2%	
Wales	683	62	2.2%		Wales	999	11	1.7%	
Scotland	1,363	140	5.1%		Scotland	2,313	40	6.2%	
TOTAL	21,103	2,763	100.0%		TOTAL	31,843	641	100.0%	

5.10 This supports the earlier hypothesis that business R&D in the chemical and process sector is based outside of the manufacturing base within the Northern Powerhouse.

5.11 Within the Innovate UK funding portfolio, **Knowledge Transfer Partnerships** (KTPs) provide funding for projects between UK universities and businesses; they are used to address core strategic needs within a business by identifying innovative solutions. So far 275 KTPs have been completed in areas relevant to the chemical and process sector in the UK, 110 of which were led by universities within the SIA area. The area therefore accounts for 40% of all completed UK chemical and process sector KTPs in terms of university involvement. There are currently 22 ongoing KTPs in the chemical and process sector within the UK, 5 of which are led by universities in the Northern Powerhouse **[70] [71]**.

Figure 5.4: Completed KTPs in the Northern Powerhouse compared to the rest of the UK as of 2018 [70]

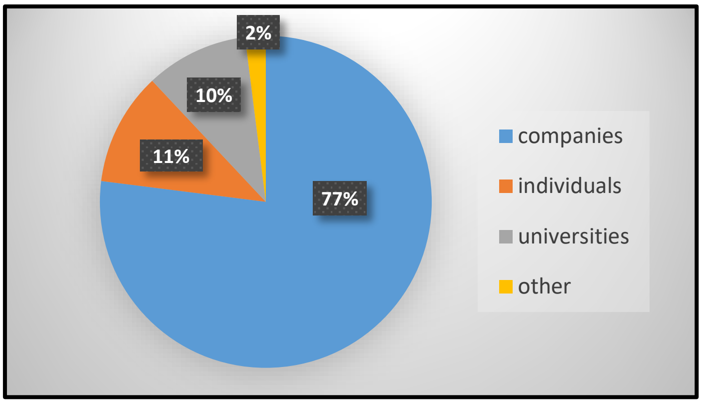


5.12 Considering the leading company partner involved in KTPs within the region, 96 of 275 completed KTPs had a leading company partner located in the SIA area, accounting for 35%, as compared with the rest of the UK, as seen in figure 5.4. Of the ongoing KTPs, 7 of 22 had a leading company partner located in the SIA area (32%) **[70] [71]**.

Patent Data

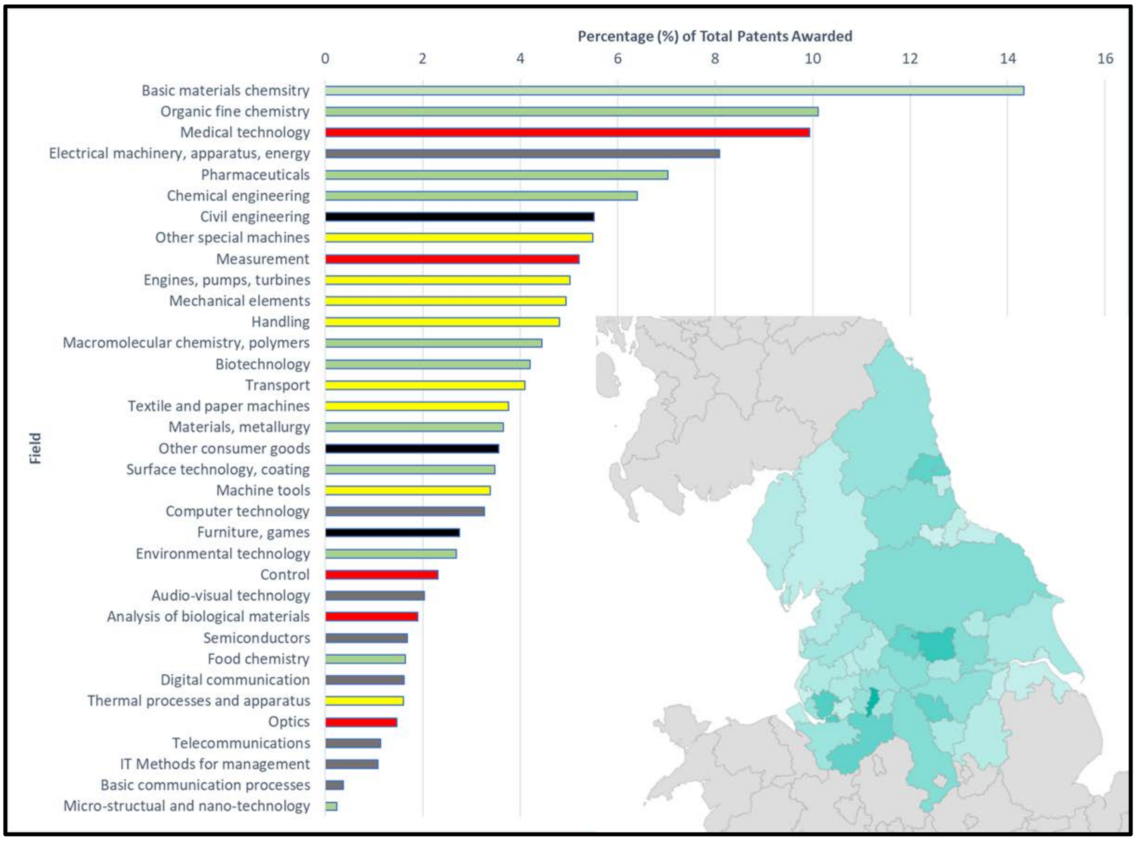
5.13 The PATSTAT database was analysed for chemical and processing technologies patented within the geographical SIA area **[72]**. The number of chemistry related patents from the SIA region accounted for 26% of UK patent applications between 2007 and 2017 from 18% of unique UK applicants. The larger share of applications than unique applicants in the region suggests a strength in the area. The majority of unique applicants within the SIA area were companies (figure 5.5) and most collaboration on patents was with between co-inventors in the US and the Netherlands **[72]**. The latter interaction should clearly be considered in the context of Brexit. Further details are provided in Appendix 8.

Figure 5.5: Chemistry related patents in the SIA region [72]



5.14 Figure 5.6 shows the breakdown of patents awarded in the SIA area by sub-sector. Over half of the patents filed in the SIA region were in fields related to the chemicals and process sector emphasising the importance of this sector to this region. Basic materials chemistry (14%) and organic fine chemistry (10%) represented the strongest categories within this field. A heat map of where in the region all patents have been filed is shown in the inset. Further heat maps of patent applications in the key sub-sectors are shown in Appendix 8. Most patent activity in the region is concentrated on the M62 corridor between Yorkshire and Humberside and the North West and with a hotspot north of Newcastle (P&G and also an adjacent pharma manufacturing cluster).

Figure 5.6: Number of Patent Applications by WIPO Sector [73]



5.15 Analysis of the relative specialisations with respect to the key chemical sector within the SIA area is provided in Table 5.2 which compares the relative proportion of patents filed against the proportions filed across the UK. The Northern Powerhouse shows a particularly strong specialisation in basic materials chemistry, macromolecular & polymer chemistry, materials & metallurgy, surface coating and technologies and showed below average specialisation only in the areas of pharmaceuticals, biotechnology, food chemistry and microstructural & nanotechnology. Appendix 8b provides a detailed comparison between the NPH and the UK overall.

Table 5.2: Relative Specialisation of IP filed on the Chemical Technologies [72]

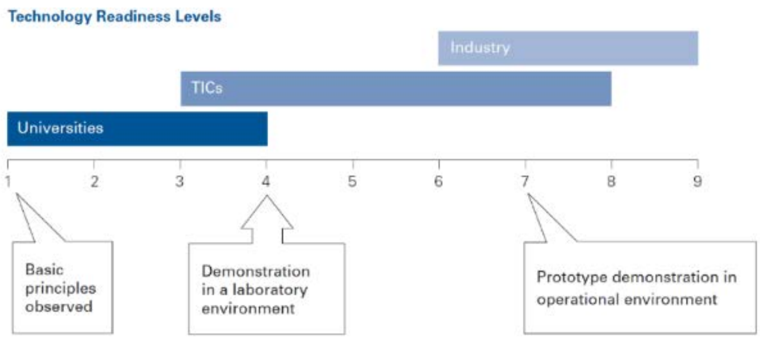
Chemical Sector Technologies	SIA Area	UK	Specialisation
Basic Materials Chemistry	10.8%	4.1%	**2.63**
Organic chemistry	6.9%	5.1%	**1.35**
Pharmaceuticals	4.4%	6.1%	0.72
Chemical engineering	3.6%	2.5%	**1.44**
Macromolecular Chemistry & Polymers	2.5%	1.1%	**2.27**
Biotechnology	2.9%	3.4%	0.85
Materials & metallurgy	2.1%	1.2%	**1.75**
Environmental technology	1.8%	1.3%	**1.38**
Food Chemistry	1.1%	1.5%	0.73
Micro-structural and nanotechnology	0.1%	0.2%	0.5
Surface technology and coatings	1.9%	1.0%	**1.9**
All chemical sector technologies	38.0%	27.6%	**1.38**

Catapults and National Innovation Centres

5.16 It is not surprising, considering the geographical strength of this sector that there is a northern cluster of internationally and nationally important Catapults and other National Innovation Centres that support the chemicals and process sector. The consortium includes the Centre for Process Innovation (CPI), the Materials Processing Institute, TWI, the Royce Centre and Materials Innovation Factory. These innovation centres work closely with academia and industry to foster and encourage innovation in key areas.

5.17 CPI is particularly relevant to the SIA as part of the High Value Manufacturing Catapult it is the innovation centre for the process industries. The Catapult Centres were a direct response to the 2010 Hauser Report **[74]** which recommended that the UK form a series of Technology and Innovation centres that are open to companies of all types and sizes to assist them on their innovation journey. These centres translate scientific discoveries into economic commercial success by providing equipment, knowledge and people to companies of all sizes so that they can build the collaborative partnerships that translate ideas into tangible businesses. As has already been discussed, the UK has an excellent science capability but falls short of translating these into leading positions in industry and this gap can only be closed by making new technologies investment ready. The Catapults are therefore designed to exploit the most promising new technologies where there is genuine potential for the UK to gain a competitive advantage, operating in Technology Readiness Levels 3 to 8 bridging the gap between academic discovery and commercial exploitation as illustrated in Figure 5.7.

Figure 5.7: Technology Readiness levels [74]



5.18 There are currently 10 catapult centres across the UK, of these, four have facilities in the SIA area: Centre for Process Innovation (CPI), (part of the High Value Manufacturing Catapult), currently has five National innovation centres in the North East region with facilities at Wilton, NETPark (Sedgefield) and Darlington. These national centres are in: biological pharmaceuticals, formulation, graphene applications, industrial biotechnology, and printable electronics. The Digital Catapult has the NE and Tees Valley Centres at NETPark (Sedgefield) and the Yorkshire Centre in Bradford. The Satellite Applications Catapult has a Centre of Excellence at NETPark (Sedgefield). The fourth Catapult in the Northern Powerhouse is the Offshore Renewables Catapult facility at Blyth.

5.19 CPI is providing critically important facilities to support to the chemical and process industries using applied knowledge in science and engineering combined with state of the art development facilities to enable its partners to develop, scale up and prove new products and processes for market adoption. CPI has been operating for over 15 years and has carried out over 2500 projects with a total value in excess of £600m. With over 400 employees, it works with companies from major multi-nationals to SMES with over 50% of the activity with SMEs. It provides solutions for the process and operational challenges in all the UK's major process industries including the development of the bio-economy and converting wastes into valuable products. It provides process and product development facilities to companies with the overall aim of creating lower carbon, lower waste and cleaner, more efficient and more economic products and processes. The major markets that benefit directly include: transportation, built environment, pharmaceuticals, personal care, materials production, electronics, food, energy, waste and lighting.

5.20 The CPI model helps companies understand their business and operational challenges through a techno-economic analysis approach that focuses on resource efficiency and carbon reduction. This is aligned with provision of open access to over £160m of process development and proving assets that partners can use to develop and commercialise next generation products and processes. This model reduces risk for its partners by reducing the cost and increasing the speed of development programmes. CPI links its flexible assets with engineering capability supported by sustained public investment in the open innovation model. CPI owns and operates the five scale-up and proving centres in: Biologics Manufacturing, Formulation, Graphene Applications, Industrial Biotechnology and Printable Electronics. In building these assets, CPI has succeeded in attracting significant national capability and the leadership of national initiatives to the Northern Powerhouse.

5.21 National Innovation Centres in the SIA area that support the sector include TWI, with strong emphasis on materials technologies with research centres within the NPH in Sheffield and Middlesbrough as well as it's Cambridge headquarters. TWI is a leader in materials technologies around joining, inspection and in service performance and failure. It provides research and innovation services directly to industry, leads on international standard committees and delivers industrial training to over 20,000 students internationally. TWI has recently established the National Structural Integrity Centre which is training over 530 post graduate students based on TWI sites. It has also established a growing Innovation network which currently consists of 9 university innovation centres co-located at TWI.

5.22 The Materials Processing Institute at Redcar is internationally renowned for its expertise in challenging processes, particularly those involving high temperatures, hostile environments and high specification metals and inorganic materials.

5.23 University led translational centres working at slightly lower TRLs include the National Graphene Centre and the Henry Royce Institute in Manchester and the Materials Innovation Centre on Merseyside. Appendix 9 provides summary information on the Catapults and other National Innovation Centres in the SIA area. Table 5.3 provides further information on key areas of focus and scale.

Table 5.3: Focal areas of the key SIA Area National Innovation Centres

Organisation	Focal Areas	Scale of activity
CPI	UK's innovation centre for the Process Industries: Technology Platforms: • Biological pharmaceuticals, • Industrial biotechnology, • Formulation and flexible manufacturing • Graphene applications • Printable electronics • Healthcare photonics • Medicines manufacturing Market Focus: • Healthcare	Company • Not for profit company limited by guarantee • >400 people with over 24% qualified to postgraduate degree level. • £200m of assets at replacement cost. • Turnover of c.£35m/yr. • Projects with c.40 universities and c.100 companies at any time.

Organisation	Focal Areas	Scale of activity
	• Food & agriculture • Personal care and FMCG • Transport and mobility • Energy generation & storage • Construction Development Themes: • Healthcare systems • Digital manufacturing • Materials • Resource efficiency and clean growth	• Leading innovation management processes that have delivered over £250m of investment in UK companies and the benefit of their annual employment and economic contribution.
TWI	TWI's main technical focus is around Materials Technologies, with a strong emphasis on how to design, manufacture and use materials safely in different applications and environments. Key technology areas include, • Materials Performance, including corrosion, fatigue, harsh environment testing, coatings and failure analysis. • Joining of metals plastics, composites and ceramics including processes such as welding, brazing, adhesives, friction and laser joining and Integrity Management, • materials inspection technologies, asset life, safe operation of plant	• a world leading, not for profit independent research and technology organisation, established in 1946 • Research centres in Cambridge, Middlesbrough, Rotherham and Port Talbot, as well as training facilities internationally. • TWI is owned by its 700 industrial member companies, it provides innovation and research services to industry, and trains around 20,000 students per year internationally. • TWI also manages an Innovation Network, consisting of 9 university innovation centres co-located at TWI alongside the National Structural Integrity Centre which will train over 530 post graduate students
Materials Processing Institute	• Advanced Materials (predominantly focussed on metals and inorganics) • Circular Economy • Low Carbon Energy • Digital Process Technologies	• Turnover of £5.2Mpa • 90% private industry funding • ROI of 8:1 for clients • 75 staff
Henry Royce Institute	UK national centre for research and innovation in advanced materials:	• £235m earmarked for increased research efforts across the partners.

Organisation	Focal Areas	Scale of activity
	• Hub and spoke model, with the University of Manchester as the hub • Initial spokes at the universities of Sheffield, Leeds, Liverpool, Cambridge, Oxford and Imperial College London, as well as UKAEA and NNL. • Intention is to grow to include more of the UK's leading materials scientists. Planned research areas: • 2d materials • Advanced metal processing • Atoms to devices • Biomedical materials • Chemical materials design • Energy storage • Materials systems for demanding environments • Materials for energy efficient ICT • Nuclear materials	• Still in the early stages of implementation.
National Graphene Institute	Research Institute at the University of Manchester focused on research into graphene.	£61 million National Graphene Institute to research and incubate graphene towards commercialisation.
Materials Innovation Factory	University of Liverpool centre to deliver research and support computer aided materials design with a focus on functional materials for the personal care industry. Unilever is an investment partner.	£68m Centre built and operating working with a number of partners on a range of research challenges. Croda International joined the Centre in November 2017.

Sectoral Bodies

5.24 Strong sectoral bodies have been established to support the sector across the Northern Powerhouse. These include NEPIC in the Northeast, Chemicals NW in the Northwest, and HCF CATCH in Humberside recently merged with the YCF in Yorkshire. The large pharmaceutical intermediates cluster in the NE is supported by the First for Pharma organisation. Further details are provided in Appendix 10.

Workforce Capability and Capacity

5.25 In the following section workforce capability and capacity is assessed by reviewing the following supply side information:

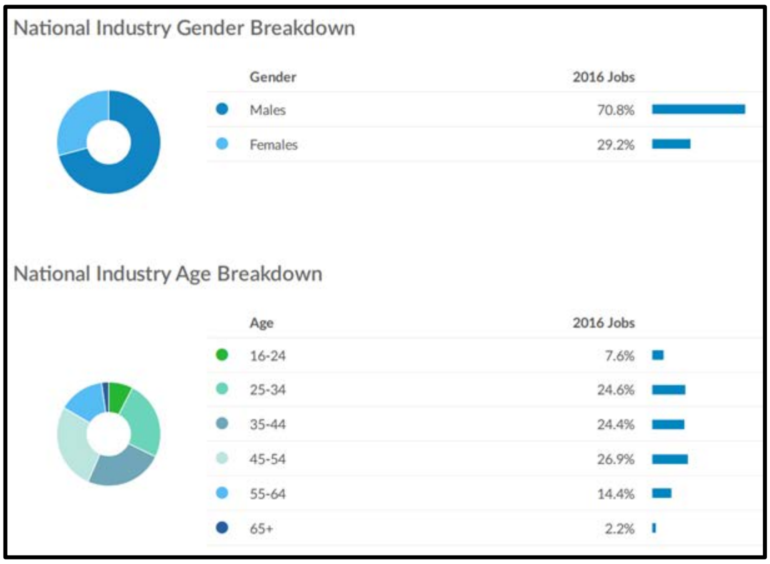
- Gender and Age Profile; and
- Existing and Projected Skillsets.

The detailed report can be found in Appendix 12.

Gender and Age Profiles

5.26 The gender and age profile for the chemicals and process sector is provided in Figure 5.8.

Figure 5.8: Gender and Age Profile of the Chemical and Process Sector 2017 [51]



5.27 Figures 5.9 and 5.10 goes further and provides comparative data on gender and age balance across a broad range of sectors.

