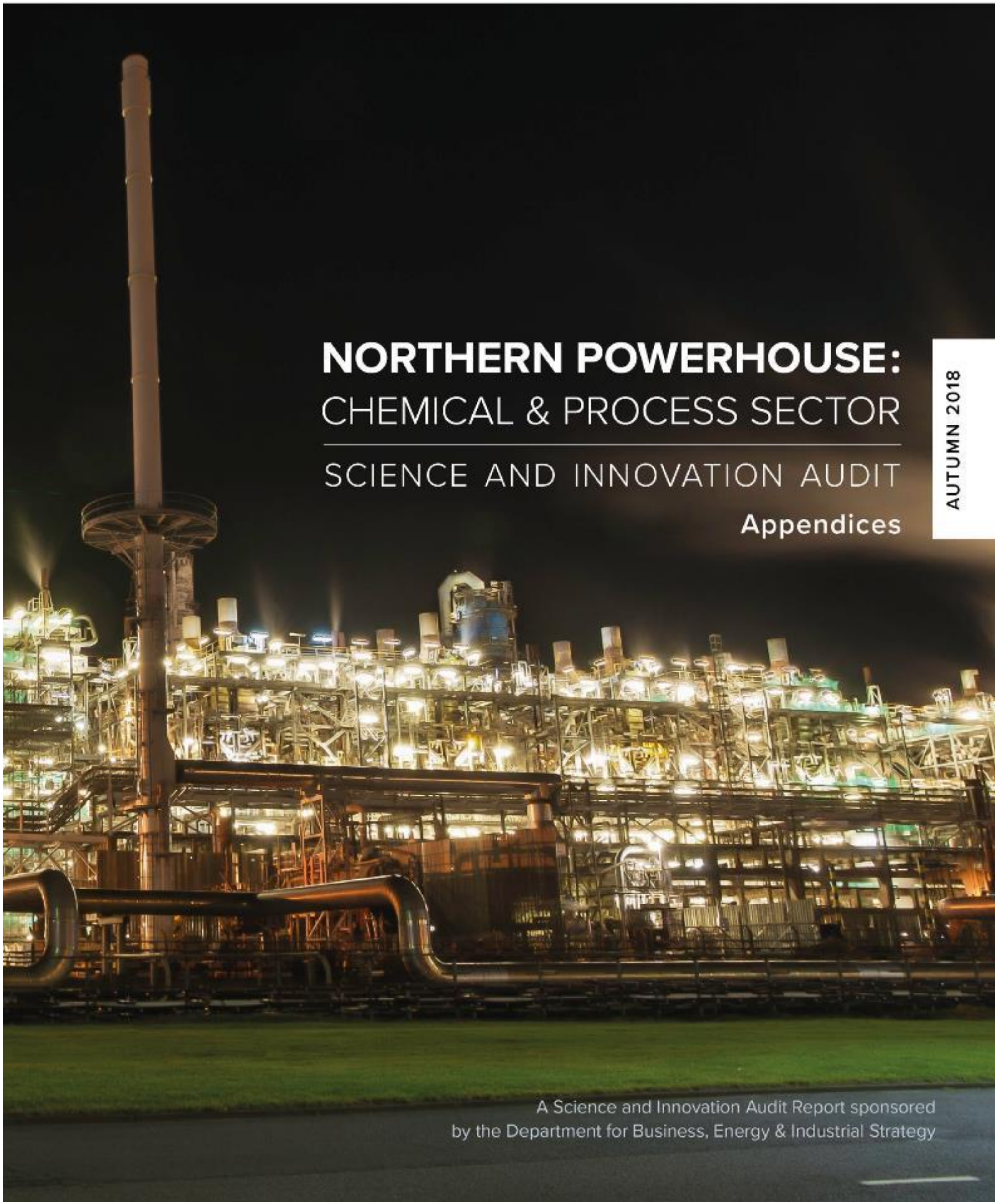
NORTHERN POWERHOUSE HM Government

Department for Business, Energy & Industrial Strategy



NORTHERN POWERHOUSE: CHEMICAL & PROCESS SECTOR

SCIENCE AND INNOVATION AUDIT

Appendices

AUTUMN 2018

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

Table of Contents

Appendix 1: Sub-sector Definitions

Sub-Sector	Definition	SIC Code
Chemical Manufacturing (Bulk Chemicals)	The transformation of organic and inorganic raw materials by a chemical process and the formation of products. This sector has different SIC codes which distinguish the production of basic chemicals from the production of intermediate and end products **[1]**:	20
	Manufacture of industrial gases	20.11
	Manufacture of dyes and pigments	20.12
	Manufacture of other inorganic basic chemicals	20.13
	Manufacture of other organic basic chemicals	20.14
	Manufacture of fertilisers and nitrogen compounds	20.15
	Manufacture of synthetic rubber in primary forms	20.17
	Other chemical products n.e.c.	
	Large-scale bulk commodities used in chemical sub-sectors further downstream **[2]**.	20.59
Speciality Chemicals	Differentiated performance products used on the basis of their function **[3]**.	
	Pesticides and other agrochemical products	
	Paints, varnishes and similar coatings, printing inks and mastics	20.20
	Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	20.3
	Explosives	20.4
	Glues	20.51
	Essential oils	20.52
	The manufacture of basic pharmaceutical products and pharmaceutical preparations.	20.53
	Including the manufacture of medicinal chemical and botanical products.	21
	… As with advanced materials but chemical functionality is the desired outcome rather than mechanical functionality...	
Polymers and Plastics	Manufacture of resins, plastics materials, non-vulcanisable thermoplastic elastomers, the mixing and blending of resins on a custom basis, as well as the manufacture of non-customised synthetic resins **[1]**.	20.16
	Processing new or spent (recycled) plastics resins into intermediate or final products using such processes as compression moulding; injection moulding; blow moulding and casting **[1]**.	22.2
Materials	The process of transferring industrial materials from a raw-material state into finished parts or products **[4]**.	
	Man-made fibres	
	Manufacture of rubber products	20.6
	Manufacture of other non-metallic mineral products	22.1
	Manufacture of plastic products	23
	(Advanced materials): Research, developments and applications of materials designed to have superior properties (e.g. strength, weight, conductivity) or functionality than existing/ traditional materials **[5]**.	22.29
	Materials whose structure and functionality has been modified to satisfy demanding requirements of specific applications. It also includes the innovative use of basic materials to significantly improve performance of a product or technology **[6]**.	
Technical Consultancies	Companies providing expert advice within a particular field through technical support, trouble-shooting functions and resolving customer issues.	
Wider Supply Chain	The sequence of processes involved in the production and distribution of a commodity or product.	

Appendix 2: GVA of the Chemicals and Process Sector

Data for GVA, both by region and sector, was obtained from GVA data available from the Office for National Statistics **[7]**. Balanced GVA as well as GVA at current price estimates was the measure of GVA used to obtain the tables below. This was taken for each region and broad sector and then further analysed by sub-sectors of the manufacturing industrial groups.

The data was published in December 2017 and analysed 2016 (provisional) data. The analysis was undertaken on Table 3, the dataset for NUTS1 & UK current price estimates. Estimates of workplace based GVA allocate values to the region in which the economic activity takes place.

Summary data is provided in Table A2.1.

Table A2.1: Sector Scale nationally and in NPH region (Source: ONS 2016 Provisional results)

Chemical and Pharmaceutical Manufacturing and Manufacture of coke and refined petroleum products SIC 19 to 21	Total GVA	Total employees	Total GVA per employee	SIC 19-21 GVA		SIC 19-21 Employees		SIC 19-21 GVA per employee	CGS wider sector definition	
	£m	Number	£	£m	LQ (UK=1)	Number	LQ (GB=1)	£	No of employees	LQ (GB=1)
Tees Valley and County Durham	21,312	424,000	50,000	1,078	3.2	7,000	3.7	154,000	59,000	1.4
Humber	18,378	381,000	48,000	1,502	5.1	7,000	4.1	215,000	65,000	1.7
Cheshire & Merseyside	60,196	1,102,000	55,000	6,739	7.0	15,000	3.0	449,000	117,000	1.1
Total 3 SIA sub-areas	**99,886**	**1,908,000**	**52,000**	**9,319**	**5.8**	**29,000**	**3.4**	**321,000**	**240,000**	**1.3**
North of England (NE, NW & Y&H)	**329,411**	**6,629,000**	**50,000**	**13,395**	**2.1**	**55,000**	**1.8**	**244,000**	**777,000**	**1.2**
Total SIA area	**338,684**	**6,819,000**	**50,000**	**n/a**	**n/a**	**56,000**	**1.8**	**n/a**	**809,000**	**1.2**
Midlands	226,676	4,575,000	50,000	1,837	0.5	16,000	0.8	115,000	621,000	1.4
Greater South East	814,763	11,893,000	69,000	7,122	0.5	35,000	0.7	203,000	835,000	0.7
South West	127,372	2,433,000	52,000	1,682	0.8	8,000	0.7	210,000	260,000	1.1
England	**1,498,221**	**25,530,000**	**59,000**	**24,037**	**1.0**	**114,000**	**1.0**	**211,000**	**2,493,000**	**1.0**
Scotland	134,038	2,482,000	54,000	1,942	0.9	11,000	1.0	177,000	252,000	1.0
Wales	59,585	1,255,000	47,000	1,493	1.6	8,000	1.4	187,000	155,000	1.2
Northern Ireland	37,237	n/a	n/a	566	0.9	n/a	n/a	n/a	n/a	n/a
Great Britain	n/a	29,268,000	n/a	n/a	n/a	132,000	1.0	n/a	2,900,000	1.0
UK	1,747,647	n/a	n/a	28,038	1.0	n/a	n/a	n/a	n/a	n/a

Detailed analysis broken down by region across the UK is provided in:
Table A2.2: GVA contribution data by region across the UK economy.
Table A2.3: the relative importance of the chemicals and process sectors to UK manufacturing GVA.
Table A2.4: the contribution of Chemicals and process sectors to manufacturing GVA by region.

Key conclusions 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 chemical sector represents £13.40bn GVA in the NPH, 48% of the UK total
- This represents 26.5% of all NPH manufacturing GVA, 1.7 times that seen across the UK as a whole (21.2%)

Figures A2.1 and A2.2 summarise the data by region.