Figure 5.9: Gender Composition of the Sector 2017 [51]

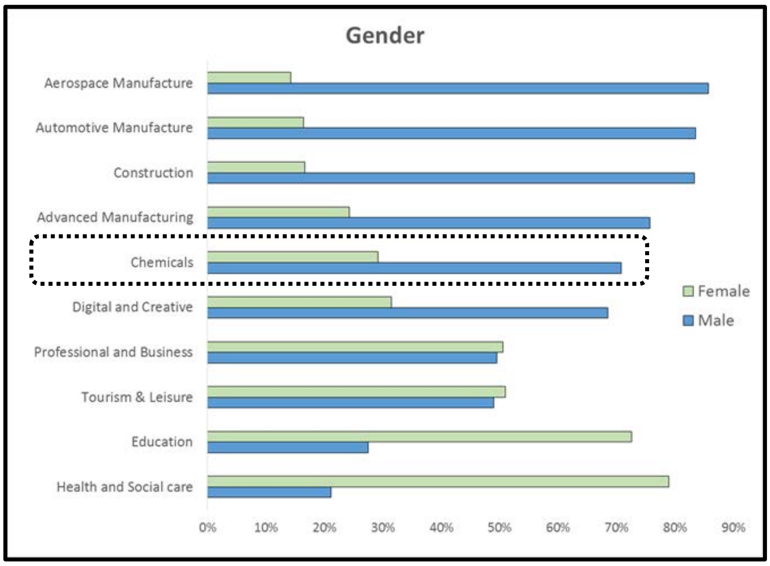
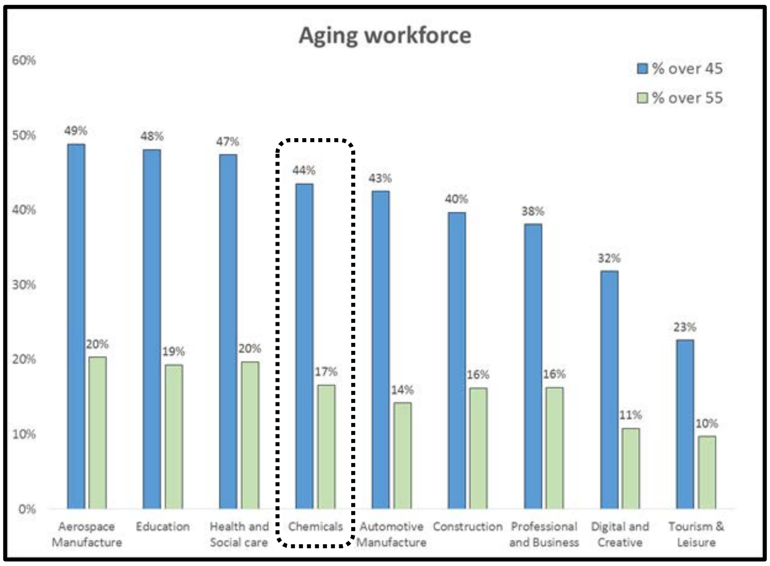


Figure 5.10: Workforce aged over 45 and 55 across sectors [51]



5.28 The key points to note:

- The chemicals sector is comparable to the wider manufacturing sector in terms of gender and age profile. The imbalance seen across the sector is perhaps not surprising when the age of the workforce is considered. Nationally almost 50% of the workforce across relevant sectors is over the age of 45 (figure 5.10), a generation in which females were not often encouraged into jobs within the sector;
- The ageing workforce will have significant implications for the sector going forward, in particular high levels of replacement demand for higher skilled/technical and managerial functions, for which there is not an immediate source; and
- There is a need to encourage more in-work training within the sector, to address the replacement demand issue, at the same time as encouraging more female participation.

Apprenticeships and Vacancies

5.29 In the year 2016/17, 39% of all chemical sciences related apprenticeships in England were started by residents of the SIA area with a total of 36,300 chemical science related apprenticeships started in the Northern Powerhouse. 19% of all apprenticeships undertaken by SIA area residents were in chemical science related subjects, the same proportion as across the whole UK **[75]**. The demand for apprenticeships was high with approximately 12 applications per position within the chemical sciences.

In 2017 there were 1230 vacancies for chemical scientists within the SIA area, accounting for one third of all chemical scientist vacancies within the UK. The number of vacancies in the Northern Powerhouse increased by 61% compared to 2016, against a national average increase of 31% in 2017 **[75]**. Whilst the large increase in chemical scientist vacancies could suggest significant growth in the region, it could also be indicative of a widening skills gap within the sector. The NPH Universities are attracting a strong talent pool of undergraduate and postgraduates from outside the region onto their courses in the chemical and physical sciences. This could potentially be turned to an advantage in filling these vacancies provided that the opportunity was targeted to these cohorts.

Guided by stakeholder feedback and the results of the NESTA report on digital skills **[76]**, it is anticipated that future demand will be in the following areas:

- Industrial Digitisation – Electrical engineers, data scientists, general technicians
- Circular Economy – Mechanical engineers and general technicians

- Attraction and Retention of talent - Research scientists, Senior Managers, Procurement/Supply Chain Specialists, Regulatory Impact Analysts, Sales Staff and Customs Clearance Staff.

Future Skillset requirements

5.30 Data from Working Futures 2014-2024 study **[77]** shows a growing trend towards a more highly skilled workforce, both within the Northern Powerhouse and nationwide, at the same time as there is a denudation of existing skillsets due to the ageing of the workforce.

5.31 This is illustrated more clearly in figures 5.11, 5.12 and 5.13. Extrapolating these findings to the chemicals and process sector of the Northern Powerhouse, as educational attainment increases, it is clear that the sector needs to continue to attract the very best graduates from the area and beyond in order to remain competitive. A case study is provided in Appendix 11 of TTE, a training provider for employees within the sector which aims to address this gap.

Figure 5.11: Percentage of people employed at degree level and above (2014-2024) [77]

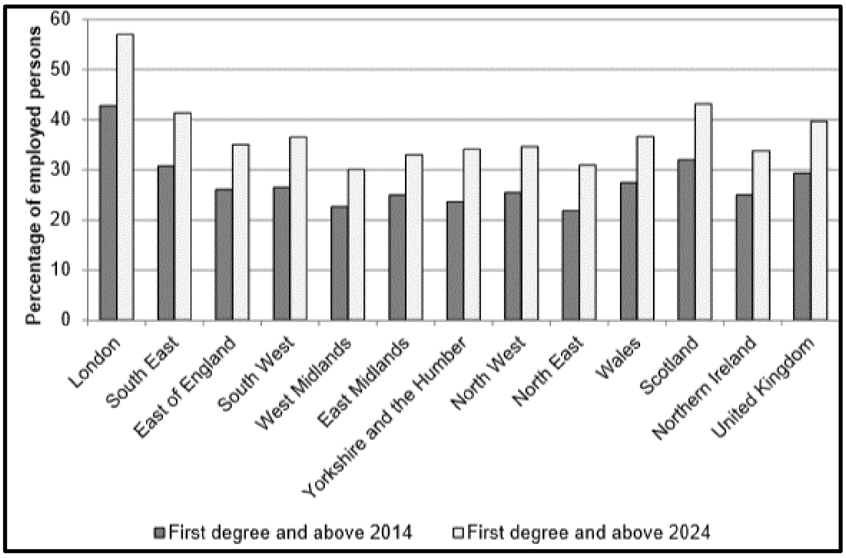


Figure 5.12: Projected figures for 2024 of highest qualification level by region [77]

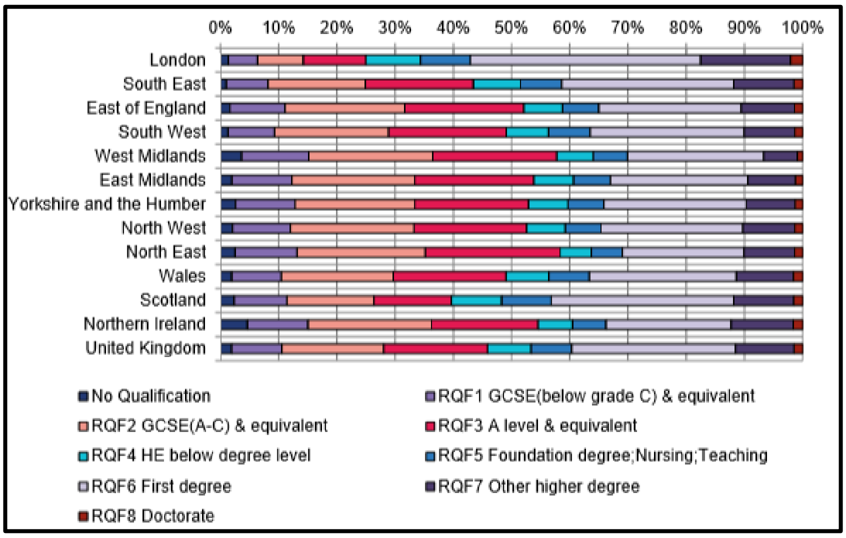
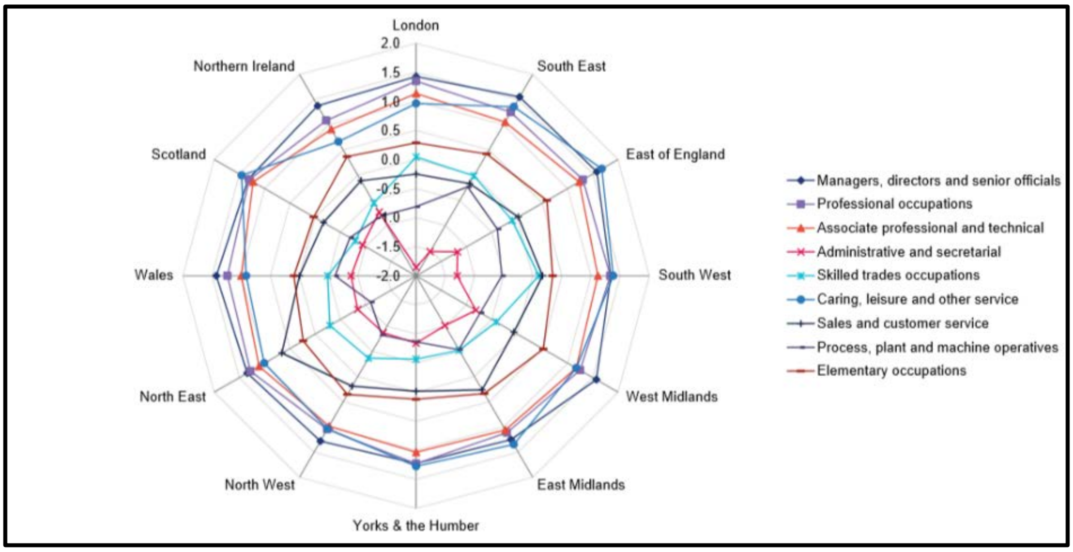


Figure 5.13: Projected percentage change (2014-2024) in employment type, by region [77]



5.32 However, i two other factors need to be considered in terms of the emerging skills profile and demand for labour:

- **Impact of loss of local Headquarter and R&Di function:** As noted in the review of industrial structure, there has been a reduction over the last decade of higher managerial and scientific positions across the Northern Powerhouse as overseas buyouts have seen much of this activity moved out with the region and consequently a reduction both in demand and supply of these skillsets. The loss of such higher functions acts as constraint to attracting and retaining all levels of staff as it is perceived that there is limited job churn and clear progression paths;
- **Impact of new technology:** The chemicals sector is relatively mature and for the last quarter of a century has not seen significant disruptions in the technology used and consequently the skillsets required. However, the Science Industry Partnership Skills Strategy 2025 states that the skills needs of the future will be driven by the adoption of new scientifically focused key enabling technologies (KETs) and the evolving industrial context. At the same time, attention must be paid to the continuing need for core science skills which lay the foundations for new technology driven skills. The following section identifies a number of key emerging skills needs related to the aforementioned KETs:
  - **Industrial Digitisation and Big Data Skills:** There is high demand for ‘big data’ staff across all areas of the economy. There is a particular difficulty in finding people with the right mix of skills – those who combine scientific or healthcare knowledge with computational, statistical data mining and analytical competence. Informatics, computational science and statistics are some of the most commonly relayed skills gaps picked up in recent science industries skills research. There is a need to upskill a large proportion of the existing scientific workforce, who received little or no informatics training during their education. The use of machine learning and artificial intelligence (AI) to conduct analysis, make predictions on data and learn, is expected to grow significantly in the future. In addition to core maths and stats skills, developing and working with AI systems requires programming and coding ability and as such these skills are expected to become increasingly valued;
  - **Materials Science Skills:** Material science has been identified as a growing area of skills shortage, where companies ae struggling to find large enough pools to recruit

from with sufficient depth of knowledge to fill available roles. In future it is expected that an understanding of the properties of advanced materials will be required more widely across the workforce as UK manufacturers face growing competition from China, the USA and emerging economies. For instance production managers and directors in manufacturing will need to keep abreast of the latest developments, enabling them to appraise these technologies for their potential usefulness to the manufacturing process;

- **Formulation Skills:** There is a significant lack of relevant vocational and higher education in formulation, as it does not fit into traditional discipline areas due to its multidisciplinary nature. There are problems in recruitment of people with relevant experience, therefore companies are mostly reliant on recruiting individuals from aligned disciplines and providing in-house training to develop formulation skills; and
- **Cross-cutting skills:** The spread of new technologies is dependent on people. These people need to have the cross-cutting skills which enable communication and innovation. As industries fragment there is a greater need for collaborative working. This involves sharing knowledge and resources across organisational and international boundaries. Knowledge transfer between experienced workers and new entrants will also be essential as significant proportions of the workforce approach retirement. The adoption of new technologies, formulations and materials have resulted in more complex processes and products. This requires more quality control staff, greater regulatory and intellectual property awareness and better problem solving skills. This complexity also puts an increased focus on supply chain management and regulatory assurance. Managing the manufacturing process beyond the boundaries of individual organisations will drive the need for production staff with stronger business skills. Leadership, team working and commercial awareness will become ever more important.

Conclusion

5.33 The sector seems to be impacted by three counterbalancing trends, an ageing workforce disproportionately affecting the supply of higher technical and managerial skilled individuals. This is coupled with the threat posed by Brexit on the potential ability to attract international talent coupled at the same time to the reduction of HQ and R&Di functions affecting the demand for such functions. However, such a situation will not lead to economic equilibrium, rather unless it is addressed, the sector could face a vicious cycle of perceived declining opportunities. Rather the reshoring of value adding activities at the same time as the impact of the two disruptive technologies will cause an increased demand for more technical staff across the region, particularly those who can operate in multi-disciplinary environments.

6 Theme 1: Industrial Structure

Key Messages

- The chemical sector across the UK and particularly in the Northern Powerhouse, is mature, both in the technology being used and also the age of companies within the sector. There are few if any new business start-ups, largely down to the maturity of the technology.
- However unlike other sectors of a similar level of maturity, chemicals and process companies are becoming more fragmented, rather than consolidating. Much of this fragmentation is the result of overseas buy out of key aspects of the supply chain, which has denuded much of the sector of higher value adding functions such as Headquarters and research and development. It has also broken existing supply chains and collaborative research because of an absence of local autonomy in terms of purchasing and decision making;
- Potential actions to address this increasing trend towards fragmentation of structure and scale of ownership include the reshoring of higher managerial functions, as well as strengthening links with the local innovation ecosystem;
- The use of digitisation / big data solutions may also facilitate more flexible supply chain interventions and address fragmentation; and
- There is a need for targeted support at indigenously owned middle sized companies, in particular, supply chain diversification.

6.1 This section draws upon research from the Enterprise Research Centre (ERC) **[78]** which postulates that there is a correlation between scale of enterprise, export orientation and absorptive capacity in innovation:

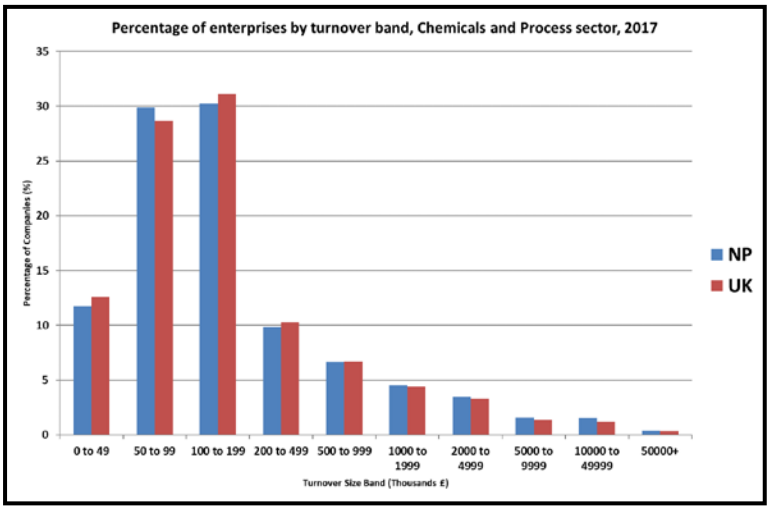
''*In larger firms, R&D may be formally organised in an R&D department or unit. In the majority of smaller firms, reflecting the nature of innovation activity itself, R&D activity where it takes place is more often informal… R&D in SMEs is also less likely to be a specialist function than in larger firms, with development work often being undertaken by skilled employees or senior management. One implication – strongly supported by the empirical evidence – is that innovation in smaller firms is less dependent on internal R&D than that in larger firms and more dependent on external knowledge obtained either through partnerships or spillovers.''* **[78].**

6.2 The SIA also investigates the importance of not only scale, but structure of ownership and sectoral maturity as determinants of absorptive capacity. As seen in previous chapters, the structure and scale of ownership is becoming increasingly fragmented, with fewer higher value adding functions across the sector leading to an impact on Gross Value Added (GVA).

Scale of businesses

6.3 A detailed analysis of the UK Chemical and Process sector has been undertaken to assess the ERC assertion. Figure 6.1 analyses ONS Annual Business Survey 2015 data (published in 2017) **[79]** across the chemicals and process sector for the Northern Powerhouse and the UK generally. The Northern Powerhouse shows close alignment to the UK profile. For this reason, we felt that a pan-UK analysis would provide best insight to structural issues.

Figure 6.1: Turnover in Chemicals and Process Sector, Northern Powerhouse / UK comparison (2015 data, published in 2017 by ONS) [79]



6.4 The following points are noted:

- 95% of firms within the sector are SMEs., with the UK and Northern Powerhouse sectors largely mirroring one another;
- Top four large firms account for 16.5% of total sector employment, as well as 38% of turnover;
- Top seven large firms account for 23% of total sector employment, as well as 41% of turnover;
- The proportion of SMEs is at variance to the wider economy in which there are circa 88% micro and 98% small enterprises **[79]** compared to circa 12% micro and 30% small enterprises for the chemicals sector;
- There is also greater variance in the composition of the sector by scale than between sectors, with the pharmaceutical sector have the greatest preponderance of micro enterprises, which reflects the higher number and proportion of new starts within this subsector; and
- Overall the chemicals sector has a higher proportion of middle sized firms than the economy as a whole.

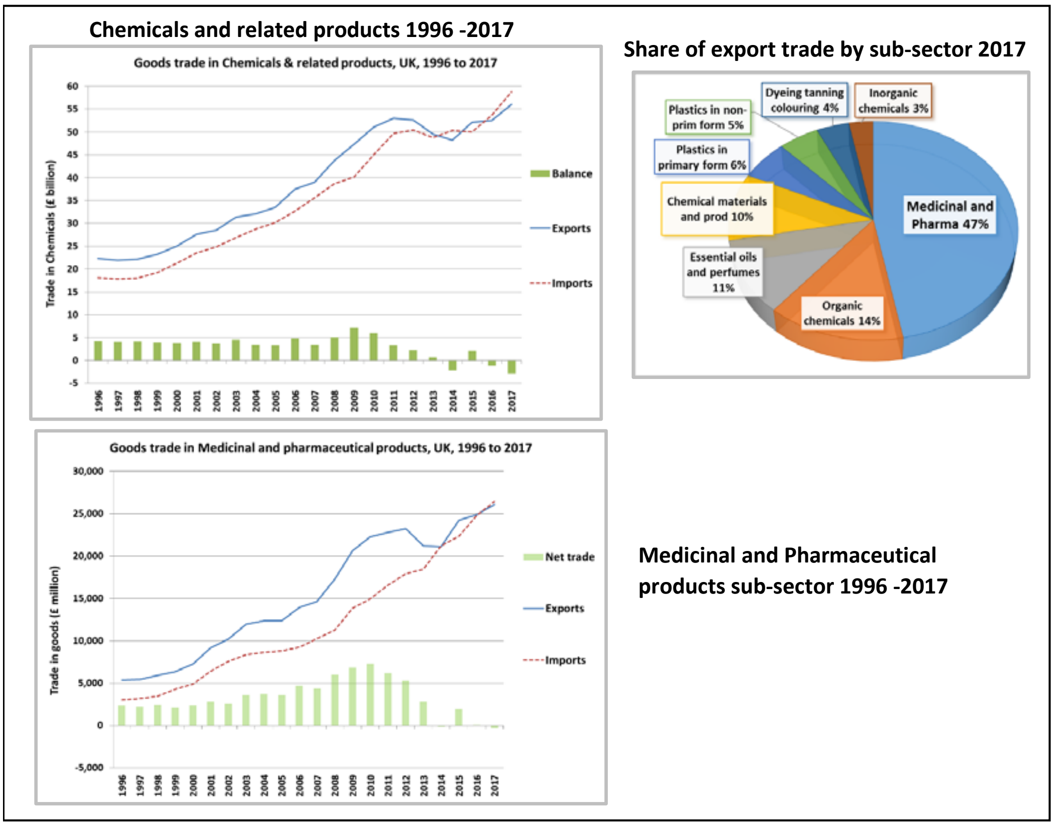
Export Orientation

6.5 This sub section assesses the export orientation of the chemicals sector, in particular the emerging gap between exports and imports within the Northern Powerhouse and how this is reflected in key sub-sectors including pharma, organics and inorganics before identifying potential mitigating factors.