Figure A2.1: GVA/£m 2016: SIC 19-21, manufacture of coke, refined petroleum and chemicals, pharmaceutical products

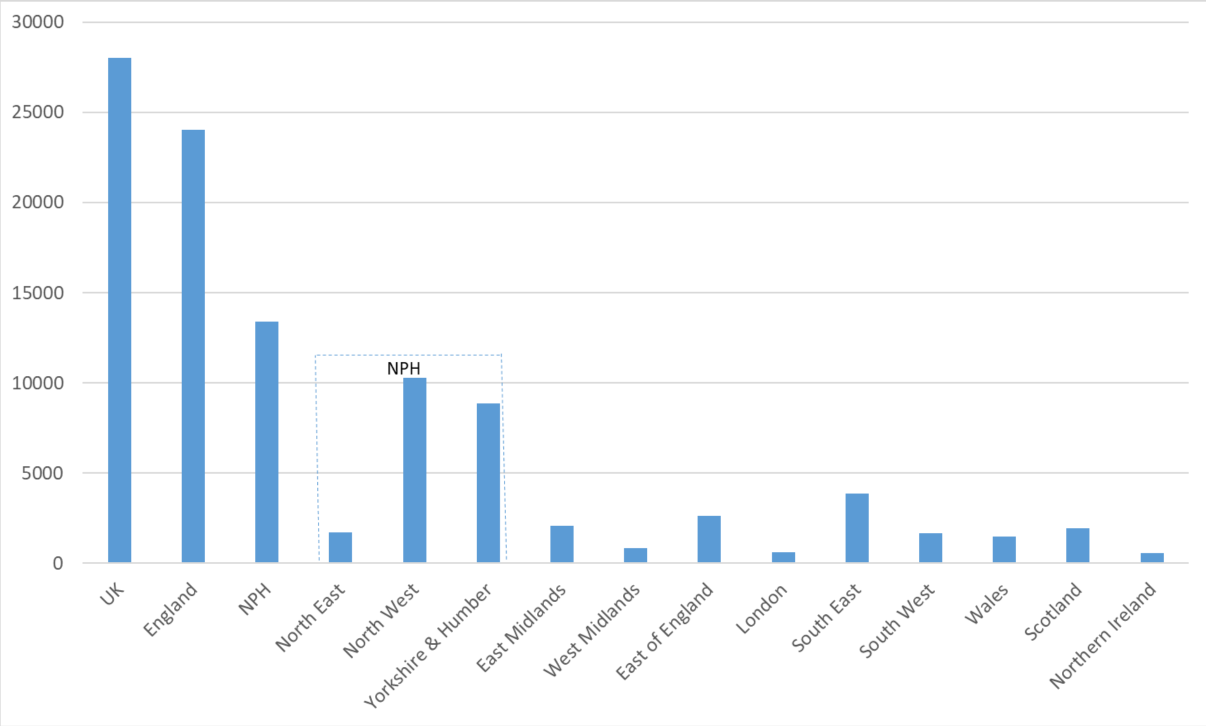


Figure A2.2: Proportion of Manufacturing GVA: SIC 19-21 manufacture of coke, refined petroleum and chemicals, pharmaceutical products

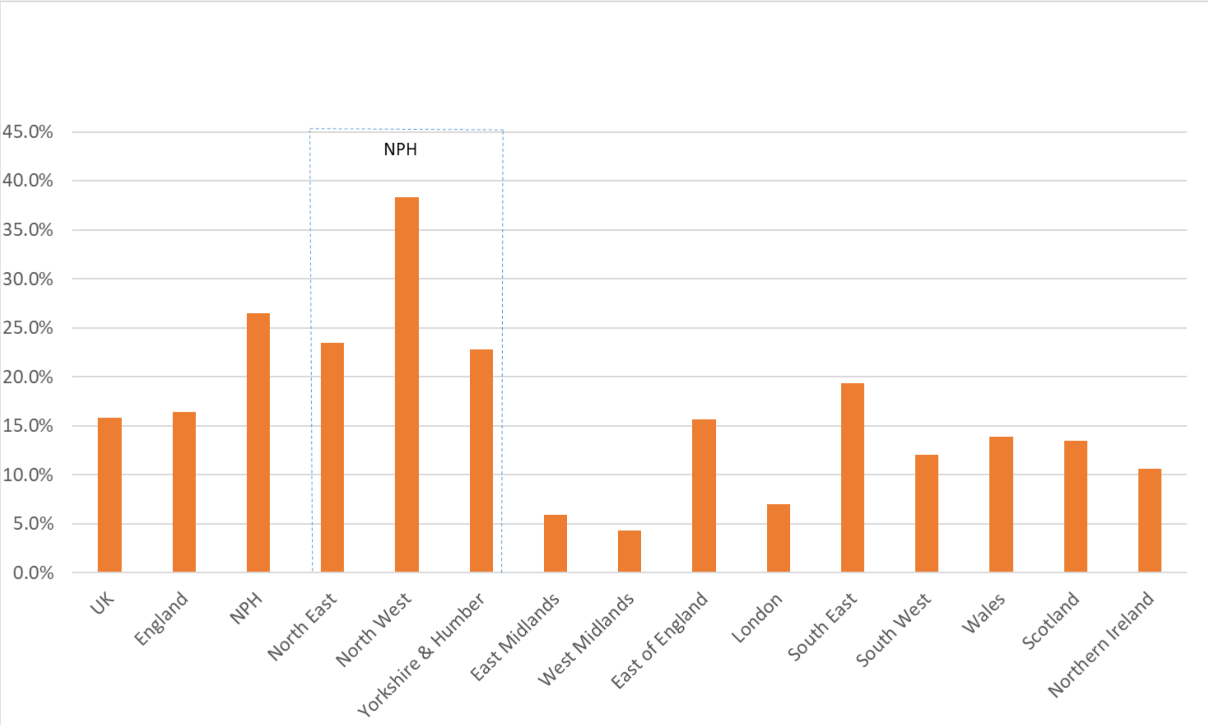


Table A2.1: GVA analysis of the UK economy, 2016

NUTS1 & UK current price estimates of GVA/ £m		UK		NPH		North East		North West		Yorkshire /Humber		England		East Midlands	
SIC07 c	SIC07 description	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%
A	Agriculture, forestry and fishing	10528	0.6%	1962	0.6%	311	0.6%	669	0.4%	982	0.9%	7694	0.5%	922	0.9%
B	Mining and quarrying	21505	1.2%	564	0.2%	193	0.4%	178	0.1%	193	0.2%	2066	0.1%	415	0.4%
C	Manufacturing	176996	10.1%	50571	15.4%	7246	14.3%	26885	16.1%	16440	14.7%	146512	9.8%	16577	16.6%
D	Electricity, gas, steam and air conditioning supply	28454	1.6%	5308	1.6%	1121	2.2%	2020	1.2%	2167	1.9%	22068	1.5%	2894	2.9%
E	Water supply; sewerage and waste management	17458	1.0%	3584	1.1%	562	1.1%	1803	1.1%	1219	1.1%	14223	0.9%	984	1.0%
F	Construction	108124	6.2%	19223	5.8%	2966	5.9%	9257	5.6%	7000	6.2%	93981	6.3%	6843	6.8%
G-T	Service Sectors	1384582	79.2%	248201	75.3%	38276	75.5%	125731	75.5%	84194	75.0%	1211677	80.9%	71450	71.4%
Total	All industries	**1747647**	**100.0%**	**329413**	**100.0%**	**50675**	**100.0%**	**166543**	**100.0%**	**112195**	**100.0%**	**1498221**	**100.0%**	**100087**	**100.0%**

NUTS1 & UK current price estimates of GVA/ £m		West Midlands		East of England		London		South East		South West		Wales		Scotland		Northern Ireland		Extra-Regio	
SIC07 c	SIC07 description	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%
A	Agriculture, forestry and fishing	895	0.7%	1496	1.0%	47	0.0%	1079	0.4%	1293	1.0%	435	0.7%	1889	1.4%	510	1.4%	0	0.0%
B	Mining and quarrying	100	0.1%	180	0.1%	145	0.0%	344	0.1%	318	0.2%	143	0.2%	2076	1.5%	165	0.4%	17055	91.9%
C	Manufacturing	19791	15.6%	16785	11.4%	8777	2.1%	20046	7.7%	13965	11.0%	10745	18.0%	14386	10.7%	5353	14.4%	0	0.0%
D	Electricity, gas, steam and air conditioning supply	3081	2.4%	1498	1.0%	2516	0.6%	4514	1.7%	2257	1.8%	1349	2.3%	4504	3.4%	533	1.4%	0	0.0%
E	Water supply; sewerage and waste management	1426	1.1%	1545	1.0%	1705	0.4%	3121	1.2%	1858	1.5%	886	1.5%	1831	1.4%	519	1.4%	0	0.0%
F	Construction	7718	6.1%	13124	8.9%	20850	5.1%	17477	6.8%	8744	6.9%	3537	5.9%	7907	5.9%	2699	7.2%	0	0.0%
G-T	Service Sectors	93578	73.9%	112754	76.5%	374441	91.7%	212320	82.0%	98935	77.7%	42492	71.3%	101445	75.7%	27461	73.7%	1510	8.1%
Total	All industries	**126589**	**100.0%**	**147382**	**100.0%**	**408479**	**100.0%**	**258902**	**100.0%**	**127372**	**100.0%**	**59585**	**100.0%**	**134038**	**100.0%**	**37237**	**100.0%**	**18565**	**100.0%**

Table A2.2: GVA analysis of the manufacturing sector, 2016 (chemical sector estimates from SIC codes 19-22)

NUTS1 & UK current price estimates of GVA (Manufacturing) /£) , 2016		UK		England		NPH		North East		North West		Yorkshire & Humber		East Midlands	
SIC07 code	SIC07 description	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%
CA	Manufacture of food, beverages and tobacco	27664	15.6%	20442	14.0%	7072	14.0%	608	8.4%	3072	11.4%	3392	20.6%	3390	20.5%
CB	Manufacture of textiles, wearing apparel and leather	6300	3.6%	5408	3.7%	2018	4.0%	182	2.5%	993	3.7%	843	5.1%	1258	7.6%
CC	Manufacture of wood and paper products and printing	11963	6.8%	9990	6.8%	3591	7.1%	533	7.4%	1769	6.6%	1289	7.8%	1201	7.2%
19-20	Manufacture of coke, refined petroleum and chemicals	15197	8.6%	12765	8.7%	7109	14.1%	1109	15.3%	4018	14.9%	1982	12.1%	582	3.5%
21	Manufacture of pharmaceutical products	12841	7.3%	11272	7.7%	6286	12.4%	590	8.1%	4872	18.1%	824	5.0%	397	2.4%
22	Manufacture of rubber and plastic products	9319	5.3%	7832	5.3%	2837	5.6%	487	6.7%	1414	5.3%	936	5.7%	1097	6.6%
23	Manufacture of other non-metallic mineral products	5662	3.2%	4829	3.3%	1717	3.4%	246	3.4%	650	2.4%	821	5.0%	953	5.7%
CH	Manufacture of basic and fabricated metal products	20893	11.8%	17585	12.0%	6114	12.1%	1000	13.8%	2734	10.2%	2380	14.5%	1547	9.3%
CI	Manufacture of computer, electronic and optical products	7945	4.5%	6453	4.4%	834	1.6%	105	1.4%	533	2.0%	196	1.2%	622	3.8%
CJ	Manufacture of electrical equipment	4926	2.8%	4126	2.8%	1191	2.4%	282	3.9%	456	1.7%	453	2.8%	319	1.9%
CK	Manufacture of machinery and equipment	10839	6.1%	9532	6.5%	2687	5.3%	716	9.9%	812	3.0%	1159	7.0%	1328	8.0%
CL	Manufacture of transport equipment	26252	14.8%	23046	15.7%	5665	11.2%	963	13.3%	4105	15.3%	597	3.6%	2551	15.4%
CM	Other manufacturing, repair and installation	17195	9.7%	13233	9.0%	3449	6.8%	424	5.9%	1457	5.4%	1568	9.5%	1332	8.0%
C	**TOTAL Manufacturing**	**176996**	**100.0%**	**146513**	**100.0%**	**50570**	**100.0%**	**7245**	**100.0%**	**26885**	**100.0%**	**16440**	**100.0%**	**16577**	**100.0%**

NUTS1 & UK current price estimates of GVA (Manufacturing) /£) , 2016		West Midlands		East of England		London		South East		South West		Wales		Scotland		Northern Ireland	
SIC07 code	SIC07 description	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%	GVA	%
CA	Manufacture of food, beverages and tobacco	1566	7.9%	2769	16.5%	2237	25.5%	1746	8.7%	1662	11.9%	1547	14.4%	4182	29.1%	1493	27.9%
CB	Manufacture of textiles, wearing apparel and leather	359	1.8%	254	1.5%	863	9.8%	267	1.3%	390	2.8%	160	1.5%	589	4.1%	142	2.7%
CC	Manufacture of wood and paper products and printing	784	4.0%	1202	7.2%	782	8.9%	1602	8.0%	828	5.9%	697	6.5%	945	6.6%	331	6.2%
19-20	Manufacture of coke, refined petroleum and chemicals	775	3.9%	1191	7.1%	234	2.7%	2342	11.7%	531	3.8%	996	9.3%	1158	8.0%	278	5.2%
21	Manufacture of pharmaceutical products	83	0.4%	1434	8.5%	381	4.3%	1540	7.7%	1151	8.2%	497	4.6%	783	5.4%	288	5.4%
22	Manufacture of rubber and plastic products	1199	6.1%	939	5.6%	313	3.6%	679	3.4%	768	5.5%	538	5.0%	588	4.1%	362	6.8%
23	Manufacture of other non-metallic mineral products	673	3.4%	491	2.9%	151	1.7%	507	2.5%	338	2.4%	227	2.1%	368	2.6%	238	4.4%
CH	Manufacture of basic and fabricated metal products	3723	18.8%	1848	11.0%	751	8.6%	2163	10.8%	1439	10.3%	1267	11.8%	1529	10.6%	513	9.6%
CI	Manufacture of computer, electronic and optical products	424	2.1%	1109	6.6%	258	2.9%	2283	11.4%	924	6.6%	497	4.6%	658	4.6%	337	6.3%
CJ	Manufacture of electrical equipment	540	2.7%	378	2.3%	308	3.5%	782	3.9%	608	4.4%	293	2.7%	337	2.3%	170	3.2%
CK	Manufacture of machinery and equipment	1471	7.4%	1696	10.1%	172	2.0%	1245	6.2%	934	6.7%	230	2.1%	732	5.1%	346	6.5%
CL	Manufacture of transport equipment	6640	33.5%	1950	11.6%	1372	15.6%	1941	9.7%	2927	21.0%	1930	18.0%	687	4.8%	590	11.0%
CM	Other manufacturing, repair and installation	1556	7.9%	1525	9.1%	956	10.9%	2948	14.7%	1466	10.5%	1866	17.4%	1830	12.7%	265	5.0%
C	**TOTAL Manufacturing**	**19793**	**100.0%**	**16786**	**100.0%**	**8778**	**100.0%**	**20045**	**100.0%**	**13966**	**100.0%**	**10745**	**100.0%**	**14386**	**100.0%**	**5353**	**100.0%**

Table A2.3: Contribution of chemicals and process sectors to manufacturing GVA by region, 2016

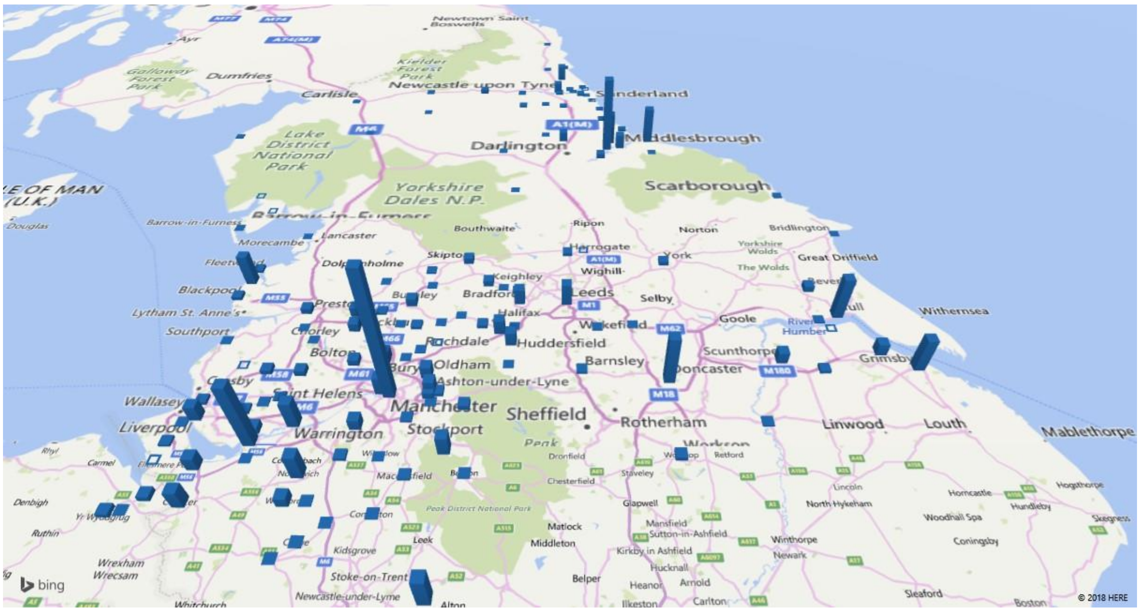
Region	GVA/ £m 2016	% of Manuf
UK	28038	15.8%
England	24037	16.4%
NPH	13395	26.5%
North East	1699	23.5%
North West	10304	38.3%
Yorkshire & Humber	8890	22.8%
East Midlands	2076	5.9%
West Midlands	858	4.3%
East of England	2625	15.6%
London	615	7.0%
South East	3882	19.4%
South West	1682	12.0%
Wales	1493	13.9%
Scotland	1941	13.5%
Northern Ireland	566	10.6%

Appendix 3: Company Location within the NPH

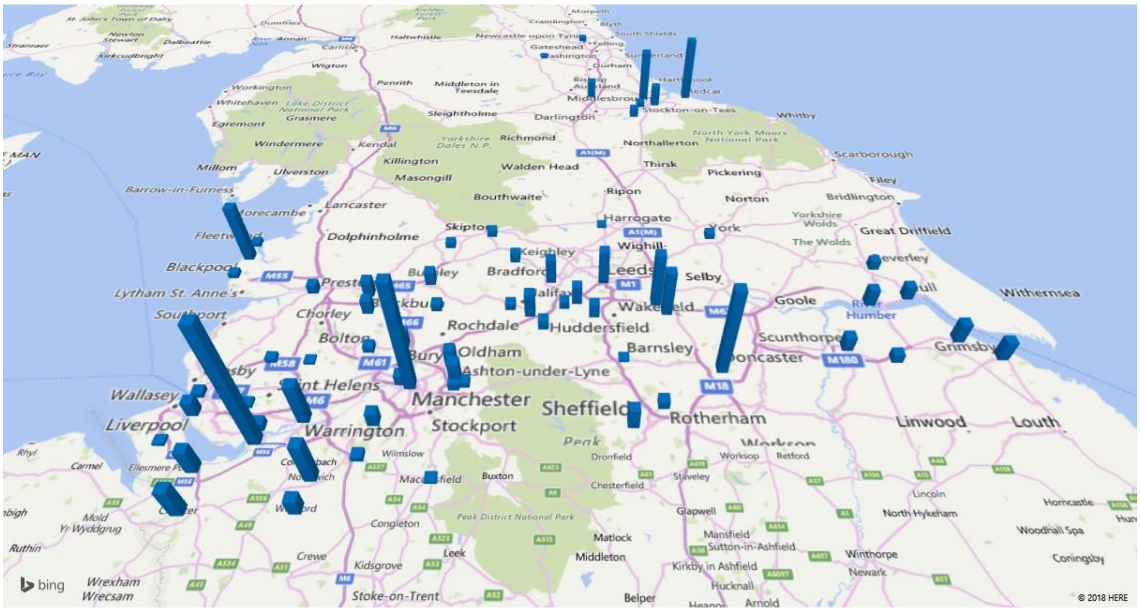
Company annual return data was used to provide an indication of location and density of businesses within the sector (SIC 20 - Manufacture of chemicals and chemical products, SIC 21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations and SIC 22 - Manufacture of rubber and plastic products). This should be interpreted in a qualitative way as the location data will be biased by company headquarter location, particularly for the larger businesses registered outside of the region. The ORBIS database **[8]** was interrogated for company turnover and location from the most recent annual reports filed at Companies House in August 2018. A total of 1880 firms within the UK chemicals and process sector reported data. Of these firms, 559 are based in the Northern Powerhouse. The data was plotted by numbers of companies and total turnover by location.