6.6 Appendix 14 provides detailed charts that analyse the trade performance across the chemical and process sub-sectors for both the UK as a whole and within the Northern Powerhouse.

6.7 Figure 6.2 compares overall goods trade with the trade in medical and pharmaceutical sub-sector between 1996 and 2017.

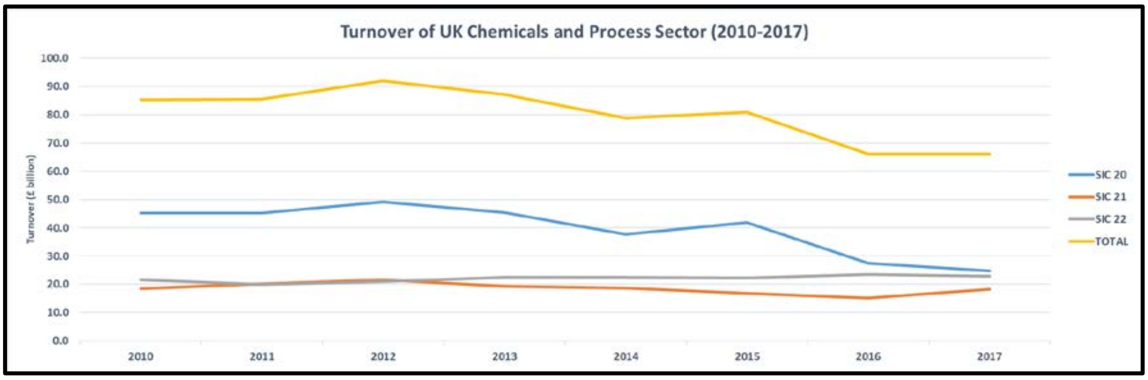
Figure 6.2: UK Goods Trade [56]



6.8 The pharma sector represents almost 50% of chemical goods trade and it can be seen that the performance reflects that of the sector overall. The exact reasons for the reduction in trade balance from 2012/13 are still to be fully understood though discussions with the BEIS chemical sector team have indicated that a contributory factor might be a number of key Astra Zeneca products going off- patent during this period. AstraZeneca's 2013 Annual Report **[80, p. 147]** gives the following figures for export sales from the UK: 2011 $11,056m, 2012 $8,072m, 2013 $6,192m (all in US$ as AZ reports in this currency). These reflect the loss of patent exclusivity for several of AZ's major products which are then subject to generic competition and price pressure (Appendix 14b analyses data for the Northern Powerhouse region with similar trends observed).

6.9 This export performance is in the context of a decline in overall turnover within the sector as outlined in Appendix 14d) and Figure 6.3 below.

Figure 6.3: Sector Turnover 2010-2017



6.10 Key issues:

- Export performance is in the context of a decline in overall turnover within the sector;

- Trade, both in terms of imports and exports of chemicals has more than doubled in the last twenty years, which is in line with the overall economy, however the significance of the chemicals sector to Britain's overall trade figures continues to increase, but at a declining rate, in particular:
  - Chemicals exports have risen from circa £23bn in 1996 to £56bn in 2016 with a more significant rise in imports from a baseline of circa £18bn in 1996 to £58bn in 2016 (Overall exports have risen from £167bn in 1996 to £306bn with imports rising from £180bn to £462bn in 2016); and
  - In proportionate terms, the importance of the chemical sector has increased from 14% to 18% for overall exports and 10% to 12% in terms of imports.
- 2014 was the first time there was a net imbalance in trade for the chemicals sector, which can largely be attributed to the Astra Zeneca effect;
- In terms of quantum, medicinal and pharmaceutical products are the most significant in overall terms of trade and are moving into a negative trade imbalance. This is also the case with essential oils and perfume materials, plastics in non –primary forms, inorganic chemicals and trade in fertilisers;
- The UK and Northern Powerhouse continues to have positive trade balances in organic chemicals, chemical materials and products and dyeing, tanning and colouring; and
- The reduction in exports has been mainly in price sensitive sub-sectors such as organic and inorganic chemicals.

6.11 However, the increase in imports for the Northern Powerhouse is at a faster rate than growth in the sector as a whole, indicating that imports are substituting domestic production and in increasingly higher value-added elements such as medical & pharmaceutical products, i.e. 19 times the value in 2016 compared to 1996. This sub-sector accounted for £3.5bn (42%) of the total increase of the whole Chemicals sector.

6.12 The reduction in exports has been across the board including price sensitive sub sectors like manufacture of organic chemicals and fertilisers and nitrogen, but also in high value products such as pharmaceuticals.

6.13 In short, the Northern Powerhouse is losing its competitiveness, access to supply chains and export orientation across the full range of products, at the same time as a proportionate decline in export activity across most chemical sub-sectors. This decline in export orientation may have a causal effect on the level of innovation activity undertaken.

Methods of mitigating loss of market

6.14 As noted above there is a need to curb the loss of market share and this is largely related to import substitution and reshoring of key supply chain opportunities.

6.15 In considering import substitution and reshoring of activities, consideration should be given to areas where the UK can compete on the basis of scale and cost aligned with an understanding of how the innovation base might re-shore critical high value activities.

6.16 An example of this is the area of manufacture of bulk epoxy resins, where significant capital investment has been made in recent years in China and Korea. Significant investment is required to catch up with International competitors who also have advantages in terms of resource and labour cost. Focus should be upon the use of the innovation base to support the development and manufacture of the high value additives that are critical in delivering the material performance.

6.17 The development of and investment in the Circular Economy and resource efficiency represents a significant opportunity for the chemical and process sector to reshore activity and build new product bases. The use, re-use and remanufacture of raw materials and products aligned with further resource efficiency has the potential to address many of the present sector asks. This opportunity is explored in detail in Chapter 8.

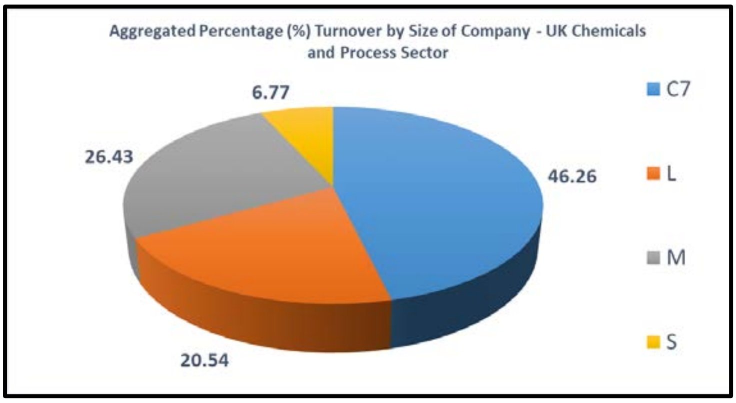
Importance of Mid-Sized Businesses

6.18 The following section focuses on mid-sized businesses, highlighting their relative importance to the sector and their particular characteristics. Using the Bureau van Dijk ORBIS database **[67],** 3,472 firms were identified as being in the process and chemicals sector. Appendix 13 provides a detailed analysis of the business characteristics of the sector with key conclusions sumarised below

6.19 Figure 6.4 illustrates the sector breakdown by company size. The Mid-sized Businesses Growth Review **[81]** uses a definition based on annual turnover of £25m-£500m.

Figure 6.4: Aggregated percentage turnover by company size [67]

(2016 & 2017 Companies House, exported from the ORBIS database)



6.20 Whilst the large firms account for over two-thirds of turnover, there are 652 mid-sized firms that between them account for 26.4% of turnover for the sector **[67]**. These mid-sized businesses have the following characteristics:

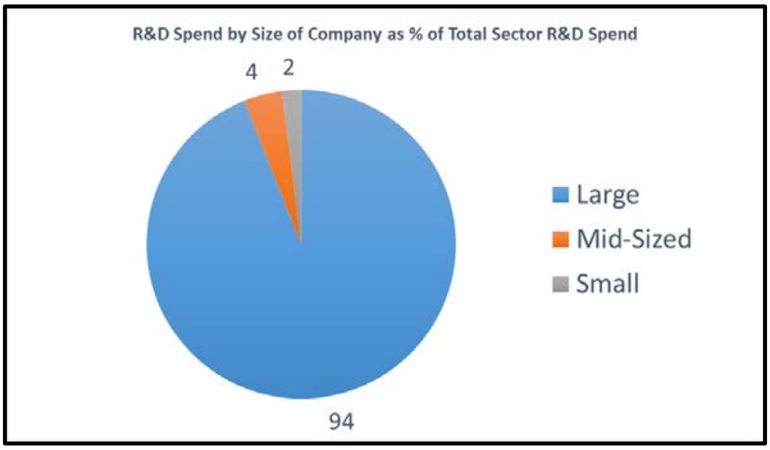
- Predominantly producers of intermediary goods, supplying a few (but large) internationally owned exporters. There is also a higher (but diminishing) proportion of family owned firms in the sector;
- Highly price-sensitive, due to their role in the supply chain;
- Limited supply chain diversification, with only a few companies involved in exporting;
- Export inactivity directly linked to low levels of innovation; and
- Emerging trend is tier 1 companies acquiring these local intermediaries, with consequent reduction in local added value (impact on export activity), as R&Di and higher managerial functions are relocated back to the acquisition company's HQ.

6.21 Figure 6.5 shows that the vast majority of R&D is performed by large firms. Although mid-sized businesses account for 26.42% of turnover (figure 6.5), they only perform around 4% of R&D expenditure. This shows there is an imbalance within the sector, skewed towards the larger firms in terms of innovation. Using our measure of absorptive capacity, R&D can be used as an indicator of innovation and so our results show that these mid size companies are of vital importance to the sector, but that this is not reflected in R&D performance.

6.22 Reflecting upon the ERC analysis, the chemicals sector should be exhibiting the following characteristics in relation to innovation:

- Strong formal R&D functions within large companies; and
- Enhanced use of open innovation solutions by SMEs and in particular medium sized enterprises to address emerging constraints related to exporting/supply chain diversification.

Figure 6.5: R&D spend by size of firm [67]



6.23 As noted in the analysis of R&D activity, the sector within the Northern Powerhouse is not exhibiting these characteristics which can partially be attributed to the market concentration of the chemical supply chain. The following subsections focus on maturity and ownership structure of the sector to provide a rationale for this perceived underperformance.

Market Concentration

6.24 The following section looks at market concentration (whether the firm is a price taker or a price maker) as an indicator for innovation activity. Using the Herfindahl-Hirschman index (HHI) the entire sector was analysed by comparison to other key sectors. Secondly, the top four (C4) and top seven (C7) largest firms within the chemicals and process sector as a whole were identified, in order to show concentration of ownership as a proxy for assessing market control. See Table 6.1.

Table 6.1: The top 4 (C4) and top 7 (C7) Chemical and Process sector business data [67]
(2016 & 2017 Companies House, exported from the ORBIS database)

Sector	Top 4 (C4)			Top 7 (C7)		
	Age / Maturity	Turnover %	Employment %	Age / Maturity	Turnover %	Employment %
Chemicals and Process Sector	59.25	33.79	27.67	48.57	46.26	40.93
	GlaxoSmithKline, AstraZeneca, Reckitt Benckiser (RB), Johnson Matthey (JM).			C4 plus Shire, United Company Rusal and Bunzl.		
SIC 20 - Manufacture of chemicals and chemical products	53.25	41.35	40.88	57.9	47.28	44.6
	C4= Reckitt Benckiser, Johnson Matthey, United Company Rusal and Ineos.			C4 plus Unilever, Venator and Synthomer.		
SIC 21: Manufacture of basic pharmaceutical products and pharmaceutical preparations	41	72.74	69.94	53	76.63	74.21
	GlaxoSmithKline, AstraZeneca, Shire and AAH Pharmaceuticals.			C4 plus Hikma, Roche and Eli Lilly.		
SIC 22 - Manufacture of rubber and plastic products	68.25	18.08	16.09	53	23.05	20.45
	RPC, ITW, Michelin and Philips.			C4 plus Polypipe, Linpac and British Polythene Limited.		

6.25 Figure 6.6 provides a comparison with other key sectors of the UK economy. Whilst the aerospace and automotive manufacturing sectors are more concentrated, clearly the chemicals and process sector is still very highly concentrated when compared to other industries. Figure 6.7 provides the resulting HHI indices (a measure of market concentration, see Appendix 13 for definition)

Figure 6.6: Market concentration of C4 and C7 companies compared with other sectors [67]
(2016 & 2017 Companies House, exported from the ORBIS database)

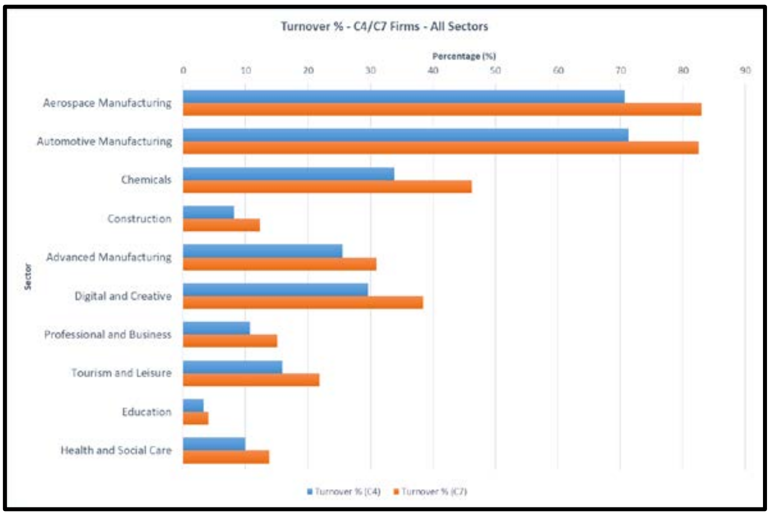
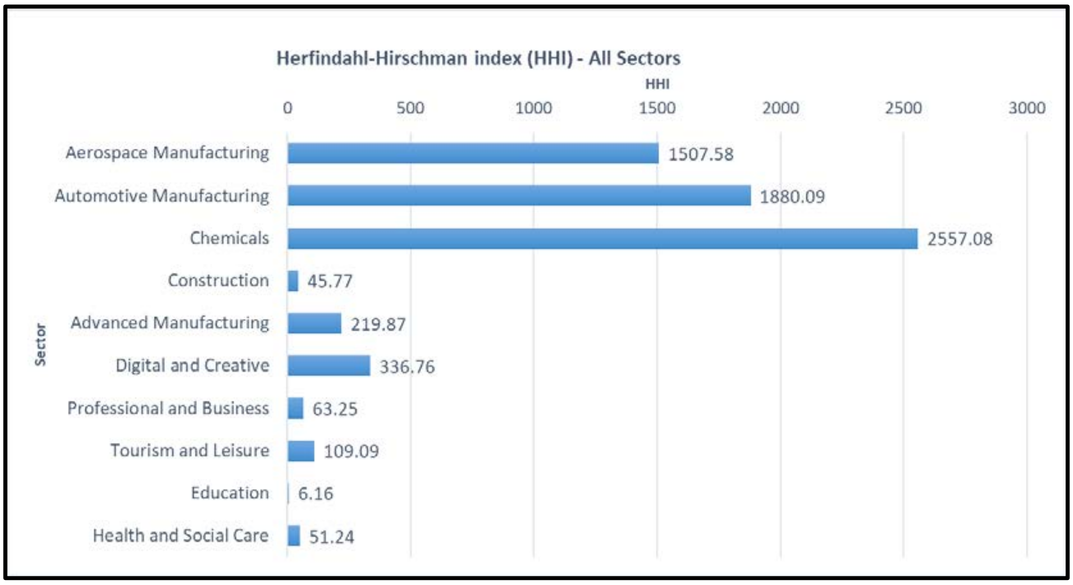


Figure 6.7: HHI for the chemicals and process sector in comparison to other sectors [67]
(2016 & 2017 Companies House, exported from the ORBIS database)



6.26 The HHI of 2557.08 indicates that the UK chemicals and process sector is highly concentrated. The sector is dominated by a relatively small number of companies, who have significant control of supply chains and are consequently price makers rather than price takers. This enables these firms to benefit from economies of scale but has the wider implication of making it more difficult for smaller firms to compete and may stifle the innovation of the sector generally, particularly if R&D is not used as a driver of competition across the entire firm/sector.

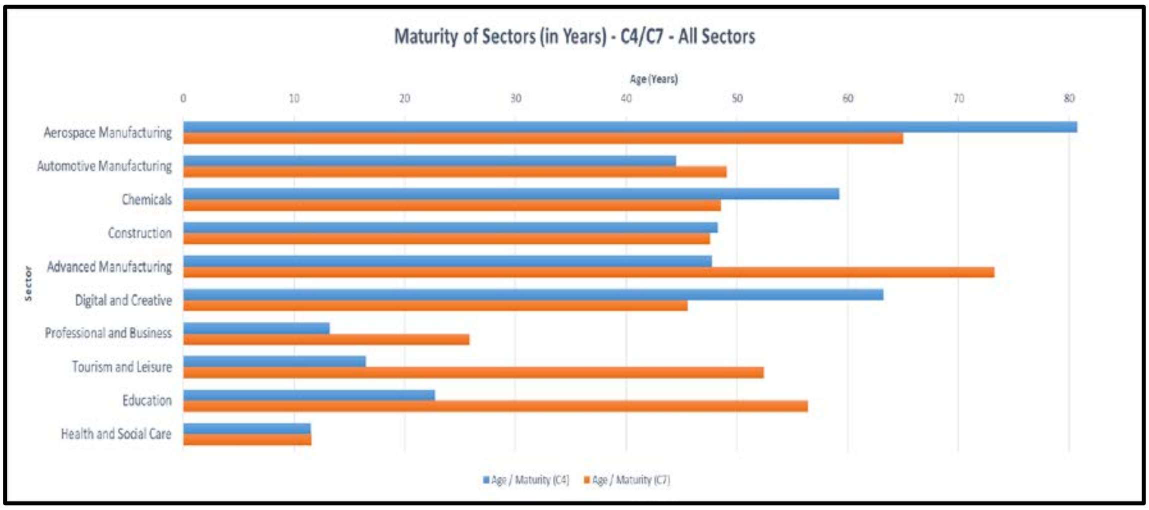
Sectoral Maturity

6.27 Absorptive incapacity theory identifies a correlation between sectoral maturity and low levels of innovation, due to technology being largely proven and most trading relationships being based on price, rather than other competitive issues.

6.28 The following table utilises information from the Orbis database to assess the relative maturity of the chemical and process sector to other leading UK sectors:

6.29 The maturity of the chemical and process sector and sub-sectors are shown in figure 6.8, alongside a comparison with other key UK sectors. We can see that the average age of firms across the chemicals and process sector as well as the sub-sectors shows little variation. However, we can only gain insight as to what this level of maturity means when compared to other key sectors of the UK economy.

Figure 6.8: Maturity of C4 and C7 companies compared with other key sectors [67]



6.30 Key messages from this analysis are:

- Mature sector (average age across the sector of 31 years) and few new entrants; and
- The maturity of the sector, linked to the lack of disruptive technology being used implies lower levels of investment in innovation and consequently reduced absorptive capacity when compared to sectors in an early stage of growth.

Conclusions

6.31 The structure and scale of ownership is becoming increasingly fragmented with fewer higher value adding functions across the sector leading to an impact on Gross Value Add (GVA). In addition, the sector is mature, with few new market entrants and is losing its export orientation.

6.32 There is a need to curb this loss of market share/reduced export orientation and this may in part be largely mitigated through import substitution and reshoring of key supply chain opportunities.