Number of companies by location – Northern Powerhouse (n=559)

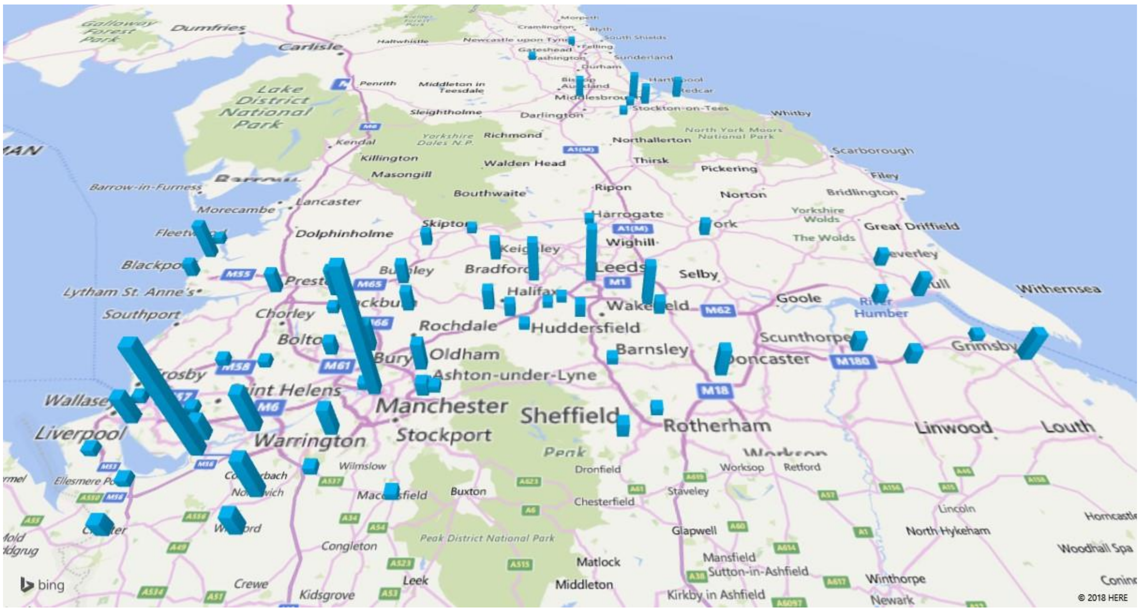
Total turnover by location – Northern Powerhouse (total= £26,968m)



Total turnover by location – Northern Powerhouse based mid-sized businesses (£25m-£500m) (total= £16,446m)

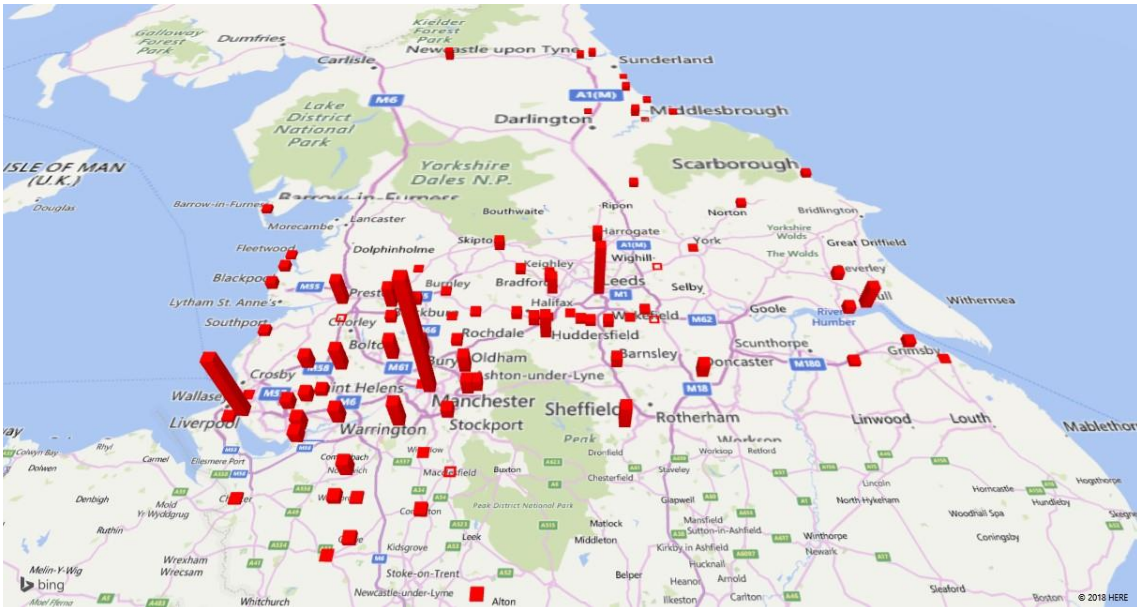


Total companies by location – Northern Powerhouse based mid-sized businesses (£25m-£500m) (n=194)



Number of SMEs by location – Northern Powerhouse (n=318)

SME total turnover by location (total= £3,196m)



Appendix 4: Research Base – Universities

Research base - Universities (consortium members)	
Durham (N8)	Durham is at the centre of the chemicals and processing innovation ecosystem with strategic partnerships with Procter & Gamble and the Centre for Process Innovation (CPI) and multiple company interactions that span the sector. There is a strong focus on multidisciplinary research across the University reflected in its institutes and centres of excellence. Durham Chemistry was ranked first in the UK for chemistry research impact in the REF2014 and is working with Physics, Engineering and Biosciences on a broad range of material and chemical systems, including soft and hard materials, electronic and quantum materials, surfaces, interfaces and complex systems. Durham academics have a breadth and depth of expertise spanning materials synthesis, characterisation, formulation, design, simulation and theory. The Centre for Sustainable Chemical Processes addresses the need to integrate a resource-sustainable ethos into chemical research and development and has a range of synthetic expertise spanning organic, inorganic and process chemistry and catalysis. The Durham Centre for Soft Matter and associated Durham led EPSRC SOFI Centre for Doctoral Training brings together internationally recognised expertise from across the science faculty with the aim of providing a focal point for soft matter and polymer research. Researchers at the Durham Energy Institute are tackling key issues underpinning pressures on the sector including core research on carbon capture and storage. The Bio-X network provides complementary expertise focusing on multidisciplinary research in support of the bioeconomy, biophysics and bio-mathematics. Within this network, the Biophysical Sciences Institute is using interdisciplinary teams to understand aqueous process issues such as biofouling and applying advanced chemistry to solve biological problems. Durham is also active in commercialising its research outputs in this sector including the 50 employee AIM listed spinout Applied Graphene Materials and invented the liquid repellant technology that P2i have used to waterproof over 100 million mobile phones to date.
Lancaster (N8)	Lancaster University conducts novel and innovative interdisciplinary research across the chemicals and process sector through its new Chemistry and Chemical Engineering departments where specialism in materials chemistry and computational chemistry are underpinned by class-leading analytical and diagnostic instrumentation. The Chemistry Department also hosts the Directors of both the Energy Lancaster and Materials Science Institute research centres, which has ensured a vibrant cross-disciplinary research ethos. A special feature of the chemistry department is its Collaborative Technology Access Programme (cTAP). This is an £11.4m capital investment that has been part funded by almost £9m from the North West Operational Programme for the European Regional Development Fund (ERDF) and provides industry with managed access to state of the art technology facilities and associated academic and technical expertise to support and facilitate commercially focused research. The funding has provided a 1000m^2 three-floor building (further extending the Chemistry Department infrastructure to include industrially-focused laboratory space, and hot-desk office space to support SMEs and start-up companies) in addition to a range of equipment worth almost £7m.
Leeds (N8)	The breadth of activities at the University of Leeds within Chemical and Process Engineering are captured under the umbrella of the High Value Engineering (HVE) theme. The aspiration of HVE is to bring together the expertise from across the University to help develop the products of tomorrow. To this end

	there is a focus on activities embraced through the concept of Molecules to Manufacturing, connecting research across the many scales needed to make such products. The expertise ranges from synthesis and scale up of novel chemicals (including biosynthesis) and crystalline pharma APIs to high performance products with their designed structures, made by processes that control such structure at a small scale. All of this is underpinned by modelling expertise across the scales and state of the art materials characterisation (Leeds Electron Microscopy and Spectroscopy Centre (LEMAS)) through to activities in the areas of particulate engineering, colloids and polymer engineering, nanotechnology, computational fluid dynamics and functional surfaces. Supporting these activities are Centres for Doctoral Training in Complex Particulate Products and Processes; Fluid Dynamics and Soft Matter and Functional Interfaces. The research at Leeds is enhanced by significant partnerships with industry including P&G, AstraZeneca, NNL, Sellafield with many of the industry-facing activities emanating through the Institute of Process Research and Development. Many of the afore-mentioned activities will come together in the International Centre for Engineering & Physical Science (ICEPS), a £96m investment. Furthermore the University is committed to developing effective partnerships to drive collaborative innovation and is investing £40m in a 10,000m^2 Innovation and Enterprise centre – Nexus. This will support innovation in HVE and wider opportunities to drive partnership with industry, funders and other stakeholders to ensure economic and social value is created from the University.
Liverpool (N8)	Liverpool's Chemistry Department was ranked 2nd in the UK for world-leading research in the most recent UK research assessment exercise (REF 2014) and is recognised for its excellence and contribution to the international knowledge base in Materials Chemistry, Energy, Catalysis, Functional Interfaces, Medicinal and Bio-nano Chemistry. The department has a depth in leadership, with two active researchers being Fellows of the Royal Society and the recently awarded Regius Professorship, along with a substantial funding portfolio awarded on the basis of research excellence, including major long-term grants and Centres such as the largest EPSRC programme grant (£6.65m), and the Leverhulme Centre for Functional Materials Design (£10m over 10 years). Based on an Open Innovation Model the department continues to deliver enduring academic-industrial partnerships. Previous examples include the Centre for Materials Discovery, the Micro Bio Refinery, the Ultra Mixing Facility and the Open Innovation Hub for Antimicrobial Surfaces. This successful partnership model has led to the creation of the Materials Innovation Factory, funded from a £68m Research Partnership Investment Fund with Unilever, HEFCE and the University of Liverpool. The globally unique facility will include high throughput automated robotic methodologies that will accelerate the research process by a factor of up to 200, greatly reducing new product discovery times for companies thereby driving economic growth and international competitiveness.
Manchester (N8)	The University of Manchester (UoM) has a grant portfolio of >£100m in chemistry, chemical engineering and materials science over the last 3 years. Experimental research is underpinned by analytical, modelling, simulation and computational expertise at all scales. Much of the work is in collaboration with industry, both global and SMEs. The Organic Materials Innovation Centre (OMIC) is based in Manchester School of Chemistry for the speciality organic materials and polymer industries. In the period 2003-2014, OMIC carried out over 150 projects for over 75 companies