6.33 In considering import substitution and reshoring of activities, consideration should be given to areas where the UK can compete on the basis of scale and cost aligned with an understanding of how the innovation base might reshore critical high value activities.

6.34 The development of and investment in the Circular Economy and resource efficiency represents a significant opportunity for the chemical and process sector to reshore activity and build new product bases. The use, re-use and remanufacture of raw materials and products aligned with further resource efficiency has the potential to address many of the present sector asks. In addition, industrial digitisation and particularly mass machine learning has the potential to mitigate sectoral fragmentation and address the coordination market failure which usually impedes the roll out of circular economy solutions at the industrial level. These opportunities are explored in detail in Chapter 8.

6.35 As noted earlier, the principal variable affecting competitiveness, export orientation and the absorptive capacity of innovation is scale of enterprise and in particular the division between large and mid-sized companies. The following identifies key challenges affecting large and mid-sized companies:

- For large, internationally-owned businesses:
    - Tightening local sourced supply chains (circular economy solution);
    - Need to encourage more Northern Powerhouse sourced knowledge transfer, by enhancing the visibility of the local innovation ecosystem; and
    - Need to re-shore higher value add functions to the Northern Powerhouse.
- For mid-sized businesses:
    - Increased supply chain diversification;
    - Use supply chain/export diversification as a catalyst for innovation;
    - Address the absorptive incapacity of mid-sized businesses with enhanced knowledge transfer from Northern Powerhouse innovation ecosystem;
    - Enhanced use of pilots/testbeds in disruptor technologies to encourage innovation (circular economy and digitisation), with a particular focus in the three principal clusters; and
    - More sector specific innovation support.

7 Theme 2: Importance of Place and Physical Co-location is Increasing

Key Messages
• The Audit has identified an increasing trend towards more mobile investment patterns and the growing importance of co-location in a few, but large globally competitive locations; • The Audit has also identified the relative importance of the following factors in terms of place promotion and the attraction of mobile investment, including: Cost of feedstocks, energy costs, Supply chains/access to markets, skilled labour force, financial and innovation ecosystems and the application of emerging technologies; • The principal determinant of regional attractiveness is access/cost of feedstocks, with the US model illustrating the step change that cheaper feedstock can bring to productivity and international competitiveness; and • Opportunities to attract more profit centres to the region, through cheaper feedstocks and access to the regional innovation ecosystem.

7.1 The previous sections were focused on two aspects of industrial structure:

- The export orientation of the Northern Powerhouse and how this could be regained through investment in innovation, enhanced reshoring and use of the circular economy;
- The impact of industrial fragmentation and opportunities to address this, arising from industrial digitisation and its role as a catalyst for tighter supply chains and the use of data to increase productivity.

7.2 In this section, the focus is on the growing importance of place as a determinant of global competitiveness. Unlike other sectors, it is our contention that even though ownership is becoming increasingly fragmented, technological advancement such as industrial digitisation and the circular economy may facilitate more integration. In addition, industry is becoming increasingly clustered in fewer but more globally competitive locations.

7.3 The audit involved extensive primary research, including company interviews (83 companies were contacted, circa 20% completed the interviews) and international benchmarking which was used to determine the comparative competitiveness of the Northern Powerhouse against the following competitor regions:

- Rheinhessen-Pfalz;
- Antwerp- Rotterdam;
- Geleen;
- Gulf Coast (USA);
- Singapore; and
- Busan (formerly Pusan) South Korea.

(The full International Benchmarking Report undertaken by Technopolis in support of this audit can be found in Appendix 16).

7.4 Using stakeholder feedback and the results of the international benchmarking exercise, comparisons were made between the Northern Powerhouse and the six competitor regions in terms of:

- Comparative scale; and
- Place competitiveness variables.

Table 7.1 provides an assessment of the comparative scales of activity of the international comparators with the Northern Powerhouse.

7.5 The following points are noted:

- The Northern Powerhouse is larger and has the necessary critical mass to compete against key European regions, including the wider ARRRA region which includes Antwerp, Rotterdam and Rheinhessen-Pfalz. However, as will be noted in the table below, there is a question of the degree of supply chain integration across the region when assessed against other comparators;
- The average size of enterprise across the Northern Powerhouse is smaller than the other comparator regions (with the exception of Geleen which is skewed by the higher prevalence of business start- ups); and
- Average wages are lower, however GVA per employee is close to the highest comparator, and this largely reflects the higher incidence in the Northern Powerhouse of the pharmaceutical sector. The European regions tend to reflect the industrial structure within Tees Valley and Humberside.

Table 7.1: International comparators scale of activity

Variable	Rheinhessen -Pfalz	Antwerp-Rotterdam	Geleen	Singapore	Northern Powerhouse
Number of Companies	2,315	459	479	744	3,975
Av. sectoral GVA per employee (€'s p.a.)	87,000 (Germany)	166,000 (Belgium)	137,000 (Holland)	n/a	158,000 (UK)
Average wage (€'s p.a.)	54,700	66,100	55,600	44,200	43,500
Average size of enterprise (Number of employees)	49	70	29	53	31

Source: Technopolis Benchmarking Report 2018, Eurostat, Sector definition includes SIC codes 20, 21, 22 and 23.

7.6 Using the presence of headquarter functions and tier one companies as a proxy for international competitiveness and high absorptive capacity, Table 7.2 identifies the level of coverage in each of the benchmarked regions:

Table 7.2: Headquarter Functions of tier 1 companies

Company	HQ	Other (production) sites in benchmarked regions
BASF	Rheinhessen-Pfalz	Gulf Coast, US, Bradford, UK, Flanders, BE, Zuid-Holland, NL, Limburg, NL, Singapore and South Korea
Dow Chemical Company	N/A	Gulf Coast, US, Flanders, BE, Zuid- Holland, NL, **Multiple Locations in the UK**, Singapore, South Korea
Sinopec	N/A	N/A
SABIC	N/A	Gulf Coast, US, Singapore, South Korea, **Tees Valley, UK**, Limburg
ExxonMobil	Gulf Coast	Singapore, South Korea, Fawley, UK, Zuid- Holland, NL, Flanders, BE
Formosa Plastics	N/A	Texas, US

Company	HQ	Other (production) sites in benchmarked regions
LyondellBasell	Gulf Coast, US	Rheinhessen-Pfalz, DE, Zuid-Holland, NL, **Multiple Locations in the UK,** Singapore, South Korea
DuPont	N/A	Flanders, BE, Zuid-Holland, NL, **Multiple Locations in the UK**, Gulf Coast, US, South Korea and Singapore
Ineos	N/A	**Multiple locations in the UK**, Flanders, BE, Limburg, NL, Singapore, South Korea, Texas, Alabama, Louisiana, US and Rheinhessen-Pfalz, DE
Bayer	N/A	Flanders, BE, South Korea, Reading, UK

7.7 Although neither the Northern Powerhouse, nor the wider UK economy has a world headquarters of any of the largest 10 global companies, the region does contain production facilities for five of them. This brings with it two potential opportunities:

- The attraction of enhanced profit centre functions from global companies; and
- Greater engagement between the global companies and the local innovation ecosystem.

7.8 Key conclusions from the company Northern Powerhouse stakeholders' interviews are summarised in Table 7.3.

Table 7.3: Analysis of SIA Area business stakeholder Interviews

Area	Analysis of responses
Company profile	50% SMEs; 44% multinationals; 81% conduct research and development in the region 69% are headquartered in the region.
R&D Focus	88% of innovation activity was related to process and or product development, with only 12% of respondents noting investment in R&D. This reflects the production orientation of the Northern Powerhouse 50% of respondents are reviewing the application of digitisation as opposed to 13% who are seeking to innovate around the circular economy. Respondents, primarily within the pharma sector, noted that the implementation of circular economy solutions was constrained by regulatory issues related to traceability within the supply chain, a situation which in part can be addressed through possible blockchain solutions.
Skills and Experience	The biotech and pharmaceutical companies experienced the most problems in obtaining and retaining skilled staff at all levels and invested significant resource in training, however the financial lure of the golden triangle in London, Cambridge and Oxford was exacerbating local skills shortages.
Energy and Feedstock Costs	This was seen as the most important consideration, particularly for those companies who had no other option other than to purchase energy from the national grid. Use of alternative energy sources, such as shale gas was mooted.

7.9 Table 7.4 focuses more on emerging perceptions as to how the Northern Powerhouse compares against the following variables of place competitiveness and will be more important for future inward investment decisions:

Table 7.4: Relative priorities across comparator regions

	Rheinhessen-Pfalz	Antwerp-Rotterdam	Geleen	Gulf Coast	Singapore	Busan	Relative Prioritisation
Access/Cost of Feedstocks	↑	↑	↑	↑	↓	↑	**1st**
Access to transport/ location of main markets	↑	↑	↑	↑	↑	=	**2nd**
Application of emergent technologies	=	=	=	↑	↑	=	**3rd**
Skilled labour force	=	=	=	↑	↓	↑	**4th**
Innovation Ecosystem	=	=	=	↑	↑	↓	**5th**
KEY	Comparative strength to NPH	↑	Comparative weakness to NPH	↓	Comparable NPH	=	

7.10 The table also uses the findings of the UK stakeholder engagement process to prioritise the relative importance of each of the variables to potential inward investors. The following points must be noted in terms of prioritisation:

- **Feedstocks:** In terms of overall competitiveness, the Gulf Coast ranks first and the region's chemical sector is anticipated to double in size over the next 15 years. This competitive position has been enhanced by the availability of cheap feedstocks and a very favourable investment climate, particularly in relation to support for infrastructure and reshoring of economic activity;
- **Innovation ecosystem:** All focus regions showed significant movement towards greater investment and strategic inclusion of the chemicals manufacturing industry. Summary points on the innovation ecosystem across the focus regions are as follows:
  - All three European regions were rated as 'innovation leaders' in the European Innovation Scoreboard. Innovation clusters were identified in Antwerp and Geleen as being key to the development of new start-ups and driving innovation;
  - Analysis showed that Government supported incentives for SMEs and start-ups were a particular priority for Antwerp, Geleen, Gulf Coast (Texas) and South Korea;
  - Singapore and South Korea have invested significant amounts into R&D, benefitting the chemical industry. Singapore's business expenditure on R&D in the chemicals and materials sector more than quadrupled from 2002-2012 due to significant investment from foreign companies.

  Singapore is the clear leader in terms of the application of innovation and the use of emergent technologies. Even though the region has few natural resources, is constrained by a lack of space and has tight labour market conditions, investment in innovation is going some way to mitigating these issues, particularly in its adoption of industrial digitisation, emerging skills agenda and the wider low carbon solutions;

- **Skills:** A common challenge facing most of the regions studied is the provision of a sufficient pipeline of skills and talent to support the sector and to drive innovation. Several factors have contributed to skills shortages:
    - An ageing workforce;
    - Too few young people choosing to study STEM subjects and enter related careers;
    - Outdated and negative perceptions of the chemical industry and of the regions where it is mainly located; and
    - Technological and other changes resulting in new skills demand, an example being the increasing digitisation of the chemical and process sector.
- **Application of new technologies:** The European regions explicitly include 'circular economy' solutions in their regional and national strategies, many of which have been in place for a number of years. The other three regions were less developed in this respect. Florida, in the Gulf Coast, has only recently passed legislation to allow pyrolysis (plastics to fuel). As for digitisation, IBM and Maersk are currently piloting new blockchain technology in the Port of Houston to digitize the supply chain process from end to end and South Korea has a smart factories initiative which aims to expand into the chemical sector;
- **Cluster Development (Translational Research)**: Traditionally the UK has placed more weight on universities as a driver for innovation compared to other economies, where a stronger role was played by 'intermediate institutes' (e.g. Fraunhofer in Germany, TNO in the Netherlands, VITO in Flanders and A* STAR in Singapore). A further qualitative advantage for the Geleen and Antwerp-Rotterdam clusters is the Dutch tendency towards collaboration and compacts, influencing the country's approach to innovation, cooperation between business and government. European performance is roughly comparable to that in the Northern Powerhouse, however the most significant competitive advantage arises in terms of access to transport and highly integrated supply chains, which between them bring the efficiency gains related to the creation of critical mass and associated economies of agglomeration.

7.11 However, the most important issue to arise from the consultation exercise was confirmation of the longer-term trend of more flexible investment patterns and the consolidation of the sector into fewer but more globally competitive clusters in which the aforementioned variables of place competitiveness are increasingly important.

7.12 Table 7.5 provides detailed descriptions as to potential interventions aimed at enhancing place competitiveness.

Table 7.5: Potential place- based interventions aimed at enhancing competitiveness

Opportunity /Constraint	Description	Applicability
Access/Cost of Feedstocks	**New Feedstocks** The availability of inexpensive natural gas in the Gulf Coast has been the key to its success as the gas is used as a feedstock in the production of various chemical commodities. This is turn has brought significant investment to the region in what is called the 'shale gas boom. Dow has committed to expanding its operations in the Gulf spending $6bn on facilities including a new 'cracker' to produce ethylene. In its 2015 'Fuelling Export Growth' report, Nexant found that US chemistry exports linked to shale gas could double from $60 billion in 2014 to £123billion by 2030. The trade balance in plastic resins, in particular, is expected to accelerate.	The local sourcing of affordable resources, will not only permit import substitution, but will also be a prime motivator for the reshoring of further production methods. The price of feedstocks was judged to be the most important factor in support of inward investment.
	Tax Environment The simplification of the American Tax system, through the Tax Cuts and Jobs Act 2018 has led to significant increase in reshoring of chemical manufacturing activity. A potential consequence of the proposed tax reform, specifically lowering business taxes, is that the U.S. would be a more attractive place for foreign capital (investment money). In addition, the Gulf Coast has a long tradition of utilizing sector specific (chemical) approaches to free trade zones, such as: • No customs duty on goods imported into the free trade zone and then re-exported; • Inverted tariffs are permitted meaning that goods produced in the zone benefitted from lower import taxes; and	There is the opportunity to utilise the reform of the tax system post Brexit to develop a sectoral Free Trade Zone (possibly using blockchain solutions)

Opportunity /Constraint	Description	Applicability
	• Additional infrastructure and utility support.	
	Use of Circular Economy Solutions BASF has developed a biomass balance approach which aims to contribute to the use of renewable raw materials in the integrated production system. The basic idea involves using renewable resources such as biogas or bio-naptha together with fossil resources already at the beginning of production. The renewable raw materials are then allocated to the respective sales products using a novel certification method. The certified products this contribute to sustainable development by saving fossil resources	There are a number of benefits stemming from this approach: • It is a driver for the use of renewable resources, thereby reducing the need to import raw materials; • It provides opportunities for reshoring further activities; • It provides an opportunity for further embedding best practice
Access to transport/ Location of main markets	Cluster Development The Catalisti cluster was set up to capitalise on access to transport, encourage more co-location at transport hubs, create supply chain solutions and address any constraints through the development of cross sectoral partnerships between small and large companies, research institutions and government organisations. The mode of operation of Catalisti is based on a triple helix partnership between the Flemish industrial sectors, the Flemish Government and the Flemish research institutions.	Recent experience shows that this open model of collaboration and single point of entry for research provision can yield significant results and create a leverage effect for investments. It also develops the necessary critical mass to attract inward investment.
Application of emergent technologies	Digitisation of chemicals manufacturing is the cornerstone of the Industry Transformation Map for the energy and chemical sector in Singapore. It is anticipated that it will support productivity through automated measurement using advanced manufacturing sensor technology, sophisticated data analytics and visualisation will enable improved	This will facilitate greater integration of processes and consequent reduction in energy consumption and waste by 10-20%.

Opportunity /Constraint	Description	Applicability
	manufacturing efficiency while connectivity across the supply chain will streamline the sector as a whole. There will also be implications for the safety of people, assets and cybersecurity.	
Skilled Labour Force	The Economic Development Board for Singapore have appointed consultants, Accenture in mapping digital skills needed, including data and trend analysis, automation management, cybersecurity, big data management, modelling and simulation and user interface design.	This will ensure the successful utilisation of industrial digitisation.
Innovation Ecosystem	Translational Research Formed by three partners, The Province of Limburg, Maastricht University and DSM, Chemelot is located in the southern part of the Netherlands and brings together materials and chemicals companies into a single, open innovation community of several thousand knowledge workers. The campus provides a creative ground for innovation and for new companies. Every year, the campus provides a creative ground for innovation and for new company formation (circa 100 start-ups per year). Integrating education into applied sciences and cooperating with companies is another focus of the activities of Chemelot. More than 1,000 students are involved in projects implemented on the campus every year. In addition, Maastricht University has moved its entrepreneurship development activities to the campus in 2017, aimed at further expanding business start-up and growth	• Enhanced rates of business start-up; and • Enhanced translational research, through the co-location of research facilities and provision of on-site knowledge transfer partnerships.

8 Theme 3: Coordinated Innovation to Deliver Sector Needs

Key Messages

- Development of detailed route maps with respect to the application and impact of the circular economy on UK chemical and process sector. Identification of key innovation needs mapped to RD& I capability within the science and innovation base coupled with detailed economic analysis.
- Prioritisation of the Circular Economy and resource efficiency as a major sub-theme within the UK Industrial Strategy.
- Closer coordination of research assets with respect to realisation of a circular economy. In the case of the Universities, a model that spans the working principles of two best practice exemplars, the Northern Sustainable Chemistry (NORSC) consortium and the Knowledge Centre for Materials Chemistry (KCMC) should be considered as a mechanism to address industry challenges in simpler ways and ultimately expand R&D investment in the region
- Detailed consideration of investment in effective, sustainable, low carbon systems e.g. the hydrogen economy, taking into account, particular strengths in location and infrastructure within the Northern Powerhouse.
- Strengthened links between researchers, innovators, companies and investors potentially through best practice "Innovation campuses" that also strengthen links to Catapults and other Innovation Centres.
- Alignment of the chemical and process sector supply chains to key applications that have been prioritised for chemical using industries within the UK Industrial Strategy will be critical. A detailed mapping of future needs aligned to the present base will lead to opportunities to: Strengthen existing supply chains by reintegrating them using next generation technology and to develop next generation supply chains e.g. solid state batteries, biologics, intelligent packaging etc.
- Further facilitation of adoption of digital technologies is needed to drive general economic benefits to the process industries from reduced operational costs, lower maintenance costs and improved decision making. McKinsey & Company estimates that "Digital can drive significant productivity improvements to the order of 30 – 40% EBITDA increase across the industry" **[7]**.
- Additional process support investment is needed to reflect the relative maturity of the sector with large capital requirements for "traditional" plant. The development of more flexible, smaller scale processes through increasing personalisation and customisation provides good opportunity for growth.

8.1 The SIA has identified a very strong chemical manufacturing base within the Northern Powerhouse with three connected clusters in the Northwest, Teesside and Humberside respectively, linked by feedstocks, products and associated supply chains (Chapter 3). Chapter 4 has identified a strong University research base which if acting together punches well above the sum of its constituent parts. This is co-located with the largest concentration of National Innovation Centres focussed on the chemical and process sector in the UK (Chapter 5). Together, these components form the skeleton of a science and innovation network which has the potential to deliver significantly more impact if national resources were deployed to join up the dots and support the delivery of the key innovations that have been highlighted in Chapters 6 and 7 to drive growth and productivity for the sector.