	with a total project value in excess of £5m. OMIC is a major partner in the 'Knowledge Centre for Materials Chemistry', which brings together applied materials chemistry at the Universities of Bolton, Liverpool, and Manchester, and the molecular modelling capabilities of the Science and Technology Facilities Council at Daresbury. UoM is the hub institution to the Sir Henry Royce Institute for advanced materials (see National Innovation Centres section for summary). The Chemical Engineering and Analytical Science School hosts a number of facilities. The Process Integration Research Consortium (Centre for Process Integration) is formed by 26 major companies representing the process and utility industries and provides a focal point for integration methodologies and rapid technology transfer through software and training. Unilever and the UoM established the Centre for Advancement of Structured Liquid Engineering (CASTLE) in 2006. There are typically 5 visiting Unilever researchers working within CASTLE at any one time. Manchester Institute of Biotechnology (MIB) focuses on green manufacture of industrial chemicals, bio- and second-generation fuels, with research covering atomic, molecular, systems, and organism levels. SYNBIOCHEM is a European Centre of Excellence for the synthetic biology of fine and speciality chemicals production. UoM is also home of the Manchester Biomanufacturing Centre where CoEBio3 has its core research facility with focus on biocatalysis for rapid access to high-value fine chemicals.
Sheffield (N8)	The University of Sheffield is home to the Departments of Chemical and Biological Engineering, ranked in the top 5 in the UK for output, and Chemistry, where 98% of its research ranked world-class or internationally excellent (REF 2014). It hosts a number of relevant interdisciplinary and translational research centres, including the UK centre for Carbon Dioxide Utilisation and CO^2Chem, which brings together academics, industrialists and policy makers over a wide range of disciplines to consider the utilisation of carbon dioxide as a single carbon chemical feedstock for the production of value added products. Its Polymer Centre is the UK's largest single-university network of polymer science and engineering and leads a CDT in this area. Its Diamond Integrated Pilot Plant, a multimillion pound investment in facilities controlled, monitored and optimised by a state of the art distributed control system, enables industry driven research and learning across (i) Power to X, (ii) Next-generation biofuels, and (iii) Manufacturing high value formatted products through industry scale continuous powder processing - the first of its kind in any UK University. In addition, and as set out in its recent Science and Innovation Audit, it is a UK leader with global leading innovation assets in advanced materials and manufacturing, with particular comparative strengths relating to the development and application of Industry 4.0 technologies, processes and techniques. Sheffield is the first university to join Siemens' MindSphere Innovation Network (MINe) and through our MindSphere Lounge gains access to Siemens' Internet of Things (IoT) operating system and data analytics services.
Newcastle (N8)	Newcastle University's School of Chemistry has a strong track record in medicinal chemistry and chemical biology, developing novel chemical entities, independently and in collaboration with significant industrial partners such as Astex. The medicinal chemistry group has a proven track record, for example with the translation of Rubraca (Rucaparib) from medicinal chemistry through to FDA approval in 2016 in ovarian cancer. The School also exploits research strengths in Nanosciences and photonic materials. The University's School of

	Chemical Engineering and Advanced Materials has additionally strong research in areas relevant to the chemical and processing industry, including Process Intensification and Bioprocessing. Chemistry also has significant input into a number of other combined academic strengths in Newcastle, such as its large grouping of biofilm related researchers and projects.
York (N8)	York University's Department of Chemistry was placed in the top 10 UK Universities for Research Power in the 2014 REF. The Green Chemistry Centre of Excellence works closely with industry to deliver competitive tailor-made solutions that are more profitable, less wasteful, less damaging to the environment and more socially acceptable A new Industrial Engagement Facility (IEF) has now been integrated within the new Green Chemistry Centre building. This includes a hot desk area, laboratory space and access to specialist instrumentation dedicated to visiting industrial partners in the new Centre geared to their specific applied research interests. In addition, an industrial engagement space, a large multi-function, seminar/lecture room and meeting room facilitating one-to-one discussions, small seminars as well as larger events. Green Chemistry works with a large number of industry partners and can scale innovations from mg / ml to multi litre / multi kg scale through facilities at the Biorenewables Development Centre. Green Chemistry has also started the RenewChem program with a number of industry partners and has co-developed a process to produce a new bio-renewable solvent which is now being scaled up to 50 tonne / year production in Australia. York leads on the second round SIA on the bioeconomy from which support and information will be shared with this audit.
Teesside	Teesside University expertise focuses upon: Advanced Materials (Hodgson and Olea Groups) for use in harsh environments and catalytic reactions within the process and chemicals industries; Data Management Research within the Architectural, Engineering and Construction (AEC) industries (Dawood Group); Process Innovation through Big Data analysis, System Modelling, Process Control and Optimisation (Montague, Zeng, Angione and Tang. The University has strong interactions with the process and chemical sector and the technical consultancy constituency, and strategic relationships with CPI, NEPIC, the Materials Processing Institute and TWI. Relevant current and recent KTPs include those with Johnson Matthey, Unasys, Datum360, DKS, Hazdet and Hodgson Sayers. European and International projects include Dr BOB and BIM - Qatar Foundation.
Bradford	The University of Bradford's contributions to innovation in chemicals and process industries apply scientific capability in chemistry and chemical, materials and pharmaceutical engineering through worldwide collaborative partnerships, including more than 50 businesses based in the North. The School of Chemistry and Forensic Sciences enjoys major strengths in materials chemistry, analytical sciences and chemical biology and biophysics alongside the University's international reputation in skin science. Materials chemistry (e.g. polymers, metal-organic frameworks, nanoparticles, peptides) and analytical sciences are particularly outward-facing and major contributors to the North's chemicals industry. Chemistry's expertise in materials complements Bradford Engineering's major strengths in polymer processing. Our Chemical and Process Engineering activities encourage national and international collaboration on short and long term projects on the development and use of computational tools and experimental methods in all aspects of chemical and process engineering

	activities, on the key topics of design, operation, control and enhanced productivity of a wide range of processes. The Centre for Pharmaceutical Engineering Science (CPES) spans pharmaceutical and chemical sciences and chemical engineering. CPES focuses on tailoring material properties through crystal and process engineering and works in strong partnerships with companies in the nutraceutical, pharmaceuticals, personal care and FMCG sectors.
Chester and Thornton Science Park	Acquiring the legacy and infrastructure of Shell's International Research Centre at Thornton and establishing a new Faculty of Science and Engineering, demonstrates the commitment of the University of Chester to support knowledge development and skill supply to the technology based industries in the North West. Thornton Science Park today is a cross sector, multi-disciplinary campus, and home to dozens of technology based small, medium and large businesses. The Faculty of Science and Engineering, comprising of seven Research Groups; The Mathematical Sciences Research Group; Microelectromechanical systems and Smart Microsystems; Visualization, Interaction and Graphics; Computational Condensed Matter Physics; Microscopy, Microanalysis and Surface Science; Thornton Air Lab; Thornton Analytical Centre,. The Materials Science Lab and Chemical Engineering showcase the capabilities to tailor solutions to the evolving requirements of the industries in the region. This co-operative innovation ecosystem forms the prime driver in stimulating collaborative R&D, innovation and enterprise at Thornton. The University, public and private partners are jointly investing £17m to develop an internationally recognised Centre in Advanced Energy Systems capitalising on unique assets. The University is using Local Growth Funds to build an Intelligent Energy Systems Demonstrator. The University also operates >£10m business support programs including the Business Growth Programme for Cheshire and Warrington, medium term research and development support for Innovation to Commercialisation, and long term research support for commercialisation of low carbon products and services.
Huddersfield	The University of Huddersfield conducts interdisciplinary research across the Chemicals and Process sector that combines key strengths most relevantly within Chemical Sciences, Chemical Engineering, Pharmacy, Biological Sciences and Mechanical Engineering. Links with business are deeply embedded in these activities, for example Innovative Physical Organic Solutions (IPOS) is a commercial-facing facility operating from purpose built laboratories at the University, and provides process development and contract analytical services to the chemical industry with ISO9001 and EU GMP accreditation. Within Chemical Sciences and Chemical Engineering there are specific industry-relevant research interests spanning organic synthesis and reaction design through to carbohydrate chemistry – development, analysis and formulation. The Biorefinery Engineering and Bioprocessing Research Centre focuses on the assessment of industrial symbiotic schemes based on waste reuse, with an application to the reuse of biorefinery waste streams. The multidisciplinary Centre for Industrial Analytics is at the forefront of applied research into the visualisation and comprehension of complex data and engages with all aspects of evidence-based business transformation. Mechanical Engineering interest and expertise most relevant to the sector, focuses on flow control, modelling and measurement with specific expertise in valve design and development where we have extensive industry collaborations. The 3M Buckley Innovation Centre (BIC), the University's key commercial engagement and innovation

	facility, also houses numerous companies with substantive sector interest including Surfachem and Here2Grow. Additionally relevant to the sector, the National Physical Laboratory's Huddersfield site, specialising in dimensional inspection and measurement of complex components and assemblies, is housed in the 3M BIC.
Hull	The University of Hull established a School of Chemical Engineering with senior business partners from the £6billion Humber chemical industry. It shares specially built premises at the Centre for Assessment of Technical Competency Humber (CATCH), a realistic industrial training environment that is internationally recognised as a best-in-class facility. In 2016 Hull was ranked joint second in the UK for Chemical Engineering in the National Student Survey.
Northumbria	Northumbria University has longstanding expertise promoted through its Bioeconomy multidisciplinary research theme: its Nzomics biocatalysis consultancy provides enzyme discovery and optimisation services to an international client base; Northumbria has expertise in analytical chemistry for the identification and quantitation of components in complex mixtures or environmental samples, with dedicated chromatography and -omics technology laboratories, including its NU-Omics and FoodTrac Scientific services. The Smart Materials and Soft Matter group focuses on liquid/surface interactions, while the Northumbria Photovoltaic Applications Group has an established track record in thin-film photovoltaics based on sustainable and abundant materials. These groups have received funding from a range of sources including RCUK, Royal Society, European Commission, Innovate UK and from industrial research partners.
Sunderland	Expertise in Process Innovation at the University of Sunderland resides both in the Faculty of Engineering & Advanced Manufacturing and in the School of Pharmacy. Sunderland School of Pharmacy applies its expertise in formulation, pharmaceutical analysis and medicinal chemistry to the challenges of pharmaceutical development. Our analytical facilities enable us to detect and identify materials, confirm their structure and evaluate stability. The faculty of Engineering and Advanced Manufacturing has expertise in material science including the formulation of Nano-composites and foams for the automotive sector. Our research aims to improve energy-efficient and safety using composite materials incorporating graphene. AMAP (http://centres.sunderland.ac.uk/amap) has expertise in advanced maintenance strategy development, modelling reliability and intelligent software incorporating the concepts of Industry 4.0. AMAP works collaboratively with local industry to support competitiveness through applied maintenance strategies.

b) Higher Education Institutions in the North of England

1 - Durham University

2 - Edge Hill University

3 - Lancaster University

4 - Leeds Beckett University

5 - Leeds College of Art

6 - Leeds Trinity University

7 - Liverpool Hope University

8 - Liverpool Institute of the Performing Arts

9 - Liverpool John Moores University

10 - Liverpool School of Tropical Medicine

11 - Manchester Metropolitan University

12 - Newcastle University

13 - Northumbria University Newcastle

14 - Royal Northern College of Music

15 - Sheffield Hallam University

16 - Teesside University

17 - The Open University

18 - University of Bolton

19 - University of Bradford

20 - University of Central Lancashire

21 - University of Chester

22 - University of Cumbria

23 - University of Huddersfield

24 - University of Hull

25 - University of Leeds

26 - University of Liverpool

27 - University of Manchester

28 - University of Salford

29 - University of Sheffield

30 - University of Sunderland

31 - University of York

32 - York St John University

c) Examples of Strong Research Collaboration with Industry

Examples are provided of strong collaborative research partnerships with industry, broken down across 5 key themes as summarised below:

1. Raw Materials and Feedstocks (including biomass, waste/recycled materials, catalysis):
2. Formulated organics (including personal/home-care products, pharmaceuticals, polymers, composites): Sheffield, Manchester (Joint Lead), Durham, Liverpool. Combined expertise spans organic synthesis, polymer chemistry, organic nano-materials, colloid science, rheology.
3. Digitisation for productivity, quality, modelling and operations/supply chain optimisation: Teesside/Leeds (Joint leads), Newcastle, Sheffield. This theme is a hybrid of computational mathematics and chemical engineering.
4. Formulated inorganics (including nanomaterials, pigments, catalysts): Combined expertise spans inorganic synthesis, materials chemistry, nano-materials, catalysis.
5. Circular economy, promoting product design for end-of-life recycling and exploitation of by-products/side-streams:

Durham		
1, 5	EPSRC Sustainable Chemical Feedstocks Call grant: *MacroBioCrude: Developing an Integrated Supply and Processing Pipeline for the Sustained Production of Ensiled Macroalgae-derived Hydrocarbon Fuels*	£1.5m project bringing together academics from four Universities with expertise in agriculture, fisheries, aquaculture, sustainable feedstocks, heterogeneous catalysis, stakeholder engagement/public perception, and gasification to establish the viability of seaweed as a contributing technology for the manufacture of hydrocarbon transportation fuels. Here the viability of ensiled seaweed as an energy vector/storage methodology has been established. Aspects of the project involves collaboration with SMEs, Johnson Matthey and Shell and the Fraunhofer Institute For Environmental, Safety and Energy Technology (Sulzbach-Rosenberg, Germany) to demonstrate industrial viability of technologies employed. (Dyer = PI)
2	Industrial take up of direct fluorination and continuous flow fluorination technologies	Graham Sandford awarded 2018 SCI Process Chemistry Award sponsored by GlaxoSmithKline-AstraZeneca-Syngenta-Pfizer for research on selective direct fluorination and continuous flow fluorination technology development. The highly competitive award recognises research into industrially-relevant areas of synthetic organic chemistry in the pharmaceutical and agrochemical industries.
5	Industrial take up of low cost synthesis methodology of flucytosine	Research between Graham Sandford's group and industrial collaborators Sanofi-Aventis and MEPI (France), funded by the European Union Innovative Medicines Initiative has led to a new, more efficient way of producing flucytosine, a WHO essential medicine used to treat a common and often deadly fungal form of meningitis in people with HIV / AIDS.
1,2,4,5	Establishment of the Durham Chemistry's Integrated Chemical Reaction Facility (ICRF)	The ICRF was established following a £1.1m Durham University-funded refurbishment of Durham Chemistry Department's unique high pressure laboratory and highly reactive/toxic gas handling laboratory facilities. It brings together state-of-the-art equipment and instrumentation creating a world-class laboratory for the development and exploitation of interdisciplinary sustainable, efficient chemical reactions and

		energy-related research projects, many in collaboration with industry and was run by an experience lab manager.
2	SOFI CDT (Funded and renewal at full application stage)	Soft matter CDT funded with significant industrial input. .
2,3,4	P&G Strategic partnership	Strategic partnership working with P&G research units globally. 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 £2m EPSRC award/industry project on molecular migration with partners Durham, Sheffield, York and Birmingham Universities and P&G, Akzo and Mondelez.
2	EP/N025245/1: Evaporative Drying of Droplets and the Formation of Micro-structured and Functional Particles and Films	Durham lead (Bain) with Leeds and Bristol and 15 industrial partners. Developing a predictive understanding of droplet drying and how it can be used to produce micro-structured particles and thin films, both in manufacturing processes and in end-use applications. Supporting a wide range of academic and industrial fields including solar cells, pharmaceuticals, coatings, food, printing and additive manufacturing.
4	EU ITN: BImetallic catalysts Knowledge-based development for Energy applications {BIKE} (Dyer/Beaumont/Johnson Matthey).	Consortium of 9 Universities and 3 partner organisations. Durham-supervised ESRs: 1 x ESR embedded in Johnson Matthey, 1 x Durham Chemistry.
2,4	"Oil Company" project: Design, synthesis and application of novel additives for enhancing oil recovery.	Developed novel drilling muds for improved deep oil-well drilling capabilities, using a combination of designed organic and inorganic additives. 15 patents submitted on novel inorganic hybrid layered materials, novel organic surfactants and novel drilling fluid formulations and performance testing.
Lancaster		
1	Centre for Global EcoInnovation	Funded by ERDF, the centre operates across the Faculty of Science and Technology – total value of the programme is ca £17m. To date, the project has facilitated 75PhDs, 30 Masters by Research and 150+ shorter interventions with industry in the NW over the last 6 years working in the broad area of circular economy. The 1st phase of CGE saw 5 industry partners working with chemistry/chem eng resulting in 14 new products and services so far. The second phase sees the programme working with 13 industry partners but at an early stage.
2,4	CUSP & GISMO	GISMO Greater Innovation for Smart Materials Optimisation. Is a doctoral training programme in development, total value £4m ERDF. The programme is tasked with working in the Cheshire and Warrington Science Corridor that overlaps with the identified chemistry cluster in the SIA. This programme follows the model established by CUSP – The Cumbrian Innovations Platform. This is a £4m programme targeted at Cumbrian SMEs

		that offers a blended approach that responds to innovation challenges combining management sciences and technical solutions and support at a mix of post-doctoral and PhD level. It has been designed to funnel companies through the CTAP facility.
5	Material Social Futures	DTC in Material Socials Futures. Leverhulme Funded £1.05M commenced 2018. This grant supports an interdisciplinary Doctoral training programme (21 PhDs) to explore big picture thinking in materials sciences. Students will explore impacts of their research and materials on society, the environment and will explore issues relating to sustainability and moral and ethical considerations bought about by the manufacture or use of technologies that are materials-based.
1,2,4	Collaborative Technology Access Programme	This is an ongoing £12.8m programme that opened in 2016 has been part funded by almost £9M European Regional Development Fund (ERDF) and provides industry access to dedicated state of the art technology facilities and associated academic and technical expertise to support and facilitate commercially focused research. The funding has provided a 1000m2 three-floor building (further extending the Chemistry Department infrastructure to include industrially-focused laboratory space, and hot-desk office space to support SMEs and start-up companies) in addition to a range of equipment worth almost £7M. This has been further enhanced with 4 specialist staff being recruited to run the equipment suites at ca £300k pa. It has engaged with 200+companies and has contracted with 37 industrial partners on in-depth collaborations as of December 2017.
Leeds		
1,2,3,5	CDTs	- CDT on Complex Particulate Products and Processes that covers Theme 1, 2 and 3. - CDT on Bioenergy that covers Theme 1 and 5. - CDT on Fluidic Dynamics that covers Theme 3. - Partners in the Soft Matter CDT with Durham. All of these multi-disciplinary activities contribute to research depth and training of skills in the Chemical Sector.
2, 3	ADDoPT	The £25m Advanced Digital Design of Pharmaceutical Therapeutics project is addressing the pharmaceutical industry's desire to deliver medicines more effectively to patients. ADDoPT is developing and implementing advanced digital design techniques that eliminate non-viable drug candidate formulations as early as possible, streamlining design, development and manufacturing processes.
1, 2, 3, 5	iPRD	The Institute of Process Research and Development has over the last 10 years supported more than 100 companies in the Chemical and Pharmaceutical sector in developing technology to improve productivity, quality and environmental performance with many examples of projects (Innovate UK, UKRI and direct support). It provides companies process development and scale-up facilities and is used by SMEs involved in a wide range of

		business activities. The iPRD is well known by Northern Companies and assists in sectors including pharma, fine chemicals and sustainables including specialties bioplastics, waste, food and personal care.
1, 2	CMD	The Centre for Manufacturability Design is an industry supported research activity concerned with understanding the causes of manufacturing failure in chemical manufacture that has a huge impact upon profitability and productivity. There are a number of examples of improvements in active, solid form and formulated product that have resulted in large savings and greater product consistency.
Liverpool		
2,4	Strategic partnership with Unilever	The University has a long-standing strategic relationship with Unilever. This incorporates high-profile activity from throughout the health, life and physical sciences.
2,4	Materials Innovation Factory (MIF)	Through the use of Computer Aided Materials Science and high-throughput automation the MIF aims to develop new approaches to materials science, re-thinking potential applications and bringing it into the 21st century. The MIF features a ‘Research Hotel’ whereby research teams from industry are able to co-locate with specialist facility experts on a long-term basis.
4	Leverhulme Research Centre for Functional Materials Design	The Centre was created to drive a design revolution for functional materials at the atomic scale. The award from the Leverhulme Trust will help to bridge the current design gap by fusing leading-edge synthesis concepts from the physical sciences with ideas from the forefront of computer science, alongside experts in robotics, engineering, management and social science. The Centre also runs a programme of funded PhDs in a rich interdisciplinary training environment.
1	EPSRC Programme grant: Flexible Routes to Liquid Fuels from CO2 by Advanced Catalysis and Engineering (EP/N010531/1)	The grant employs a multidisciplinary catalyst discovery, deployment and process engineering approach to develop, evaluate and optimise thermal, photo- and electro-catalysed routes to liquid fuels from CO2 and water using solar energy. Direct thermal and solar-assisted paths to methanol and DME will be compared with stepwise solar/electrochemical syngas generation plus thermal DME or Fischer-Tropsch hydrocarbon synthesis paths. The novel catalyst chemistries enabling each route will be integrated on the basis of process systems modelling and analysis to identify optimised schemes that will be benchmarked by input from industry partners with key roles in potential supply chains.
4	EPSRC Programme grant: The UK Catalysis Hub (EP/K014854/1)	The hub will couple with an extensive programme of applications, which will be distributed amongst the extensive rage of collaborating institutions and will be built round the following central themes in contemporary catalytic science: Catalysis Design, Catalysis for Energy, Chemical Transformations, Environmental Catalysis
4	EPSRC Programme grant: Integration of Computation and	Society faces major challenges that require disruptive new materials solutions. This Programme Grant will tackle the challenge by delivering the daily working-level integration of