8.2 The SIA has coordinated its evaluation of the key innovation themes with the work undertaken by the Innovation Committee of the Chemistry Growth Partnership on key priorities for innovation and investment. The key innovation themes are summarised in Table 8.1 below:

Table 8.1: CGP innovation priority themes [82]

Theme	Priority Areas
1 Advanced Materials and Molecules Demand for faster, greener travel, new pharmaceuticals and new materials for construction is increasing. For this demand to be met innovative advanced materials and molecules will need to be defined, designed and then manufactured and delivered.	• Renewable materials • Formulation of the future • New materials for composites • New materials for pharmaceuticals • Renewable packaging Innovation in these areas is necessary to facilitate growth in a variety of end-product sectors, from Life Sciences and household and personal care to aerospace and automotive.
2 Energy Storage and Distribution Innovation in this area could drive the conversion to low carbon road transport, rail transport, local shipping opportunities and energy applications such as storing renewable energy. This equates to an enormous global market, in addition to environmental value, which the UK can still lead on if we move quickly. This Innovation Theme has the potential to include energy storage materials such as nano materials (graphene for hydrogen storage) or the conversion of surplus power to other potential energy sources (compressed air). This theme includes innovation in the systems and infrastructure for energy storage such as $C0_2$ storage systems.	• Materials for batteries for electric vehicles • Facilitating the Hydrogen economy - generation, storage, distribution and usage. With collaboration, this Innovation Theme and the starting projects have the potential to create a greener, faster and healthier UK.
3 Green Supply Chains Today's manufacturing is mainly a linear economy. With space in landfills falling and the volume of unsustainable raw materials diminishing, innovation in technologies and systems is needed to facilitate a circular economy - a potentially large market with significant environmental benefits.	• Resource efficiency - industrial symbiosis • Resource efficiency - within companies • Recycling of key materials - Plastic - Steel - Precious metals - Waste to biomass
4 New Feedstocks Aligning closely with theme 3 to provide a range of sustainable feedstocks	• Bio Ethylene Oxide • Waste to Biomass • Lithium extraction for batteries • Shale gas These projects focus on the importance of reduce, reuse and recycle, whilst facilitating the production of new competitive feedstocks to create a value-producing circular economy.
5 Digitisation	This is the cross theme-enabler of innovation and productivity.

8.3 Aligning with the CGP's Innovation priorities, three key areas of particular importance to the NPH are explored in further detail below:

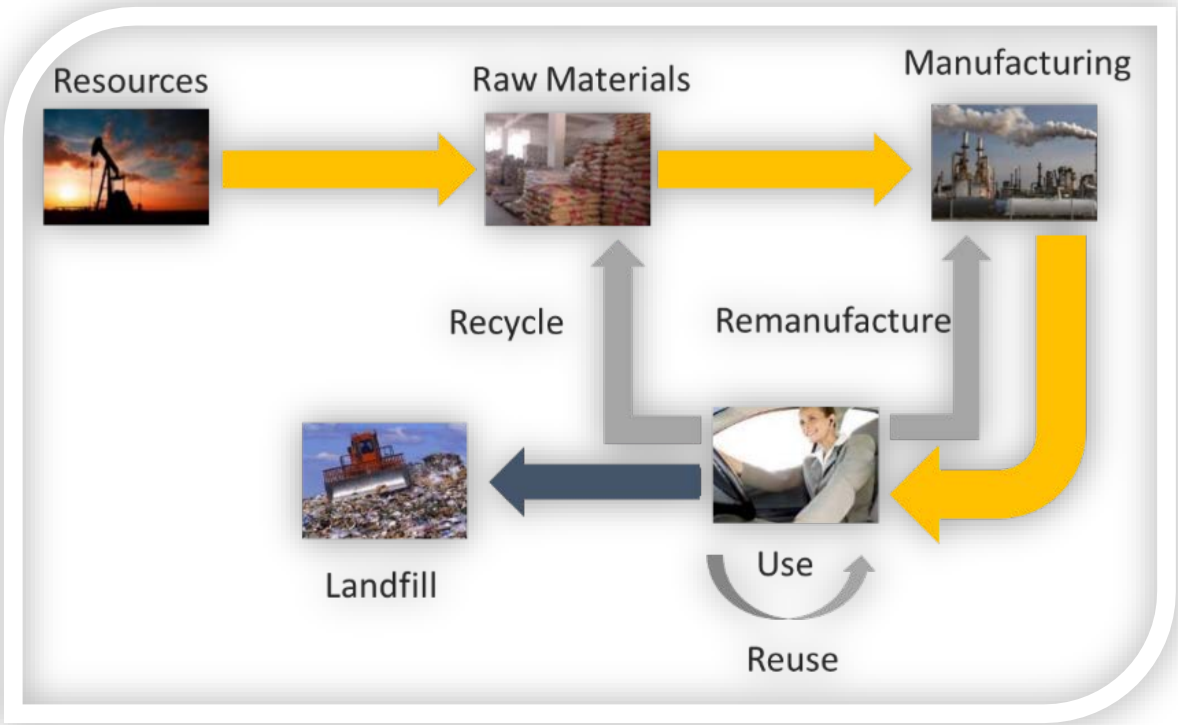
- Circular economy / resource efficiency

- Industrial Digitisation
- Interventions to support sector scale, shape and maturity.

Circular Economy/resource efficiency

8.4 A Circular Economy deviates from the more traditional linear economy whereby products are made, used and then disposed of. Resources are kept in use for as long as possible and the maximum value is extracted from them. Once their value has been extracted, the products are then recovered and regenerated to be put back into the manufacture of new products. The waste from used products therefore becomes the feedstock for the manufacture of new products. Figure 8.1 provides a schematic of how a circular economy might be applied to the chemical and process sector.

Figure 8.1 Resource Efficient Systems: Circular Economy [83]



8.5 Table 8.2 summarises the analysis of more than 20 chemical and process sector reports. The trends, drivers and opportunities delivered through a Circular Economy highlighted are red; less directly delivered drivers and opportunities highlighted orange) This analysis highlights the key importance of the circular economy in driving change in **all** of the chemical and process sub-sectors from bulk chemical manufacturing though to the wider supply chain and emphasises the need for cross-sectoral support.

8.6 Within the chemicals and processing sector, in order for a circular economy to be realised, new technologies will be required and accelerated innovation of products will be necessary. A circular economy approach requires detailed understanding and coordination of supply chains, particularly where chemicals presently cross the UK-EU border many times.

Table 8.2: Sectoral needs and opportunities – potential to address via a circular economy

Sub Sector	Trends & Drivers	Chemical Process Opportunities
Chemical Manufacturing (Bulk Chemicals) [2] [10] [15] [26] [27] [28] [31] [32] [84] [85]	• **High energy costs of production (relative to competitor economies)** • Increasing regulations on chemical production and use • **Need to maintain environmental water and air quality during production** • **Sustainable resourcing/ production** • Reducing input costs driven by competition for resources • Potential impact of changing regulation through trade deals • **Climate change driving low-carbon alternatives** • Growth of overseas markets increasing competition • **Brexit: need for security and need to build up existing infrastructure** • **Use of water within the sector, almost as important as fossil fuels and has demands on quality, waste and cost** • Fossil fuels are necessary for feedstocks and as a source of energy, doubling their importance. With the USA now providing cheap shale gas it is hard for local supplies to compete	• Productivity improvements from precise, efficient application of inputs • Increased yield, quality and sustainability of products • New, flexible, low-impact production methods • Novel catalysts and enzymes • **Low energy, clean processes** • **Innovation in raw materials** • Scalable, flexible and more resource-efficient processes • **Technically and economically viable options for CCS and usage on an industrial scale** • **Move towards closed water cycles** • **Increased efficiency of raw material production**
Speciality chemicals [2] [27] [28] [32] [33] [34] [35] [36]	• **Consumer preference for 'natural' products** • New functionality • Ageing population, meeting the medical and practical demands • **Demand for low carbon technologies** • Urbanisation • Increase in prevalence of disease • Greater production of APIs Demand for specialised healthcare	• New actives and better formulations • Formulated products with designed-in functionality • **Options for CCS and industrial usage on a large scale** • Smart/real time pharmaceutical production control
Polymers and plastics [27] [28] [37] [38] [39] [40] [41]	• **Increased demand for bio-based polymers, films and plastics** • Growing consumerism • Growth in end-use markets • **Pressure on reduction in plastic usage** • **Understanding the full life cycle of plastics**	• **Life cycle analysis** • **Recyclability and the value of recycled products** • **Move towards single polymer packaging rather than current packaging which consists of multiple polymers** • **Multiple use packaging** • **Biopolymers**

Sub Sector	Trends & Drivers	Chemical Process Opportunities
Materials [2] [27] [28] [40] [43] [86]	• **Demand for energy-efficient materials in automotive, aerospace, construction** • **End of life legislation in finished products e.g. white goods** • **Increased demand for bio-based and renewable raw materials** • Growing consumer demand • **Use and sourcing of 'natural' products** • New functionality demands • Increasing population demands • Increased proportion of people living in urban areas • More cars etc. in use • Drive towards new technologies to face challenges and meet consumer demand • **Demand for low-carbon technologies**	• Alternative and novel materials • Functional packaging for consumer goods • Smart coatings for automotive, aerospace industries etc. • Smart materials (self-healing/ self-cleaning/ sensors) for construction industries etc. • Innovation in smart manufacturing processes • Use new technologies to replace scarce metals • Formulated products with designed-in functionality • Understanding how you create material properties whilst using as little as possible • Light weighting • **Recover materials from electronics waste**
Wider supply chain [2] [10] [15] [24] [27] [28] [45] [46] [47] [48] [84] [85] [86]	• **Ethical and environmental policies from fast-moving consumer goods companies diffusing throughout their supply chains** • Reliance on imported materials • **Increased raw materials and energy prices** • **Sustainable supplies of raw materials and energy** • **Diversification of input raw materials** • **Reduced dependency on fossil fuels** • **Decreased primary energy usage** • **Limited natural resources** • Move towards a more circular economy • Energy price fluctuation • Need to re-build UK supply chains • Big companies can drain talent from their own supply chains • Suppliers may have an over-reliance on one customer	• **Sustainable sourcing of raw materials** • **Energy from industrial waste** • Enhanced cross-sectoral productivity • **Secure and competitive energy supplies** • Strengthened supply chains • **Using biomass or waste as inputs to other production processes** • **Circular economy** • Explore new foreign direct investment opportunities • **Exploitation of unconventional gas use** • **Exploitation of sustainable biofuel use** • **Re-cycling end of life products** • Supply chains with no gaps/ breaks/ deficiencies • Supporting SMEs to allow them to take risks • Understanding the factors that influence on shoring and how they can be controlled

8.7 Appendix 15a) provides further examples which exemplify the functioning of a circular economy with respect to the bulk chemicals sector, the bio-economy and polymers and plastics.

8.8 The realisation of the circular economy will require close coordination of research and innovation assets. As outlined in Chapters 4 and 5, the Northern Powerhouse has a very strong chemical and chemical engineering research base within the Universities aligned to a strong innovation base that is already working in this area, particularly though the Innovation Centres of CPI, the Materials Processing Institute and TWI. A clear outcome of this work would be a closer coordination of research assets with respect to realisation of a circular economy. In the case of the Universities, a model that spans the working principles of two best practice exemplars, the Northern Sustainable Chemistry (NORSC) consortium and the Knowledge Centre for Materials Chemistry (KCMC) should be considered as a mechanism to address industry challenges in simpler ways and ultimately expand R&D investment in the region

8.9 Aligning to the technologies, the importance of local feedstocks e.g. H_2, CO_2, power and the availability of existing infrastructure are also critical in driving down costs for implementation.

8.10 The development of the Hydrogen Economy is particularly important and is a differentiator for the NPH in particular in the North East. The UK Government has set a target of 80% reduction in greenhouse gases by 2050, signed up to the Paris Accord and set challenging air quality targets. To meet these, radical change is needed. The Hydrogen Council estimates that globally hydrogen could account for one-fifth of energy consumed by 2050 **[87]**. This would reduce annual CO_2 emissions by 6 Gigatons, and contribute 20% of the abatement required to limit global warming to 2°C. As the world population grows and consumes more energy, hydrogen has the potential to provide sustainable economic growth with the annual demand for hydrogen potentially increasing tenfold by 2050. Other counties are investing heavily in hydrogen technologies and the UK risks being left behind.

8.11 Government's Clean Growth Strategy **[88]** identifies the need for innovation to deliver low carbon growth in energy, industry and transport, with action required to improve air quality. Both hydrogen and carbon capture are essential for the UK to become a low carbon leader. Energy storage is a national priority **[89]** and within the Northern Powerhouse, the Tees Valley region has a leading position in low carbon technologies **[90]**. The Industrial Strategy Challenge Fund's £245m Faraday Battery Challenge is an example of how the Industrial Strategy Green Paper has been implemented to develop cost-effective, high-performance, durable, safe, low-weight and recyclable batteries. **[91]**

8.12 Teesside produces over half the UK's hydrogen **[92]**, is home to the UK's leading CCUS programme which will decarbonise existing hydrogen production. It is the landing point for the world's largest offshore wind farm whose renewable energy could be used to generate hydrogen, processes 14% of UK's gas, injects directly into the National Transmission System and is home to the UK's only underground hydrogen storage caverns. It has the largest network of hydrogen infrastructure in Europe and is home to industrial companies who have already converted their process to use hydrogen rather than natural gas.

8.13 The existing skills and knowledge embedded within the region combined with its industrial base and innovation network built around Teesside and Durham universities, TWI, the Materials Processing Institute and CPI, means it is uniquely placed to develop new hydrogen based technologies and applications.

8.14 Simultaneous decarbonisation of industry, energy and transport through greater use of hydrogen will radically improve the emissions profile of the country, enhance the political and economic standing internationally, attract investment from global companies, and improve the UK's export performance.

8.15 EPRSC through UKRI has issued (June 2018) an £8m call for expressions of interest in "Creative Circular Economy Approaches to Eliminate Plastics Waste" **[93]** recognising the significant issues arising from plastics waste and the opportunities that a circular economy approach might bring.

Industrial Digitisation

8.16 The drafting of this section has relied heavily upon conclusions from the work undertaken by the Applied Digital Technologies in Advanced Manufacturing SIA where there has been close collaboration between the two respective working groups. The key drivers that have been idenified are summarised in Table 8.3:

Table 8.3: Key Drivers for digitisation identified in the Advanced Digital SIA

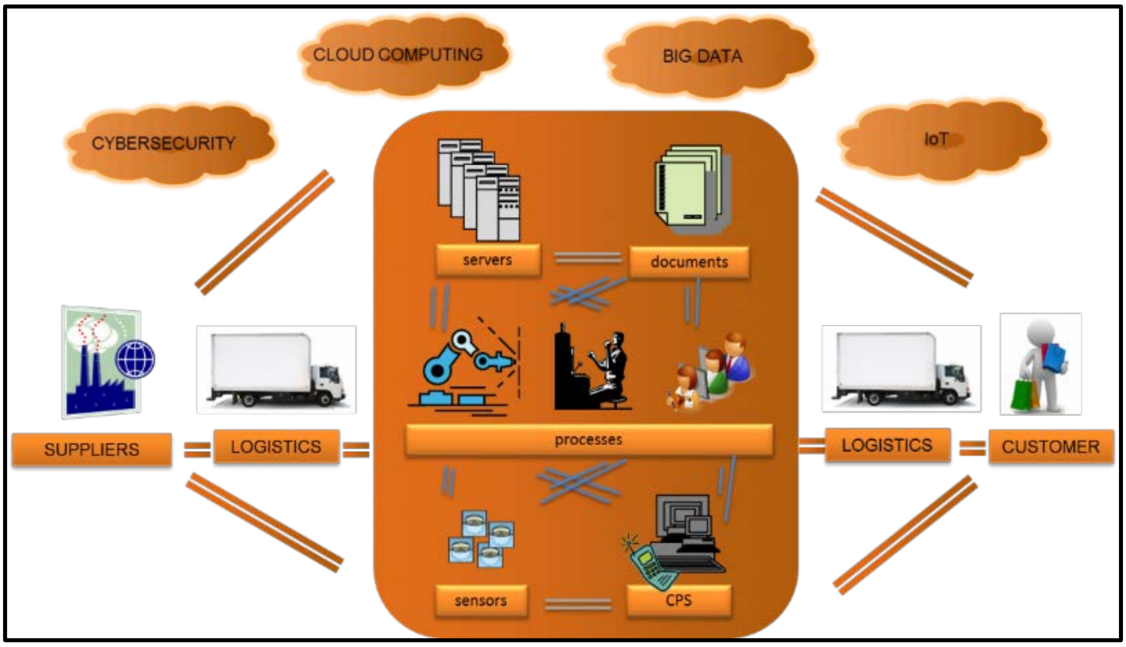
Key Drivers for sector	Estimated potential market size
Chemicals manufacturing	
• Mitigating supply chain risks, with Internet of Things technologies seen as offering opportunities (e.g. to track logistics, monitor changes in temperature and humidity, etc.) **[94]**. • More efficient management of data, with potential for this to generate valuable insights **[95]**. • Safety management, with technologies enabling greater control of manufacturing and delivery processes and the development of alternative processes (e.g. use of drones for safety checks) **[95] [96]**. • Growing international competition **[96]**.	• The materials handling robotics market is forecast to be worth more than \$3.4 billion by 2019, with a subsequent annual growth rate of 9% **[97]**. • The Internet of Things chemicals market was valued at \$3 billion in 2016, with this forecast to increase to \$4.7 billion by 2025 **[98]**. • The chemicals software market is estimated to grow at an annual rate of 11% between 2018 and 2022 **[99]**.
Pharmaceutical manufacturing	
• Tackling counterfeiting, with digital technologies providing opportunities to reduce counterfeiting in both the supply chain and in end-use products **[100]**. • Product traceability, with growing complexity in supply chains and greater data collection making this more important **[101]**. • Increase in use of individualised medicines, with intelligent machines, the Internet of Things and data analytics being critical to ensuring robustness and stability of these smaller batches **[101]**. • Increased regulation, with businesses increasingly being asked to provide continuous product monitoring **[101]**. • Recognition of efficiency gains that can be secured from digitisation **[102]**.	• The market for Internet of Things software and services in the pharmaceutical industry was valued at \$420 million in 2015 and is forecast to grow to \$2.5 billion by 2020 **[103]**. • The market for pharmaceutical robots was valued at \$130 million in 2016 and is expected to grow to \$430 million by 2025 **[104]**. • The market for data analytics for the pharmaceutical industry is forecast to grow by 15% per annum between 2016 and 2021 (from a value of \$1.3 billion in 2016) **[105]**.

8.17 Digitisation has been recognised in the above analysis as a means of addressing the key issues within the chemicals and process sector including:

- Increasingly fragmented supply chains/ownership structures;
- Hazardous but price sensitive working environments, where any closure for safety purposes is highly expensive and negatively impacts on the wider supply chain; and
- Increasing dependence on the analysis of big data, both for regulatory purposes, but also to inform demanding partners both upstream and downstream within the supply chain.

8.18 The sector is increasingly utilising industrial digitisation/Industry 4.0 to address these issues. “Industry 4.0” embodies the concept of the smart factory, where cyber-physical systems (CPS) monitor the manufacturing processes and make decentralized decisions. Industry 4.0 or Smart Manufacturing is not a single concept but the convergence of a number of key technologies the Internet of Things (IoT), Big Data and Analytics, Cloud Computing and Visualisation. Figure 8.2 provides a schematic representation.

Figure 8.2: Industrial Digitisation Schematic [106]



8.19 In response, the sector is seeking the following solutions for each of the aforementioned market failures including:

- **Fragmented supply chains:** chemicals manufacturers are increasingly realising the contribution that IoT technologies can have in managing supply chain risks. They for instance can use predictive maintenance to detect possible malfunctions, track logistics for location and authenticity, and monitor changes in temperature and moisture. Companies like Dow have built supply chain risk management programmes to help improve their supply chains in these ways **[94]**.
- **Better use of data:** for many chemicals companies, data tend to be stored on different systems: financial and marketing on one; operations, production and manufacturing on another; and R&D on another. Firms are seeing high performance computing and Industry 4.0 technologies as way of bringing all of these together and providing more meaningful insights to chemicals manufacturers **[95]**.
- **Safety management:** safety remains a pressing concern within the industry given the toxic and dangerous nature of materials used and produced. Components can also be difficult to transport which constrains supply chain flexibility, and also requires more stringent security and process safety **[96]**. In other cases, plants may have to be shut

down temporarily to make conditions safe enough for manual inspections. Consequently, some chemical manufacturers are turning to equipment such as unmanned drones fitted with high resolution cameras and a variety of sensors to facilitate safety checks and safety management **[95]**.

8.20 A key constraint is system integration and interoperability, with new technology not being compliant with existing systems. Analysis by Accenture also found that very few major chemicals companies have meaningful plans about how and why they will roll out digital processes **[107]**. Part of this may be attributable to a lack of resources given growing international competition in the sector as alluded to above. In turn, this implies that applied digital technologies are not being used as extensively or optimally as they could be.