	Experiment for Accelerated Materials Discovery (EP/N004884/1)	computation and experiment to discover new materials, driven by a closely interacting team of specialists in structure and property prediction, measurement and materials synthesis.
4	ERC Programme grant: Dynamic responsive porous crystals (692685 / Dynapore)	The programme grant 'Dynapore' will develop the methodology to synthesize dynamic responsive porous crystals. Possible applications range from enabling complex catalytic pathways through to providing a novel selective capture mechanism to help combat climate change through carbon capture.
Manchester		
1,2	Manchester Institute of Biotechnology (MIB)	The MIB is developing new biotechnologies for application by the chemical using industries in the energy economy, food security, industrial transformations and the environment. The project SynBioChem is designing and engineering biological parts, devices and systems for sustainable fine and speciality chemicals production, including new products and intermediates for drug development, agricultural chemicals and new materials for sustainable manufacturing. The project CoEBio3 was established in 2005 to drive collaborative R&D in biocatalysis and has key capabilities of interest to the SIP proposal in: (i) Molecular biology and microbiology to develop new or improved biocatalysts; (ii) Demonstrating the utility of these in synthetic organic chemistry and (iii) Process optimisation and lab scale up with commercial partners Inputs: MIB underpinning research programme worth over £50M, SynBioChem (£10M from UKRI), CoEBio3 (ERC Advanced Grants ITurner), 4 BBSRC NIBBs, BBSRC sLoLa and H2020 projects such as Chem21) Outputs: 9 Spin-out companies have been formed from the MIB, in 2006-16 the MIB filed 241 disclosures, 52 patents and 12 licences were awarded.
2,4	Royce Institute	Manchester acts as the hub for the UK National Institute for Materials Science, Research and innovation (Royce Institute), and leads the research activities of direct relevance to this proposal in 2D Materials, Biomedical Materials and Materials for Demanding Environments. Royce@Manchester is the home of the M4DE CDT. Inputs: Total funding for the Royce Institute is £235M.
5	Sustainable Consumption Institute	The SCI focusses on how people live, how they acquire, appreciate, use and dispose of goods and services, and how innovations can promote a more environmentally friendly lifestyle. Key research themes of interest to the SIP include: Working towards sustainability, System innovation and transition. Inputs: Founded in 2008 by a £25M investment by Tesco.

2,4	National Graphene Institute	The NGI is a UK national facility to deliver new science and technology in 2D materials, it facilitates collaboration between academics and their industrial partners to develop applications of 2D materials. The NGI is the home of the NowNano CDT. The Graphene Engineering Innovation Centre (GEIC), opening in late 2018, complements the NGI on higher industrial lead TRL. Inputs: Initial investment of £61M from EPSRC and ERDF. Outputs: To date over 90 industrial partners have worked on graphene projects with over 50 IP families being created and 7 spin-out companies. THE GEIC which opens later in 2018 has already 4 signed-up Tier 1 partners.
1,2,5	Centre for Process Integration	The CPI@UoM models chemical processes using a holistic approach examining all aspects of the system, including reliability, availability and maintenance. It aims to improve efficiency in the use of raw materials and water to encourage sustainability. Outputs: Software developed by CPI@UoM has been commercialised by two spin off companies, (i) Process Integration Limited (PIL) which currently employs more than 50 people in Manchester and Beijing and completes around 15 projects each year with an average benefit for each partner of $2.5M per annum, and (ii) Process Asset Integration Ltd, that has saved BP $6M in capital expenditure and increased Sinopec profitability by $2.5M per annum.
2, 4	Organic Materials Innovation Centre (KCMC)	OMIC helps companies innovate and grow through access to leading edge science in organic materials. These materials include bulk, specialty and engineering polymers, oligomers, surfactants, lubricating oils and active ingredients for use in applications as diverse as coatings, electronics, biomaterials, packaging, home and personal care. OMIC forms one of the core players in the Knowledge Centre for Materials Chemistry (KCMC). Input: Founded in 2002 by a £4.25M grant from DTI and subsequent investment of £8M from regional government to found the KCMC in 2008. Annual income from collaborative research projects with industry has averaged over £1M *p.a.* for the past 10 years. Outputs: OMIC has carried out over 150 projects with the chemical using industry over the past 10 years. An independent review of the whole KCMC (all university partners) in 2016 estimated that the impact of the KCMC will lead to an additional £164M of GVA for the UK economy.
1,4	UK Catalysis Hub	Manchester is a key partner in the UK Catalysis Hub with a large research effort in two of the Science Theme projects, (i) Catalysis for Energy and (ii) Biocatalysis and Biotransformations. Hardacre

		(Chemical Engineering) is about to be announced as Director of the Catalysis Hub. Input: EPSRC UK Catalysis Hub projects >£5M total investment. Output: The research undertaken has resulted in major progress in both liquid and gas phase processes in the fields of emission control, energy transformations, chemicals production and in understanding different modes of activating and preparing catalytic systems. The research has resulted in a substantial body of published work (over 60 to date). The work has been multi-team and multi-disciplinary in nature with 41% of the papers published incorporating work from more than two institutions. These grants have underpinned the award of a second tranche of funding for the UK Catalysis Hub within which Manchester has a key role in the projects: (i) Catalysis for the Circular Economy and Sustainable Manufacturing and (ii) Catalysis at the Water-Energy Nexus totalling ~£5m.
Newcastle		
4	Prog. grant on membranes	Newcastle lead with Imperial, Bath, Manchester, Edinburgh. Include inorganic and organic membranes as well as 2D membranes such as graphene. http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/M01486X/1
1	SUPERGEN	Led by Imperial, Bath, Newcastle and St Andrews. Hydrogen and fuel cells. http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P024807/1
1,4	The UK Catalysis Hub	Led by Manchester and all about formulation catalysts particularly for energy applications. http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/K014706/2
1,4	Centre for Advanced Materials for Integrated Energy Systems (CAM-IES)	Advanced materials for energy processes. Led by Cambridge with Queen Mary, UCL and Newcastle. http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P007767/1
1,4	Elucidation of membrane interface chemistry for electro-chemical processes	Led by Manchester with UCL and Newcastle. Fuel cells and membranes. http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/P009050/1
4	Emergent Nanomaterials (Critical Mass Proposal)	Led by St Andrews with Ulster, Imperial and Newcastle. Designed and understanding a new class of nanomaterial. Four linked grants, Newcastle grant is at: http://gow.epsrc.ac.uk/NGBOViewGrant.aspx?GrantRef=EP/R023921/1
4	ERC Advanced Grant on membranes	Membrane grant for Metcalfe on fundamental membrane processes for inorganic carbon dioxide separation membranes.
1,4	Patents	Metcalfe, I.S., 'Hydrogen Production', WO2017006121A1.
Sheffield		
2	Farapack Polymers	Farapack Polymers (a three-man University spin-out company offering various technical services in polymer science and

		technology to a wide range of UK and overseas companies; annual turnover: £250k to £500k)
4	Catalytic Clothing	http://www.catalytic-clothing.org/home.html https://www.sheffield.ac.uk/news/nr/catalytic-clothing-purify-breathe-science-fashion-1.174284 Catalytic Clothing harnesses the power of a photocatalyst to break down air borne pollutants. A catalyst is a term used to describe something that makes a reaction proceed at a greater rate but isn't actually consumed during that reaction. A photocatalyst gains the energy it needs to be active from light.
4	Air-cleansing poetry: poems that clean the air we breathe could help tackle pollution	• World's first air-cleansing poem has removed more than two tons of nitrogen oxide from the environment. • Catalytic poem is printed on specially treated material which purifies its surroundings. • Catalytic technology could help urban areas tackle high levels of pollution. https://www.sheffield.ac.uk/news/nr/catalytic-poem-air-cleansing-pollution-sheffield-1.673043
2	Nanotechnology patent	Armes sold a nanotechnology patent application for €125,000 to a global speciality chemicals company (DSM) in 2007. DSM developed this technology to create cost-effective anti-reflective coatings for cover glass used on solar cells. This new business now has annual sales of >€10m
2	£7.1 M EPSRC CDT in Polymers, Soft Matter and Colloids (Armes) EP/L016281/1	• The *only* Centre for Doctoral Training (CDT) in the UK focused on polymer science and engineering. • Secured industrial funding for 51 joint research projects from 33 corporate sponsors (including 7 SMEs) shown in Q3. • 50% of our CDT intake is female and we have excellent Early-Career Researcher (ECR) engagement.
2&5	£1.5M Innovative Manufacturing Fellowship (Slark)	Polymers are all around us and although they are an integral part to the development of the global economy, many materials are only used once. Waste production in the UK is a significant issue with 80% of materials used in manufacturing products ending up as waste, landfill approaching capacity and a 40% increase in consumer waste projected between 2016 and 2020. Against a backdrop of sustainability and the need to reduce environmental impacts, recycling, re-use and remanufacture are becoming ever more important. This Fellowship will develop smart polymers that provide high performance and also enable recycling, which will be a unique approach in the UK to a circular economy. The goal of the programme is to work with academic and industrial partners to develop a key body of knowledge via high quality underpinning science and correlating the molecular architecture of the new materials with their basic physical properties and the application performance important to the end use, in addition to