8.21 Accenture's research highlights a similar issue to that being faced in the automotive manufacturing and pharmaceutical manufacturing sectors. A shortage of digital skills amongst the workforce is preventing some 29% of chemicals companies from further using connected and intelligent products **[107]**.

8.22 The key opportunities for process industries to develop within a future 5G environment are:

- Interoperability: where machines, devices, sensors and people are connected and communicate with each another.
- Information and transactional transparency: where digital data is curated and visualised to enable industry to contextualise information relating to processes and contractual obligations.
- Decentralized and semi-autonomous decision-making: the ability of cyber-physical systems to make simple decisions on their own, utilising Machine Learning and Artificial Intelligence.

8.23 Digital Technologies offer general economic benefits to the process industries from reduced operational costs, lower maintenance costs and improved decision making. A recent report by McKinsey estimates that "Digital can drive significant productivity improvements to the order of 30 – 40% EBITDA increase across the industry by unlocking more than $200 billion globally of new value from digital marketing alone by reducing the cost to serve, improving pricing, and for fast movers, capturing growth from competitors" **[7]**.

8.24 Within the Northern Powerhouse area there exist a large number of companies at the forefront of these developing technologies including Applied Integration Ltd, Animmersion UK, Spearhead Interactive Ltd, Kraken IM Ltd and Unasys Ltd in the Tees Valley and Eon Reality and Clicks and Links (Manchester) Examples of work in the public domain include:

- Applied Integration Ltd (Stokesley and Stockton) - Working in partnership with ABB, Applied Integration, who are specialist system integrators, designed and installed the power management systems for the Francis Crick Institute developing complex hardware to monitor and control the electricity throughout the building, ensuring the provision of automated changeover from mains to generator supplies in the event of a power cut.
- The Mindsphere Lounge in the University of Sheffield. This was the first facility to join Siemen's Mindsphere Innovation Network and provides access to Mindsphere Siemens IoT and data analytics platform.
- University of Huddersfield's 3M BIC has undertaken work with major chemical companies to create Digital Twins of plant for use in asset management and planning
- Unasys Ltd are currently undertaking a KTP with Teesside University developing digital visualisation tools which allow asset holders in the Oil and Gas and other Process Industries to plan completion and decommissioning management projects more efficiently
- Animmersion (Middlesbrough) specialise in visualising products and processes utilising a full suite of animation, AR and VR tools.

- Datum360 Ltd (Stockton) - Asset Data Management System deployed in offshore and energy and process industries applications - recently announced that Maersk Oil's Danish North Sea Tyra Future Development project team are using Datum360 to manage, measure and report the engineering information as it develops. The Tyra project phase is expected to take around 5 years to complete with first gas production expected in 2022.
- The recently launched THYME Research England Connected Capability Fund project led by University of York aims to stimulate the Bioeconomy in the Tees Valley, Yorkshire and Humberside and has a strong digital activity strand focusing utilising AI and ML and robotic automation. Convert process data to process knowledge, visualise data, redesign processes and engage stakeholders with Circular Economy objectives.

8.25 Chaper 7 and Appendix 16 outline the findings from the International benchmarking of key international competitor cities and regions. Particular strategic initiatives have been highlighted are:

- On the US Gulf Coast, the Greater Houston Partnership's 'Houston Exponential' initiative [108] aims to enhance the innovation ecosystem significantly by 2022 using high-impact start-ups funded by a start-up fund. They are focusing on building critical mass in the areas of industrial internet-of-things, robotics and cybersecurity with specific focuses on energy, particularly: digital oilfields and smart grids, deep-water and remote operations and plant asset security systems.
- IBM and Maersk are currently piloting a new blockchain technology in the Port of Houston. This will help digitise the supply chain process from end-to-end to enhance transparency and secure sharing of information among trading partners **[109]**.
- In Singapore, molecular modelling using High Powered Computing (HPC) provides scientists and researchers a powerful tool to design new chemicals and materials. Since the inception of the Advanced Supercomputer for Petascale Innovation, Research and Enterprise (ASPIRE 1), the National Supercomputing Centre (NSCC) Singapore has supported four projects which are closely linked to the chemical industry **[110]**.

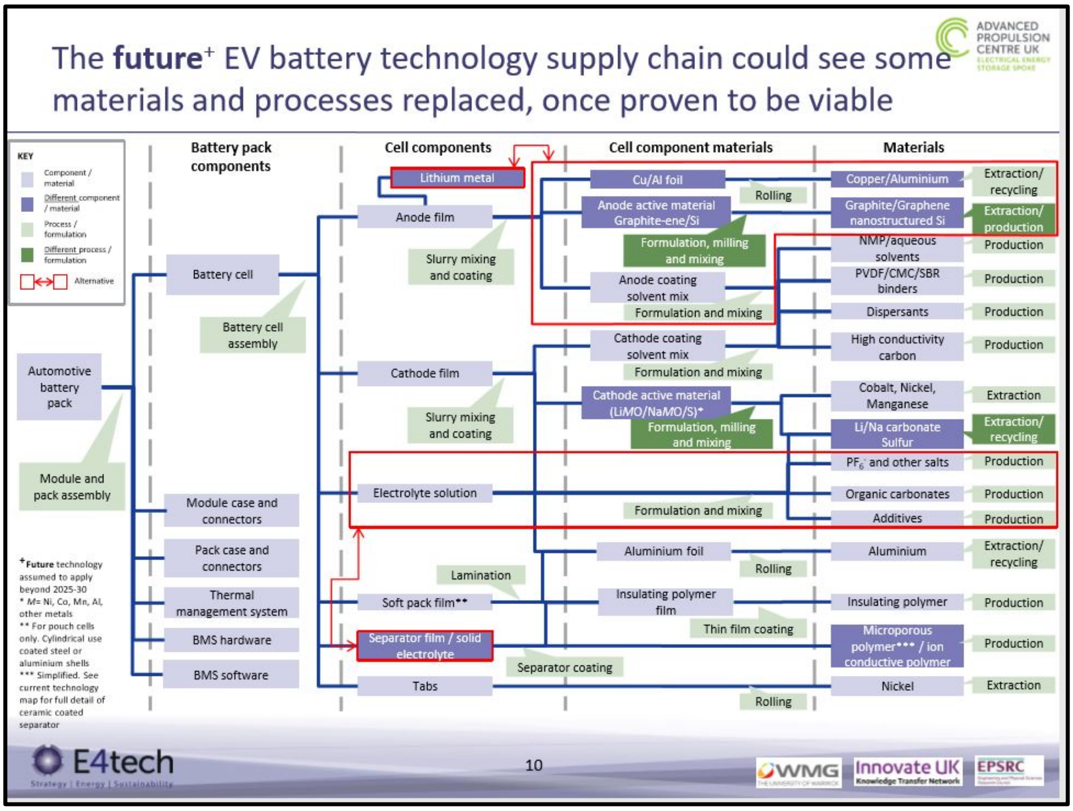
Innovation interventions to support key supply chains

8.26 A key issue facing the sector is the very close interlinkage of supply chains and the fact that chemicals cross the "UK-EU" border many times. Uncertainty over the nature of post Brexit trade deals is reinforcing the need to understand these complex relationships. CPI is presently being sponsored by BEIS to map the process industry supply chain activities. There is also a Chemistry Growth Partnership (CGP) Supply chain group that focuses on automotive and pharmaceutical supply chains.

8.27 The issue to be addressed is that there are gaps in the supply chains that are filled through activities outside of the UK. There is a strength in better integrating those supply chains so that where feasible and economically viable, the UK raw materials are used in products manufactured in the UK. The CGP Supply Chain Group and CPI work is focussed on identifying the opportunities for strengthening these UK supply chains.

8.28 The alignment of the chemical and process sector to key applications that have been proritised for chemical using industries within the UK Industrial Startegy will be critical. An example is the work that E4Tech have undertaken on the supply chain for battery manufacture **[111]**. Figure 8.3 identifies the key chemical and process supply chain opportunities that are foreseen.

Figure 8.3: Key chemical Battery Technology cell components and battery materials [111]



8.29 The fundamental issue that that work has identified is that whilst the UK has good science and research in all aspects of the next generation of batteries, there is not presently a national strategy to join that up into being a major manufacturer. Both Japan and South Korea (not low cost economies) are targeting that coordinated approach.

8.30 This case study exemplifies the gaps in the existing supply chains but also highlights the opportunity in developing future supply chains. A detailed mapping of future needs aligned to the present base will lead to opportunities to:

- Strengthen existing supply chains by reintegrating them using next generation technology e.g. investment downstream of revitalised assets like the Wilton and Grangemouth ethylene crackers.
- Develop next generation supply chains e.g. solid state batteries, biologics, intelligent packaging etc.

8.31 Applying the science base in the Northern Powerhouse for economic benefit is a huge opportunity hence the need for excellent innovation and long term collaboration across academia, companies and industries.

Innovation interventions to support sector scale, shape and maturity

8.32 Once a technology has reached maturity it has been common to go for economy of scale in the belief that it requires less capital per unit output and gives more consistent quality. It is also inferred that larger production capacity gives higher profit because operating costs are lower. This approach is effective whilst the market is growing quickly, but once maturity is reached the cost of new and replacement capital starts to become prohibitive. Markets are now increasingly differentiating product on customisation and personalisation. Capacity built on the basis of economy of scale is often unable to respond to the market need. As a consequence, returns become pressured and cost reduction strategies are followed until the end of the asset life.

8.33 This Growth in customisation and personalisation combines with lower economic growth to contribute to a drive for increased innovation. CPI Analysis **[83]** has identified a number of ways to improve manufacturing processes as summarised below:

a. Develop more sustainable processes.

b. Use resources more efficiency

c. Look at the efficiency of integrated systems

d. Convert wastes to products

e. Make better use of bio systems

f. Improve process efficiency

g. Convert batch processes to continuous ones.

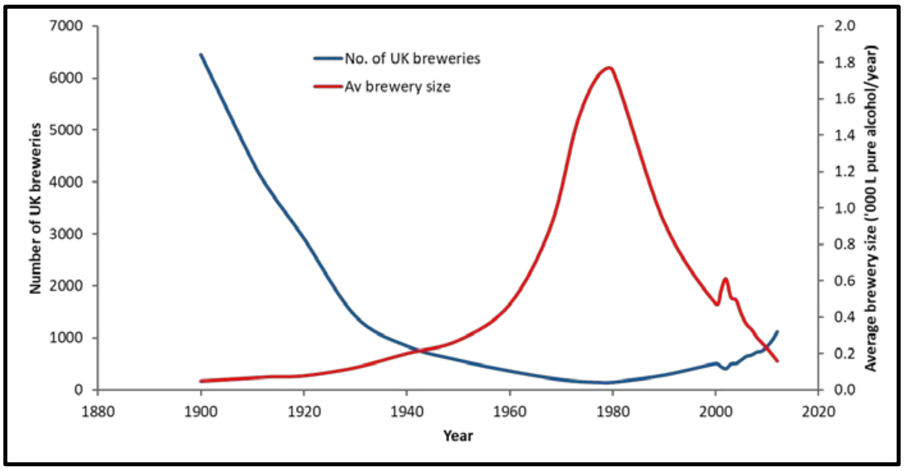
h. Create more flexible processes.

i. Introduce efficient process steps that link input data with process data and product data to assure quality.

8.34 Note that the circular economy interventions described in Chapter 6 can be applied to points (a.) to (e.). The conversion of batch to continuous processes is an example of improved process efficiency (f.). Continuous processes remove process steps to an existing product, lead to lower inventory, product is made in situ when required with highly efficient mixing and easier cleaning processes. These reactors can reduce capital cost by 50%, increase efficiency by 60% and reduce emissions by 60% **[83]**.

8.35 More flexible processes (h.) have been introduced through increasing personalisation and customisation. An example is the development of the mini-mill which has completely changed the complexion of the steel industry. Capital has been reduced by an order of magnitude with low operating cost. The process uses locally arising scrap but yields product to the same quality as virgin steel in many applications. This change was implemented by a small company within this sector but now represents 30% of all steel production **[83]**. The Brewing industry has been revolutionised in the past 20 years by moving to a distributed manufacturing model employing many more smaller breweries over the numbers used in the 1980s and 1990's as illustrated in Figure 8.4.

Figure 8.4: Number and size of new breweries [83].



Alignment and links with Wave 2 and other Wave 3 SIAs

8.36 Table 8.4 summarises key messaging related to innovation coordination in areas of focus relevant to the chemicals and process sector that been identified in Wave 2 and Wave 3 SIAs.

Table 8.4: Conclusions arising from Wave 2 and 3 SIAs

SIA	Overarching / Linking Conclusions	Proposed Actions
Liverpool City Region + A Science & Innovation Audit **[112]**	• Innovation support / access to finance. • Enhancing links / collaboration across the region. • Linking and enhancing the world class Materials Chemistry assets and capabilities in the LCR, and wider North of England, can deliver a step change in regional and national productivity growth, through competitive advantage in digital materials design.	• SIA Executive Group to oversee recommendations of SIA going forward with focus on commercialisation. • Continued collaboration, networking and tracking of results, e.g. publication of 'One year on' report. • Highlighted the Materials Innovation Factory model to drive growth with new sectors outside of fast moving consumer goods both within the LCR, and wider North of England
Applied Digital Technologies in Advanced Manufacturing Science and Innovation Audit **[113]**	• Emerging technologies / digitisation.	• Bringing together digital and advanced manufacturing firms for mutual benefit – greater integration of existing bodies to do this.
The Bioeconomy in the North of England **[114]**	• Co-ordination of business support. • Lack of integration across the region. • Innovation / collaboration. • Investment support. • Lack of policy and incentives to encourage investment.	• Formation of 'Northern Bioinnovation' as single body going forward. • Improved clustering, e.g. formation of a manufacturing park. • Targeted industry support, e.g. BioPilots UK Alliance. • Universities (e.g. N8) to focus on commercialisation.
North West Coastal Arc Clean Growth Partnership Science and Innovation Audit **[115]**	• Sustainability & importance of the circular economy. • Better integration between businesses and research centres. • Joined up approach. • Addressing skills gap. • Supporting open innovation. • Connectivity across disciplines.	• Continued recognition of NWCA as region of national significance. • Strategic alliance, action plan and implementation group. • Coordination between business and research centres. • Improved infrastructure, training, facilities and funding.

Greater Manchester and Cheshire East **[116]**	• Start-ups / commercialisation. • Test beds / pilots. • Innovative SMEs – clustering.	• More systematic approach, e.g. 'Graphene City'. • Bringing together institutions of core competencies - improve networking. • Strategic investment / business support.
A Science and Innovation Audit Report for the Midlands Engine **[117]**	• Growth in core areas, e.g. manufacturing. • Innovation / SMEs.	• Formation of 'The Cross Industry Technology Exploitation in Clusters' (CITEC) to oversee this growth. • Midlands Engine Investment Fund 'MEIF' - £250m fund across the region.

8.37 Several common themes run through these audits in particular, the importance of

- Coordinated Innovation & Business support;
- Strategic Investment & access to finance; and
- Recognition of sector identity through single body.

These closely align with the conclusions arising from this SIA and are explored more fully in Chapter 9.

8.38 There are very clear technological linkages in particular with the work of the Applied Digital SIA in the application of digitisation to the chemicals and process sector and both working groups have closely collaborated in developing their conclusions and actions and have agreed to continue to work collaboratively as they move into implementation phase post-completion of the audit.

8.39 The Northern Powerhouse Chemicals and Process SIA has identified the Circular Economy and resource efficiency as a strong enablers that cut across the key sub-sectors as a means of reshoring activity and driving growth. This is showing close alignment with messaging on the importance of eco-innovation and clean growth within the North West Coastal Arc Clean Growth SIA. Both groups have been in preliminary discussions and will seek to continue dialogue on coordinated and collaborative interventions post-completion of the audit phase.

9 Conclusions

9.1 The audit has sought to assess whether the Northern Powerhouse continues to be globally competitive in terms of the chemicals and process sector and how it could potentially contribute to the Strategy for Chemistry Fuelled Growth's ambition of creating an additional £105 billion of output by 2030.

9.2 To do this we have tested the following hypotheses using the findings of primary and secondary research and noted the following issues/opportunities in Table 9.1:

Table 9.1: Emerging Issues and Opportunities

Emerging Issues/Opportunities

Hypothesis: Demonstrate that the absorptive capacity of the sector and the wider innovation ecosystem are strong but require improvement if the region is to remain competitive.

The absorptive capacity of the region (defined as being the ability of the sector and specific companies to benefit from investment in research development and innovation) was assessed through the following approach:

- Mapping the location and size of the sectoral business and innovation base; and
- Level of engagement across the innovation ecosystem.

The following points were noted:

- Whilst the upstream chemicals sector may account for circa £40 billion (22%) of industrial GVA, it has a downstream impact on circa £212bn or 95% of the UK manufacturing sector;
- The sector accounts for 140,000 employees (6% of UK manufacturing workforce), however it has a GVA per employee of £144,000 which is more than double the UK average and is significantly higher than the GVA of aerospace (£65,000) and automotive (£108,000);
- The United Kingdom continues to be an important player in the global chemicals sector, with a market worth €60billion of sales and placing it in 10th place globally, however the UK ranking is falling (down from 7th place in 2010);
- The sector across both the UK and the Northern Powerhouse can be viewed as mature: stable in terms of industrial composition, with few new start-ups and established technology. In addition, there are a few (circa 100) internationally owned export intensive conglomerates who dominate exporting, supported by circa 500 middle sized firms who largely produce intermediate goods, compete on price and are therefore not research intensive;
- In terms of the chemistry using industries defined by the Chemical Growth Strategy, there is a location quotient of 1.8 for the Northern Powerhouse versus the rest of Great Britain;
- The Northern Powerhouse has three distinct chemical process sector concentrations, including Tees Valley and County Durham, Humber LEP area and a combination of Cheshire and Warrington and Liverpool City Region LEP areas. The tables below provide a summary of the respective areas:

Scale of clusters [51]:

	Humber	Liverpool and Cheshire	Tees Valley and Durham
Total GVA	£18,378m	£60,196m	£21,312m
GVA per employee	£215,000	£449,000	£154,000
Average wage	£35,923	£35,923	£37,543
Location Quotients	4.1	3.0	3.7
Number of establishments	192	373	163

Employment numbers [51]:

Emerging Issues/Opportunities

	Humber	Liverpool and Cheshire	Tees Valley and Durham
Chemical Manufacturing	2,729	2,149	3,912
Speciality chemicals	1,085	1,429	2,863
Polymers, plastics and materials	3,172	4,656	4,891
Pharmaceuticals	1,412	1,882	4,810

- The research ecosystem of the UK and the Northern Powerhouse was assessed from three perspectives:
  - Quality and Quantity of Research;
  - Share of Research Funding; and
  - Share of International Funding.
- The UK research base in the selected sectors continues to be globally competitive, particularly in terms of quality of research. This theme of international competitiveness is reflected within the Northern Powerhouse region, which although it is a comparatively small region it has a number of individual institutions which have international status and continue to attract significant UK and overseas publicly funded research investment.
- Although the region has over 30 higher education institutions, which cumulatively give it a global presence, the lack of individual critical mass affects perceptions of the area. There is the potential for more coordinated collaborative working between disciplines and across institutions.
- A useful proxy for business expenditure on research and development is tax credits. Of the total claims 20.5% were from the Northern Powerhouse region (business base of region is 23%), accounting for 11.4% of the total amount claimed and 9.6% of the total expenditure. These figures suggest the Northern Powerhouse region could be doing more to invest in R&D;
- Location information based on where R&D is actually performed rather than the location of the head office shows a disproportionately large amount being spent on R&D in the South East and East of England, with under-representation within the Northern Powerhouse; and
- When viewed against overall employment and production, there is a clear disconnect between it and company led activity. There is a disproportionate amount of research activity taking place in the south east and east of England, whereas manufacturing and other lower value adding activities are focused in the Northern Powerhouse. This has two implications:
  - Evidence of a disconnect between the national innovation ecosystem and actual production; and
  - A contributory factor to the lower GVA per job experienced in the Northern Powerhouse due to the absence of higher value adding headquarter and research and development functions.

Conclusion: Although there is a strong manufacturing and research element within the Northern Powerhouse, there is presently an element of disconnect with regards translational research. This disconnect, is most readily apparent amongst middle sized companies, amongst whom absorptive incapacity has arisen due to a focus on price and the use of existing technology in established supply chains and a subsequent denudation of existing R&Di skills sets in what are largely producers of intermediate goods.

Hypothesis: That a strong science and innovation base will retain, nurture and grow the sector.

The ability of a strong science and innovation base to retain, nurture and grow the sector was assessed through the following approach:

Emerging Issues/Opportunities
• Assessing the role of disruptor technologies such as industry 4.0 and the circular economy; • How we can grow new and protect existing UK supply chains via identification of critical supply chain components and through overarching reshoring and retention strategies; and • Use of technical consultancies and the University research base to encourage domestic and international diffusion of innovation. The following points were noted: • The UK and the Northern Powerhouse in particular is facing a growing trade deficit in what was historically a positive sector for UK exports. • To prevent this leading to a wider trade deficit it will be necessary to increase onshore production; • However, UK supply chains are becoming more fragmented and price sensitive, a process exacerbated by the impact of increased overseas ownership and the repatriation of production of higher value intermediate goods. Therefore re-building UK supply chains is likely to be reliant on UK SMEs serving downstream industries as the majority of large corporations in the UK are headquartered overseas; • In order to address fragmentation and price sensitivity, it will be necessary to rebuild UK supply chains and encourage the enhanced sourcing of raw materials. This will necessitate the use of circular economy and industrial digitisation solutions. With the former largely focused on re-engineering out waste and thereby reducing the need for imported virgin feedstocks and the latter primarily focused through the use of 'big data' to address fragmentation through better integration of supply chain information; and • Stakeholder consultation noted that although the region has world-class research and the presence of global technical consultancies, their co-location within the region has done little to promote domestic diffusion of innovation to overseas headquartered firms within the Northern Powerhouse, even though many of the global consultancies work with said headquarter functions. In addition, there is presently little opportunity for knowledge transfer between the global technical consultancies and the local business base across the wider region. **Conclusion: The testing and application of disruptor technologies such as the circular economy and industrial digitisation has the ability to create the necessary step change in order to ensure continued global competitiveness.**
Hypothesis: That the Northern Powerhouse has the capacity and capability to substantially deliver the Strategy for Chemistry fuelled growth and so ensure continued global competitiveness An assessment of the additional support that needs to be put in place in order to develop international knowledge networks and the domestic diffusion of innovation. The following points were noted: • Increased feedstock costs are diminishing the cost competitiveness of the Northern Powerhouse, exacerbated by a denudation of local management capacity; • Recognition that industrial fragmentation has diminished the overall internationally visibility of the sector, at the same time as increased clustering in a few but larger international hubs in areas like Antwerp, Busan, Gulf Coast and China; • When viewed cumulatively, the research capability of the region is comparable to that offered by Oxford, Cambridge and Imperial; • There are strengths in research, but there continues to be a disconnect between domestically owned middle sized companies and the innovation ecosystem, particularly translational research; • That there is a lack of international visibility for the Northern Powerhouse innovation ecosystem, which has exacerbated domestic diffusion of research to overseas owned branch plants; and

Emerging Issues/Opportunities
• That there is a need to re-establish supply chains, reshore higher value adding activities and therefore increased productivity. There is general acceptance as to the need for circular economy and industrial digitisation solutions to aid supply chain integration and enhance productivity with uncertainty as to how best these can be applied. **Conclusion: The Northern Powerhouse has the capacity and capability to deliver the Strategy for Chemistry Fuelled Growth if two existing disconnects are addressed: addressing fragmented supply chains and the disconnect in translational research.**

9.3 Table 9.2 presents a SWOT analysis of the ability of the Northern Powerhouse to successfully deliver the Strategy for Chemistry Fuelled Growth:

Table 9.2: SWOT Analysis of the Northern Powerhouse Chemicals and Process Sector

Strengths	Weaknesses
• Individual institutions with world class research; • Strong national innovation centre presence; • Strong geographic clusters in Tees Valley, Humberside and Merseyside; • Highly integrated supply chains; and • Recent upturn of investment/buy outs of and by indigenous companies.	• Business R,D&I conducted outside the region; • Disconnect between research base and technology translation functions; • Lack of recognition of the critical mass across the Northern Powerhouse • Mature sector with high costs of entry to new starts; and • Limited investment in research and development, particularly amongst mid-tier domestically owned companies.
Opportunities	**Threats**
• Increase in demand in global markets for intermediate and higher value adding goods; • Use of nascent technologies and new energy feedstocks; • Increased demand for reshoring and use of circular economy solutions; • Opportunities for use of industrial digitisation; • Opportunities to utilise sectoral free trade zones in conjunction with blockchain solutions • Opportunities to use Northern Powerhouse Diaspora • New models for commercialising technologies: public/private partnerships and associated financing mechanisms; and • Significant opportunities for scale and growth particularly in mid-sized companies.	• Consolidation into a small number of globally competitive clusters; • Increased costs related to feedstocks; • Increased price sensitivity and competition for intermediate goods; • ‘Greying workforce’ with fewer high skilled opportunities; and • Supply chain integration through buy out and further denudation of higher value added functions.

9.4 We have utilised TOWS (Threats, Opportunities, Weaknesses and Strengths) analysis to develop workable solutions to the opportunities/challenges identified in the SWOT. Table 9.3 summarises the key conclusions:

Table 9.3: TOWS analysis of opportunities and challenges identified in the SWOT.

Internal Strengths and External Opportunities (S-O)- how can they use the strengths to benefit from existing external opportunities?	Internal Strengths and External Threats (S-T) how can they benefit from their strengths to avoid or lessen (potential) external threats?
• Need to match local research strengths to emerging global demand for R&Di; and • Increasing global demand for chemicals, with enhanced opportunities for reshoring due to levelling out of costs in Far East.	• Loss of management and leadership skills in region: Address perceptions of lack of critical mass within the sector and overcome denudation of higher value-added functions; and • Increased R&Di being undertaken out of the region, need to highlight the research proposition of Northern Powerhouse and also attract private sector R&Di back into the region.
Internal Weaknesses and External Opportunities (W-O)- how can they use opportunities to overcome the organisation's internal weaknesses?	**Internal Weaknesses and External Threats (W-T)- how can they minimise weaknesses and thus avoid potential threats?**
• High feedstock costs, opportunity to use circular economy solutions; and • Fragmented supply chains, opportunity to use circular economy and industrial digitisation to promote local sourcing.	• Address local intermediaries, develop capacity and growth ambition of local management; and • Too few new entrants, development of patient/risk capital to promote start-ups.

9.5 In response the following actions have been developed:

- Develop a unique selling point for the Northern Powerhouse in conjunction with associated mechanisms and institutions to promote the region and ensure global competitiveness Including Sectoral Free Trade Zone Proposition);
- Masterplan for Northern Powerhouse development, building the capabilities and skills to deploy the following supports:
    - Development of new feedstocks;
    - Impact of industrial Digitisation/Sectoral Free Trade Blockchain Solution;
    - Supply chain consolidation and diversification;
    - Impact of the circular economy; and
    - Development of programme of support for leadership training/talent attraction and retention.

9.6 Building upon our original hypotheses, our vision, therefore, is that over the next 12 years, the NPH chemicals and process sector will:

- Be the most competitive location, by building upon its existing highly efficient bulk chemicals infrastructure, further driving down costs through accessing (existing and emerging) affordable feedstocks and utilising nascent technologies;
- Regain lost export markets and re-shore the production of high value intermediary goods and R&Di functions of locally based global concerns;
- Diversify into new geographic and sectoral supply chains;
- Deliver more knowledge transfer between industry of all size and ownership structure and the regional innovation ecosystem to enhance productivity and ensure global competitiveness;
- Be a globally recognised centre for the application and testing of industrial digitisation and circular economy solutions to the chemicals and process sector; and
- Lead the adoption of bio-processing solutions for chemicals production.

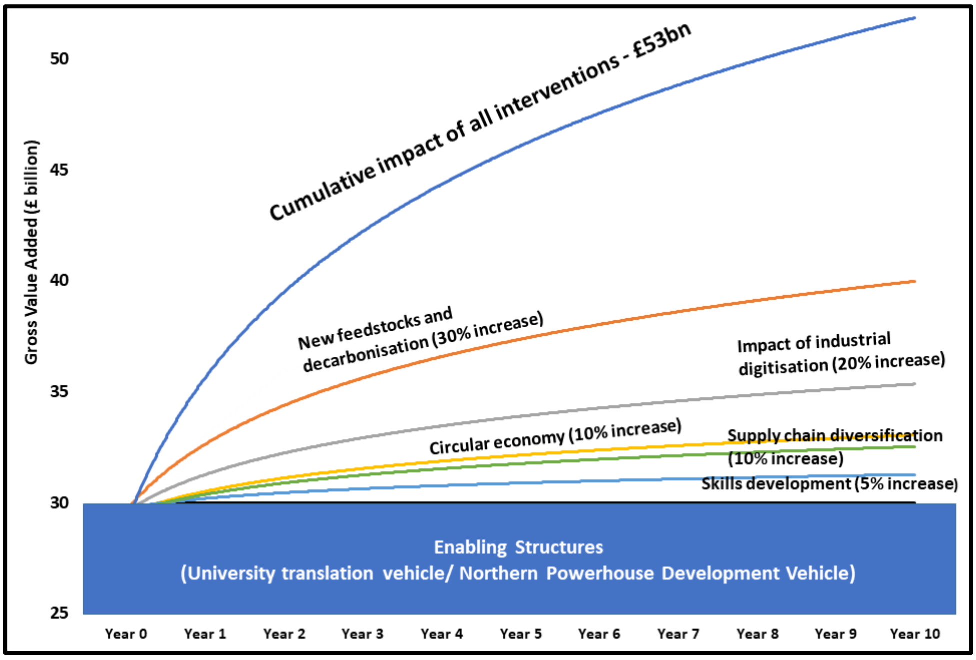
Table 9.4 uses international benchmarks to develop a robust action plan to create a step change to the region.

Table 9.4: Proposed Action Plan

Intervention	Implementation
Acting at Global scale	**NPH Chemicals and Process Sector Development Vehicle:** Augmenting existing sectoral representative bodies, it will be tasked with delivering an enhanced business support function, including but not limited to: supply chain /export diversification and foreign direct investment. Success will be enhanced added value being delivered within the NPH.
Unifying the innovation ecosystem	**Technology translation:** Creation of an innovation delivery system to valorise the academic research base and maximise the economic impact on the sector. Establish an integrated science and technology innovation network (a 'knowledge-based growth hub') integrating with the innovation scale-up of CPI and the other specialist Research Organisations in the NPH. This to provide a strong, agile translational interface accelerating the translation of University research into Industry, closely coordinating with the N11 local enterprise partnerships and science/business parks to drive infrastructure provision in support of relevant inward investment. **Accelerate Technology Commercialisation:** This would require new venture capital funding to commercialise research and provide finance for emerging companies and initiatives to promote clustering and sharing between the public and private sectors.
Increasing productivity through new feedstocks, the use of nascent technologies and decarbonisation	**Resource Efficiency: Develop new feedstock base for chemical industry:** Consider the options that (existing and emerging) affordable feedstocks (e.g. hydrogen, carbon dioxide, shale gas) may give the North. Recognise the opportunities that the bio-economy presents to feedstock development and the strength of industrial players in the NPH. This would require feasibility studies and a roadmap for industry development, as well as aligning the different stakeholder interests. **Accelerate the move towards industrial digitisation.** Northern chemicals sites could provide testbeds for the trialling of industrial digitisation and 5G solutions to address issues related to fragmentation. **Develop the circular economy proposition to mitigate feedstock concerns.** Northern chemicals sites could provide a base for new industries. This would require active engagement with the players developing these industries, as well as the development of a number of pilot / demonstrator projects.
Consolidating and diversifying supply chains	**Programme of support aimed primarily at mid-sized chemical companies**, including provision of skills, innovation and networking support for diversifying supply chains.
Delivering skills to meet sector ambition	**Programme of support to develop talent across the NPH.** Development of an integrated training and skills programme, primarily focused on the coordinated delivery of apprenticeships, including: recruitment, training and placement across the region. This will be primarily aimed at mid-sized businesses across the region. In addition, work with existing knowledge providers to impart specialist leadership and technical training driven by industry. This will in large part be driven by emerging technological absorptive incapacity in, for example the circular economy and industrial digitisation. The integrated model would address the issue of emerging fragmentation across the sector and will therefore significantly benefit both business and individuals if cross-company apprenticeships could be supported.

9.7 Figure 9.1 illustrates the projected impact of the proposed action plan and wider technological changes on the sector:

Figure 9.1: Projected impact of implementation of the Action Plan



The above table reflects the following key assumptions based on the findings of international benchmarking:

- 30% increase in output, reflects the catalytic impact on new investment as a result of reduced feedstock costs experienced in the Gulf Coast;
- 20% increase in output, reflects what was experienced as a result of investment in Singapore and sense checked to impact assumptions developed by McKinsey Consultants;
- 10% increase in output as a result of addressing gaps in the existing supply chain. This is benchmarked to the pre-2012 situation, where a number of these activities were previously delivered indigenously;
- 10% increase in output as a result of investment in circular economy solutions. Given the nature of the technology, this estimate relates to high level analysis developed by the Ellen McArthur Foundation and emerging impact associated with investment experienced in Singapore and Belgium/Northern Germany; and
- 5% increase in output is related to the increases in management efficiency and the subsequent attraction of higher value adding functions related to research and development.

10 Glossary of Terms

BEIS – Department for Business, Energy and Industrial Strategy
CATCH – Centre for Assessment for Technical Competence Humber
CCUS – Carbon capture, usage and storage
CEFIC – European Chemical Industry Council
CGS – Chemistry Growth Strategy
CPI – Centre for Process Innovation
CPS – Cyber-physical systems
CSCP – Centre for Sustainable Chemical Processes
CTAP – Collaborative Technology Access Programme
EBITDA – Earnings before interest, taxes, depreciation and amortization
ECHA – European Chemicals Agency
EoI – Expressions of Interest
EPSRC – Engineering and Physical Sciences Research Council
ERC – Enterprise Research Centre
ERDF – European Regional Development Fund
EU – European Union
FDI – Foreign Direct Investment
FMCG – Fast Moving Consumer Goods
FTE – Full Time Equivalent
FWCI – Field Weighted Citation Index
GVA – Gross Value Added
HHI – Herfindahl-Hirschman Index
HMRC – Her Majesty's Revenue and Customs
ICT – Information and Communications Technology
IoT – Internet of Things
IP – Intellectual Property
KCMC – Knowledge Centre for Materials Chemistry
KTN – Knowledge Transfer Network
KTP – Knowledge Transfer Partnership
LCR – Liverpool City Region
LEP – Local Enterprise Partnership
LQ – Location Quotient
NE – North East
NEPIC – North East Process Industries Consortium
NNL – National Nuclear Laboratory
NORSC – Northern Sustainable Chemistry
NPH – Northern Powerhouse
NVQ – National Vocational Qualification
NW – North West
NWCA – North West Coastal Arc
ONS – Office for National Statistics
P&G – Procter and Gamble
R&D – Research and Development
REACH – Registration, Evaluation, Authorisation and Restriction of Chemicals
REF – Research Excellence Framework
RoI – Return on Investment
SIA – Science and Innovation Audit
SIC – Standard Industrial Classification
SME – Small and Medium-sized Enterprises
STEM – Science, Technology, Engineering and Mathematics
SWOT – Strengths, Weaknesses, Opportunities and Threats
TOWS – Threats, Opportunities, Weaknesses and Strengths
TRL – Technology Readiness Levels
TWI – The Welding Institute
UK – United Kingdom
UKAEA – United Kingdom Atomic Energy Authority
UKRI – United Kingdom Research and Innovation
YCF – Yorkshire Chemical Focus

11 References

[1] W. F. Furter, "Chemical Process Industry," *AccessScience,* 2014.

[2] Chemistry Growth Strategy Group, "Strategy for Delivering Chemistry-Fuelled Growth of the UK Economy".

[3] Office for National Statistics, "Office for National Statistics Annual Business Survey: 2016 Provisional Results," 2017.

[4] CEFIC, "Facts and Figures 2017 of the European Chemical Industry," 2017. [Online]. Available: http://www.cefic.org/Facts-and-Figures/. [Accessed 2018].

[5] CEFIC, "Landscape of the European Chemicals Industry," 2018. [Online]. Available: https://www.chemlandscape.cefic.org/. [Accessed 19 June 2018].

[6] Worldometers.info, "Countries in the world by population (2018)," 2018. [Online]. Available: http://www.worldometers.info/world-population/population-by-country/. [Accessed 19 June 2018].

[7] McKinsey & Company, "Digital in Chemicals: From Technology to Impact," July 2017. [Online]. Available: https://www.mckinsey.com/industries/chemicals/our-insights/digital-in-chemicals-from-technology-to-impact. [Accessed 2018].

[8] Office for National Statistics, "Office for National Statistics Annual Business Survey (2015) - Revised," June 2017. [Online]. Available: https://www.ons.gov.uk/businessindustryandtrade/business/businessservices/bulletins/uknonfinancialbusinesseconomy/2015revisedresults. [Accessed June 2018].

[9] CEFIC, "Facts and Figures 2017 of the European Chemical Industry," 2017. [Online]. Available: http://www.cefic.org/Facts-and-Figures/. [Accessed 2018].

[10] Parliament UK, "Chemicals Sector Report," 2017.

[11] Chemical Industries Association, "The Chemical Industry- Brexit Priorities for UK Growth," 2017.

[12] Chemical Industries Association, "A New Industrial Partnership to Deliver Growth for Everyone".

[13] Department for Business, Energy and Industrial Strategy, "Government Unveils Industrial Strategy to Boost Productivity and Earning Power of People Across the UK," Gov.uk, 27 November 2017. [Online]. Available: https://www.gov.uk/government/news/government-unveils-industrial-strategy-to-boost-productivity-and-earning-power-of-people-across-the-uk. [Accessed 19 June 2018].

[14] Department for Business, Energy and Industrial Strategy, "Policy Paper: The Grand Challenges," Gov.uk, 21 May 2018. [Online]. Available: https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/industrial-strategy-the-grand-challenges. [Accessed 19 June 2018].

[15] CEFIC, Chemical Industries Association, "European Chemical Industry Joint Statement on Brexit and the Future," 2017.

[16] American Chemistry Council, "Statista," 2017. [Online]. Available: https://www.statista.com/statistics/302081/revenue-of-global-chemical-industry/. [Accessed January 2018].

[17] AT Kearney, "Chemical Industry Vision 2030: A European Perspective".

[18] Chemistry Growth Partnership, "Importance of Chemicals in a Manucfacturing Economy; The Case for the UK".

[19] M. Gross, "A Planet With 2 Billion Cars," *Current Biology,* vol. 26, no. 8, pp. 307-310, 2016.

[20] World Energy Council, "Deciding the Future: Energy Policy Scenarios to 2050," 2007.

[21] Deloitte, "The Talent Imperative in the Global Chemical Industry," 2015.

[22] United Nations New York, "Population 2030 Demographic Challenges and Opportunities for Sustainable Development Planning," *Economic and Social Affairs,* 2015.

[23] Deloitte, "Digital Transformation: Are Chemical Enterprises Ready?," 2017.

[24] Ellen MacArthur Foundation, "Towards the Circular Economy; An Economic and Business Rationale for an Accelerated Transition".

[25] European Chemicals Agency, "Understanding REACH," [Online]. Available: https://echa.europa.eu/regulations/reach/understanding-reach. [Accessed June 2018].

[26] Chemistry Growth Partnership, "Developing a Low Carbon Future for the Chemical Industry," 2017.

[27] European Commission, "Report on Critical Raw Materials and the Circular Economy," 2018.

[28] EPSRC, "Manufacturing a Circular Economy A position statement on circular economy research in the UK," 2015.

[29] Department of Energy and Climate Change and the Department for Business, Innovation and Skills, "Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050," 2015.

[30] Knowledge Transfer Network, "From Shale Gas to Biomass: the Future of Chemical Feedstocks," 2016.

[31] Chemical Industries Association, "UK Chemical and Pharmaceutical Industry Facts and Figures," 2015.

[32] Catalyst Corporate Finance, "Chemicals and Coatings 2015/16 Review," 2016.

[33] Chemistry Growth Partnership, "Chemicals Sector; Industrial Decarbonisation and Energy Efficiency Roadmap Action Plan," 2017.

[34] Surface Engineering and Advanced Coatings Special Interest Group, "Time for Strategic Change: UK Surface Engineering and Advanced Coatings Industry," 2014.

[35] Neopost, "The UK Printing Industry Future Focus," 2014.

[36] T. Crichton, "Coatings – the basis of the UK's manufacturing economy," 2017.

[37] Ellen MacArthur Foundation, "The New Plastics Economy: Rethinking the Future and Catalysing Action".

[38] Cogent, "Polymers," 2010.

[39] Be Aware, "Polymers Sector Report".

[40] Department for Business, Innovation and Skills, "The UK Composites Strategy".

[41] European Commission, "A European Strategy for Plastics in a Circular Economy," 2018.

[42] Knowledge Transfer Network, "Supporting Excellence in UK Remanufacturing".

[43] Materials UK, "Nanotechnology: a UK Industry View".

[44] Deloitte, "Digital Transformation: Are Chemical Enterprises Ready?," 2017.

[45] European Commission, "On the implementation of the circular economy package: options to address the interface between chemical, product and waste legislation," 2018.

[46] Ellen MacArthur Foundation, "Cities in the Circular Economy: An Initial Exploration," 2017.

[47] House of Commons, "The aerospace industry: statistics and policy," 2017.

[48] House of Commons, "The motor industry: statistics and policy," 2017.

[49] Technopolis, "Core data provided by Technopolis," [Online]. Available: https://technopolisltd223.sharepoint.com/SIAW3/SitePages/Home.aspx. [Accessed January 2018].

[50] Office for National Statistics, "Nominal and real regional gross value added (balanced) by industry," ONS, December 2017. [Online]. Available: https://www.ons.gov.uk/economy/grossvalueaddedgva/datasets/nominalandrealregionalgrossvalueaddedbalancedbyindustry . [Accessed 24 July 2018].

[51] Tees Valley Combined Authority, "EMSI Overview of the Chemicals Industry Chemistry Industry," 2018.

[52] Office for National Statistics, "UK Business Register and Employment Survey (BRES): Provisional Results 2016, Revised Results 2015," Office for National Statistics, 2 October 2017. [Online]. Available: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/bulletins/businessregisterandemploymentsurveybresprovisionalresults/provisionalresults2016revisedresults2015. [Accessed April 2018].

[53] Carbon Trust for the Humber Local Enterprise Partnership, "Study of the Humber Energy Intensive Industries Cluster," March 2018. [Online]. Available: https://www.nepic.co.uk/wp-content/uploads/2016/05/TVPI_High_Level_Analysis_Report_To_Stakeholders-April-2016.pdf. [Accessed 25 June 2018].

[54] Tees Valley Unlimited, NEPIC, MPI, "Tees Valley Process Industry (TVPI) High Level Analysis," 20 April 2016. [Online]. Available: https://www.nepic.co.uk/wp-content/uploads/2016/05/TVPI_High_Level_Analysis_Report_To_Stakeholders-April-2016.pdf. [Accessed 15 June 2018].

[55] The Essential Chemistry Industry Online , "Ethene (Ethylene)," 4 January 2017. [Online]. Available: http://www.essentialchemicalindustry.org/chemicals/ethene.html. [Accessed 2 July 2018].

[56] HM Revenue & Customs, "HM Revenue & Customs Trade Statistics," [Online]. Available: https://www.uktradeinfo.com/Statistics/Pages/Statistics.aspx. [Accessed March 2018].

[57] Higher Education Statistics Agency, "HESA - Higher Education Statistics Data," 2017. [Online]. Available: https://www.hesa.ac.uk/data-and-analysis/students. [Accessed 31 May 2018].

[58] Universities UK, "Universities UK: Higher Education in Numbers," [Online]. Available: https://www.universitiesuk.ac.uk/facts-and-stats/Pages/higher-education-data.aspx. [Accessed 31 May 2018].

[59] N8 Research Partnership, "The Power of 8: Knowledge, Innovation and Growth for the North," 2015.

[60] HEFCE, "REF 2014," 2014. [Online]. Available: http://www.ref.ac.uk/2014/results/intro/. [Accessed January 2018].

[61] UK Research Council, "Gateway to Research," 2017. [Online]. Available: http://gtr.rcuk.ac.uk/. [Accessed January 2018].

[62] European Commission, "Horizon 2020: What is Horizon 2020?," [Online]. Available: https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020. [Accessed 31 May 2018].

[63] EPSRC, "Molecular Migration in Complex Matrices: Towards Predictive Design of Structured Products," 2017 June 2017. [Online]. Available: http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P007864/1. [Accessed 17 05 2018].

[64] University of Manchester, "REF 2014 Impact case studies," 28 June 2018. [Online]. Available: https://impact.ref.ac.uk/CaseStudies/CaseStudy.aspx?Id=28170. [Accessed 28 June 2018].

[65] Warwick Economics and Development, "“Independent Evaluation of the Knowledge Centre for Materials Chemistry," Warwick Economics and Development, March 2016.

[66] Office For National Statistics, "UK Business Enterprise Research and Development," 2016. [Online]. Available: https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/datasets/ukbusinessenterpriseresearchanddevelopment. [Accessed February 2018].

[67] Bureau van Dijk, "ORBIS Database," [Online]. Available: https://orbis.bvdinfo.com/version-2018523/home.serv?product=OrbisNeo. [Accessed 2018].

[68] Beauhurst, "Beauhurst," 2018. [Online]. Available: https://about.beauhurst.com/. [Accessed 2018].

[69] Innovate UK, "Innovate UK Funded Projects Since 2004," Gov.uk, [Online]. Available: https://www.gov.uk/government/publications/innovate-uk-funded-projects. [Accessed 21 May 2018].

[70] Innovate UK, "Innovate UK Completed Partnership Search," [Online]. Available: https://info.ktponline.org.uk/action/search/complete.aspx. [Accessed February 2018].

[71] Innovate UK, "Innovate UK Current Partnership Search," [Online]. Available: https://info.ktponline.org.uk/action/search/current.aspx. [Accessed February 2018].

[72] European Patent Office, "PATSTAT," [Online]. Available: https://www.epo.org/searching-for-patents/business/patstat.html#tab-1. [Accessed January 2018].

[73] European Patent Office, "Data compiled by Technopolis based on EPO - PATSTAT. Worldwide Patent Statistical Database (Spring 2017 version). Available at: https://www.epo.org/searching-for-patents/business/patstat.html".

[74] D. H. Hauser, "The Current and Future Role of Technology and Innovation Centres in the UK," 2010.

[75] Skills Funding Agency, "The Skills Funding Agency (SFA) Full Year Data Cube February 2018," 2018.

[76] NESTA, "Delivering Digital Skills: A Guide to Preparing the Workforce for an Inclusive Digital Economy," 25 April 2018. [Online]. Available: https://media.nesta.org.uk/documents/Readie_Digital_Skills_booklet_online.pdf. [Accessed August 2018].

[77] UK Commission for Employment and Skills, "Working Futures 2014-2024," 6 April 2016. [Online]. Available: https://www.gov.uk/government/publications/uk-labour-market-projections-2014-to-2024. [Accessed 24 April 2018].

[78] Enterprise Research Centre, "SME Innovation, Exporting and Growth ERC White Paper No 5," Enterprise Research Centre, 2013.

[79] Office for National Statistics, "Annual Business Survey - Regional Results 2015," 2017. [Online]. Available: https://www.ons.gov.uk/releases/uknonfinancialbusinesseconomy2015regionalresultsannualbusinesssurvey. [Accessed April 2018].

[80] Astra Zeneca, "2013 Annual Report," 2013. [Online]. Available: https://www.astrazeneca.com/investor-relations/annual-reports.html. [Accessed 08 May 2018].

[81] Department for Business, Energy & Industrial Strategy, "The Mid-sized Businesses Growth Review," 30 June 2012. [Online]. Available: https://www.gov.uk/government/collections/mid-sized-businesses. [Accessed 3 June 2018].

[82] Chemistry Growth Partnership Innovation Committee , *Innovation Priority themes - personal communications,* August, 2018.

[83] G. C. Hillier, "The Future of UK Manufacturing," in *4th Annual Conference, Centre for Industrial Sustainability*, 2015.

[84] Department of Energy and Climate Change and the Department for Business, Innovation and Skills, "Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050," 2015.

[85] Knowledge Transfer Network, "From Shale Gas to Biomass: the Future of Chemical Feedstocks," 2016.

[86] Knowledge Transfer Network, "Supporting Excellence in UK Remanufacturing".

[87] Hydrogen Council, "Hydrogen Scaling Up: A sustainable pathway for the global energy transition," November 2017. [Online]. Available: http://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-Scaling-up_Hydrogen-Council_2017.compressed.pdf. [Accessed 22 May 2018].

[88] Department for Business, Energy and Industrial Stategy, "The Clean Growth Strategy - Leading the Way to a Low Carbon Future," HM Government, 2017. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf.

[89] Department for Business, Energy and Industrial Strategy, "Building on Our Industrial Strategy - Green Paper," HM Government, 2017. [Online]. Available: https://beisgovuk.citizenspace.com/strategy/industrial-strategy/supporting_documents/buildingourindustrialstrategygreenpaper.pdf.

[90] Tees Valley Combined Authority, "Renewable Energy & Low Carbon Technologies," February 2017. [Online]. Available: https://teesvalley-ca.gov.uk/business/key-sectors/renewable-energy/.

[91] Engineering and Physical Sciences Research Council, Innovate UK, and UK Research and Innovation, "Faraday Battery Challenge: Industrial Strategy Challenge Fund," Gov.uk, 2 March 2018. [Online]. Available: https://www.gov.uk/government/collections/faraday-battery-challenge-industrial-strategy-challenge-fund. [Accessed 6 May 2018].

[92] E4tech, "E4tech Tees Valley and North East Hydrogen Economic Study - Executive Summary," 16 October 2014. [Online]. Available: http://www.element-energy.co.uk/wordpress/wp-content/uploads/2014/12/16102014-Tees-Valley-and-North-East-Hydrogen-Economic-Study-Executive-....pdf. [Accessed 22 May 2018].

[93] EPSRC, "UKRI Call: Creative Circular Economy Approaches to Eliminate Plastics Waste," June 2018. [Online]. Available: https://epsrc.ukri.org/files/funding/calls/2018/circular-plastics-call-document/. [Accessed 29 June 2018].

[94] EY, "Chemicals in Europe: the Way Forward – Balancing the Equation with Customized Innovation and Strategy," 2016. [Online]. Available: https://www.ey.com/Publication/vwLUAssets/EY-chemicals-in-europe-the-way-forward/$FILE/EY-chemicals-in-europe-the-way-forward.pdf.

[95] Deloitte, "Industry 4.0 and the Chemicals Industry: Catalysing Transformation Through Operations Improvement and Business Growth," 2016. [Online]. Available: https://www2.deloitte.com/content/dam/Deloitte/de/Documents/consumer-industrial-products/Deloitte-Industry-4.0-and-the-chemicals-industry.pdf. [Accessed April 2018].

[96] ARC Insights, "Industrie 4.0 in the Chemical Industry," 2 March 2017. [Online]. Available: https://www.osisoft.com/whitepapers/wp-Covestro-Industrie-4-0.pdf. [Accessed 23 April 2018].

[97] Modern Materials Handling, "Global Material Handling Robotics Market to Exceed $20 Billion by 2019," *Modern Materials Handling,* 30 March 216.

[98] GME, "Internet of Things in Chemicals Market Size, Share, Analysis – Forecasts to 2025.," 2018.

[99] Research and Markets, "Global Chemical Software Market 2018-2022," 2018.

[100] The Medical Futurist, "What the Hell is Blockchain and What Does it Mean for Healthcare And Pharma?," 15 February 2018. [Online]. Available: https://medicalfuturist.com/what-the-hell-is-blockchain-what-does-it-mean-for-healthcare-and-pharma/.

[101] Veeva, "Pharma 4.0 – time to rethink manufacturing and quality," 2018. [Online]. Available: https://www.veeva.com/eu/resources/pharma-4-0-time-to-rethink-manufacturing-and-quality/. [Accessed 24 June 2018].

[102] J. Markarian, The Internet of Things for Pharmaceutical Manufacturing, 2016.

[103] GlobalData PLC, "IoT Software and Services in the Pharmaceutical Sector Will Be Worth $2.4 Billion By 2020," GlobalData PLC, 2018.

[104] Grand View Research, "Pharmaceutical Robots Market Size Share Industry Report," 2017.

[105] PR Newswire, "Commerical Pharmaceutical Analytics Market to Provide Over USD 1.5 Billion Revenue Post 2016," 2016. [Online]. Available: https://www.prnewswire.com/news-releases/commercial-pharmaceutical-analytics-market-to-provide-over-usd-15-billion-revenue-post-2016-300341921.html.

[106] J. I. Barbero, "Industry 4.0: Key Features and Benefits," COCOP Coordinating Optimisation of Complex Processes European Project Under the Horizon 2020 Framework and the SPIRE Initiative, 2 October 2017. [Online]. Available: https://www.cocop-spire.eu/content/industry-40-key-features-and-benefits. [Accessed 23 March 2018].

[107] Petrochemical Update, "Digital Technology Could Boost Value of Chemical Sector by $4.4 Billion," 30 October 2017. [Online]. Available: http://analysis.petchem-update.com/workforce-development/digital-technology-could-boost-value-chemical-sector-44-billion. [Accessed 13 April 2018].

[108] The Greater Houston Partnership, "Houston Exponential," [Online]. Available: https://www.houston.org/innovation/.

[109] Petrochemical Update, "Port Houston Joins Blockchain Pilot Program to Digitize the Supply Chain," 8 March 2018. [Online]. Available: http://analysis.petchem-update.com/supply-chain-logistics/port-houston-joins-blockchain-pilot-program-digitize-supply-chain.

[110] The Singapore Chemical Industry Council, "Democratising Access to High Performance Computing (HPC) with Singapore's First Petascale Computer," 2017 July. [Online]. Available: https://www.nscc.sg/wp-content/uploads/2017/11/NSCC-featured-in-ChemDigest-July-Sep-2017-Issue.pdf. [Accessed 20 June 2018].

[111] E4Tech, "The UK chemicals and process supply chain for battery manufacture," 25 June 2018. [Online]. Available: https://www.apcuk.co.uk/app/uploads/2018/06/E4tech_Report_UK-chemical-supply-chain-for-EV-batteries_25June2018-1.pdf. [Accessed 26 June 2018].

[112] Liverpool City Region Local Enterprise Partnership, "Liverpool City Region + A Science & Innovation Audit," September 2017. [Online]. Available: https://www.liverpoollep.org/wp-content/uploads/2017/09/LCR-SIA-full-report-and-appendices-FINAL-September-2017.pdf . [Accessed June 2018].

[113] North East Local Enterprise Partnership, "Applied Digital Technologies in Advanced Manufacturing Science and Innovation Audit," 2018.

[114] University of York, "The Bioeconomy of the North of England - Full Report," August 2017. [Online]. Available: https://www.york.ac.uk/media/research/documents/sia-thebioeconomyinthenorthofengland/Science%20and%20Innovation%20Audit%20-%20the%20Bioeconomy%20in%20the%20North%20of%20England%20-%20Full%20report.pdf. [Accessed June 2018].

[115] North West Coastal Arc Clean Growth Partnership, "North West Coastal Arc Clean Growth Partnership Science and Innovation Audit," 2018.

[116] University of Manchester, "Science and Innovation Audit Report for Greater Manchester and Cheshire East," 2016.

[117] The Midlands Engine, "A Science and Innovation Audit Report for the Midlands Engine, sponsored by the Department for Business, Energy & Industrial Strategy Volume 1: Main Report," November 2016. [Online]. Available: https://www.midlandsengine.org/wp-content/uploads/2017/02/Midlands-Engine-SIA-Volume-1-Report-01-Nov-1.pdf. [Accessed June 2018].

[118] EPSRC and RSC, "The Economic Benefits of Chemistry," 2007.

[119] W. Storck, "Speciality Chemicals," *Enterprise of the Chemical Sciences.*

[120] Council for Science and Technology, "Science Landscape Seminar Series: Representative UK Advanced Materials Structure".

[121] EUROPA, "EU Open Data Portal," 2017. [Online]. Available: http://data.europa.eu/euodp/en/home. [Accessed January 2018].

[122] EPSRC, "EPSRC Priorities," 2018. [Online]. Available: https://www.epsrc.ac.uk/research/ourportfolio/themes/manufacturingthefuture/strategy/priorities/. [Accessed January 2018].

[123] HEFCE, "Knowledge Exchange Funding- HEIF," [Online]. Available: http://www.hefce.ac.uk/ke/heif/. [Accessed January 2018].

[124] HM Revenue & Customs, "Research and Development Tax Credit Statistics," 2017.

[125] Encyclopaedia Britanica, "Materials Processing," Encyclopaedia Britanica Inc, 2016.

[126] Office for National Statistics, "Annual Business Survey - Regional Results 2015," 2017. [Online]. Available: https://www.ons.gov.uk/releases/uknonfinancialbusinesseconomy2015regionalresultsannualbusinesssurvey. [Accessed April 2018].

[127] UK Commission for Employment and Skills, "Working Futures 2014-2024," 6 April 2016. [Online]. Available: https://www.gov.uk/government/publications/uk-labour-market-projections-2014-to-2024. [Accessed 24 April 2018].

[128] CEFIC, "CEFIC Position Regarding Chemicals Regulatory Cooperation After Brexit," June 2018. [Online]. Available: http://www.cefic.org/Documents/RESOURCES/PositionPapers/Cefic_Position_on_chemicals_regulatory_cooperation_after_Brexit.pdf. [Accessed 18 June 2018].

[129] Office for National Statistics, "Standard Industrial Classification of Economic Activities," 2007.

[130] US Department of Justice, "Herfindahl-Hirschman Index," AntiTrust Division, [Online]. Available: https://www.justice.gov/atr/herfindahl-hirschman-index. [Accessed 3 June 2018].

[131] Fosso Wamba, S. and Akter, S., "Big Data Analytics for Supply Chain Management: A Literature Review and Research Agenda," in *Enterprise and Organizational Modeling and Simulation. Lecture Notes in Business Information Processing.*, Springer, Cham., 2015.

[132] Tees Valley Combined Authority, "EMSI Overview of the Chemicals Industry," 2018.

[133] van der Drift, A. and Boerrigter, H., "Synthesis Gas from Biomass for Fuels and Chemicals," 2006.

[134] HEFCE, "2017-18 Grant Tables for HEIs," [Online]. Available: http://www.hefce.ac.uk/funding/annallocns/1718/1718hei/. [Accessed January 2018].

[135] Department for Business, Energy and Industrial Strategy, "Business Population Estimates 2017," Gov.uk, [Online]. Available: https://www.gov.uk/government/statistics/business-population-estimates-2017. [Accessed April 2018].

[136] UK Government, "Innovation Funding Service," Gov.uk, 2018. [Online]. Available: https://apply-for-innovation-funding.service.gov.uk/competition/search. [Accessed January 2018].

[137] UK Government, "The UK's Industrial Strategy," Gov.uk, 2017. [Online]. Available: https://www.gov.uk/government/topical-events/the-uks-industrial-strategy.

[138] Durham University, "Centre for Sustainable Chemical Processes," [Online]. Available: https://www.dur.ac.uk/cscp/norsc/. [Accessed April 2018].

[139] Ellen MacArthur Foundation, "Circular Economy System Diagram," [Online]. Available: https://www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram. [Accessed 23 April 2018].

[140] M. Morgan, "The Circular Economy," IHS Markit, [Online]. Available: https://ihsmarkit.com/research-analysis/the-circular-economy.html. [Accessed 23 April 2018].

[141] N8 Research Partnership, "N8 Research Partnership," [Online]. Available: https://www.n8research.org.uk/. [Accessed April 2018].

NORTHERN POWERHOUSE
HM Government

Department for Business, Energy & Industrial Strategy