		designing the relative compatibility between polymers to optimise their form and ultimate properties.
2	£2.0 M ERC Advanced Investigator PISA grant (Armes)	The preparation of nanoparticles with precise control over size, shape and surface chemistry is a formidable technical challenge. However, we are making tremendous progress in this field by utilising an approach known as polymerisation-induced self-assembly (PISA). These nanoparticles have various potential commercial applications, which are exploring in collaboration with many academic scientists around the world and various industrial partners. The latter include BASF, P & G, AkzoNobel, Scott Bader, DSM, Ashland and GEO Specialty Chemicals.
2	EP/R003009/1 Particle Technology Established Career Fellowship Proposal: Characterisation and Evaluation of New Block Copolymer Nanoparticles	Prestigious £1.67 million Established Career Fellowship in the field of Particle Technology. Steve's research team has focused on developing a technique known as polymerisation-induced self-assembly (PISA), which provides a powerful and versatile platform technology for the rational design of nanoparticles of controllable size, shape and surface chemistry. The research programme involves fruitful collaborations with a wide range of chemical companies, including Lubrizol, Scott Bader, Syngenta, AkzoNobel, Ashland, DSM, BASF and GEO Speciality Chemicals. His research activities, which will be conducted in close collaboration with four UK-based companies (GEO Specialty Chemicals, Scott Bader, Lubrizol & Syngenta), four UK academics and three overseas academics. This will enable him to integrate substantial academic and industrial expertise in order to tackle a range of important scientific problems that could not be addressed by a single researcher. Some of these problems are fundamental in nature, such as investigating the precise mechanism of particle formation during heterogeneous polymerisation or developing very fine particle-stabilised oil droplets that exhibit long-term stability towards droplet coalescence. Other aspects of the outlined research programme have obvious potential applications. These include: (i) the development of next-generation hydrogels for the long-term storage of human stem cells, which have the potential to transform regenerative medicine; (ii) the design of highly anisotropic worm-like particles to act as thickeners for a range of oils in cosmetics formulations; (iii) the elucidation of new high-temperature oil-thickening mechanisms for engine oils, which has the potential to improve fuel economy and hence improve air quality. Prof. Armes has worked closely with a wide range of companies and his research has already inspired the development of commercial products by BASF, Cabot and DSM. More recently, a UK SME (Diamond Dispersions) tripled its annual sales and doubled its workforce by implementing informal technical advice provided by Prof. Armes. In 2016 Lubrizol scaled-up his nanoparticle formulations from five grams to twenty kilos per batch and conducted an extensive in-house evaluation of their

		performance as additives for next-generation engine oils, with pilot plant trials now approved for 2017. Thus Prof. Armes has an excellent track record of commercially-relevant technical innovation that is of tangible value to UK plc. This augurs well for maximising the economic impact of this Fellowship.
2,4	EP/P027814/1 - Rational design of manufacturing processes for next generation optoelectronically active nanocomposite films and coatings	Our research aims to develop plastic films or coatings that change the colour and other characteristics of the light that passes through them, not by absorbing certain wavelengths of light, as a simple colour filter would, but by converting light of one wavelength to another without losing any energy. Solar cells offer an example of why this would be useful: conventional silicon solar cells are more efficient at collecting the energy of red light than they are of blue light. So if we coated the solar cell with a film that would convert every blue photon into two red photons, without losing any energy in the process, in principle we could make the silicon solar cells 30% more efficient. By the end of the project, we aim to be able to work with solar cell manufacturers to test our idea in the real world and get to the point where a product can be commercialised. If we are successful, we'll have demonstrated that we can go from understanding the fundamental science of these optical and electronic effects in these new kinds of materials to make useful products that will benefit UK industry and help solve problems of climate change. Project partners Eight19 Ltd and Total SA
2,4	Bio-Inspired Approaches to Functional Nanostructured Materials	**Steven Armes, Professor of Polymer and Colloid Chemistry,** University of Sheffield and **Fiona Meldrum, Professor of Inorganic Chemistry,** University of Leeds This interdisciplinary research proposal has the potential for substantial impact across multiple EPSRC Priority Areas. In particular, Control of Self-Assembly is currently a signposted area within EPSRC's Physical sciences portfolio, and our combined scientific expertise clearly maps onto two subsets of this portfolio: Functional ceramics and inorganics and Polymer materials. Our proposal is also relevant to both Materials engineering-composites and Materials engineering-ceramics within EPSRC's Engineering portfolio. With EPSRC support, we have established a lead of 6-9 months over our international competitors (Nature Materials, October 2011). Our unique partnership integrates cutting-edge polymer science with state-of-the-art bio-inspired materials research. Follow-on funding is now sought, so that we can capitalise on this competitive advantage in order to establish the UK as world leaders in this emerging area. The medium-term (3-5 years) objective is to exploit our rational approach, elucidate fundamental design principles and hence

		generate a wide range of novel nanocomposite materials that combine functionality with hierarchical structure. Given increasing environmental concerns, such sustainable processing routes will become increasingly important. Moreover, Procter and Gamble and Unilever have strong commercial interest in the microencapsulation of organic actives. It is difficult to specify deliverables over 10-50 years, since these will ultimately depend on as-yet unknown physical properties. Nevertheless, this work programme offers enormous potential for the development of next-generation materials and could influence the production of important biomaterials, such as artificial bone and synthetic dental enamel.
3	Digitisation for Zero-Setup and Zero-Measurement Manufacturing (Di-Zero)	Ongoing 5-year Airbus / RAEng Research Chair Award (2017-22) focused on digitisation of skill-intensive manufacturing processes, such as wing manufacture and engine assembly. Outputs: Ongoing 5 PhDs, 2 postdocs, 1 MRes.
3	AMSCI Prog. grant on Simulation and Optimisation of flexible manufacturing systems (233554)	2 PhD studentships sponsored by Advanced Manufacturing Supply Chain Initiative, 3 year project with industry partner—Cosworth. Developed simulation model and optimisation method for flexible manufacturing system. By successful completion of this project, the productivity has improved by more than 25% within industry partner's manufacturing facility.
3	Innovate UK ErgoEye project with Cosworth and Flexeye (103549)	Ongoing 2 year project sponsored by Innovate UK. Deployed advanced sensors on the shop floor to collect both productivity data from machines and ergonomic data from operators. Target to digitalise the skill sets of operators, proved realtime feedback to improve the performance of manual operations. Managing the productivity and quality problems caused by human factors within a complex manufacturing system.
5	Circular4.0: Data Driven Intelligence for a Circular Economy (EP/R032041/1)	Ongoing 3-year EPSRC project will investigate how data from products in use can inform intelligent decisions surrounding the implementation of Circular Economy strategies.
3	Innovate UK Assertive Products project with GE and Global Robots (103554)	Ongoing 2 year project sponsored by Innovate UK. Focusing on low-cost automation on the shopfloor using intelligent sensorised products.
Teesside		
1,3 and 5	Connecting Capability Fund (THYME)	**T**eesside, **H**ull, **Y**ork - **M**obilising Bioeconomy KE: Producing high-value products from bio-based wastes & by-products Re-purposing industrial sites for bio-based manufacturing Increasing productivity, reducing waste and energy use, adding value to by-products, automating manufacturing processes, developing better products using industrial biotechnology and adapting feedstocks. Incorporating use of AI and gaming platforms to increase productivity and reduce waste, and bioeconomy supply chain development.

3	Innovate UK (Health and Life Sciences Round 2)	Measurement and Control of Acrylamide in Production Processes – Industry Partners ITS Ltd, KP Snacks and Rounton Coffee. £1.9m Machine learning and pharmaceutical production BBSRC
1, 3	Knowledge Transfer Partnerships	Examples include: 3D visualisation for decommissioning (Unasys Ltd), Safety-critical software for automated safety, process control and accountability processes (Applied Integration); Natural language processing and machine- and deep- learning tools applied to collated data (TeleWare); Re-manufacturing processes using low value waste streams to produce eco composite building material (Scott Bros); Safety and control critical system production through expressive language and automation of design and testing processes (Acume); AI-informed automated mass customisation techniques for flexible manufacture and high precision (Mersen); Ai and character recognition for collation, storage and search of data; bespoke business intelligence platform to support supply chain management and product development capabilities (Hodgson Sayers)
4	Various Research and Innovate UK awards	Nanomaterials for High Temperature Insulated Wires.
2	Royal Society Grant	Organic polymers: visible light-driven catalysts for fuel production.
3	DR-BOB (H2020)	Demand response programmes adapting to levels of energy production, consumption and storage using cloud-based management systems.
York		
5	H2020: Sustainability Transition Assessment and Research of Bio-based Products (Star ProBio)	"Sustainability Transition Assessment and Research of Bio-based Products" (STAR-ProBio) is a multi-disciplinary and multi-actor collaborative project encompassing the construction of a common framework for the development of regulations and standards, suitable for horizontal industrial application, to support the growth of and transition to a bio-based economy.
1 and 3	Bio-based Industries Joint Undertaking (BBI-JU): a partnership between the EU and the Bio-based Industries Consortium (BIC): RESOLVE	ReSolve sets out to replace two hazardous solvents – toluene and NMP (*N*-methyl-2-pyrrolidone) – with safer alternatives derived from non-food carbohydrates. These new solvents will omit parts of the molecular structure that cause toxicity. The new, safer solvents will have a wide range of applications; project ReSolve will also demonstrate their sustainability, low health impact and high application performance.
1	EPSRC Integrated Energy Efficient Microwave and Unique Fermentation Processes for Pilot Scale Production of High Value Chemicals from	To meet key climate change targets, while providing sustainable economic growth, the UK must develop a robust bioeconomy. This requires the valorisation of UK-specific and abundant waste lignocelluosic streams. This project aims to develop a pilot scale multi-product biorefinery by coupling these breakthroughs in low energy biomass treatment and unique fermentation to produce marketable compounds.

	Lignocellulosic Waste Funding (IBCat)	
1	EPSRC Platform Grant – Material Substitution	The materials substitution project aims to develop green routes from bio-based platform molecules to polymerisable monomers and then to develop a wide variety of polymers from these including polyalkenes, polyethers, polyesters, polycarbonates and polyurethanes.

Appendix 5: SCOPUS Citation Analysis Methodology and Results

a) Methodology

The Scopus abstract and citation database of peer-reviewed literature: scientific journals, books and conference proceedings was accessed through
https://www.scopus.com/search/form.uri?display=basic

Key words were identified from sector reports outlining the key challenges the chemical sub-sectors in Chapter 2 Table 2.5.

Where a / is shown in the key words this was replaced with OR e.g. Paints OR inks OR pigments. If no / is present spaces between words were replaced with AND.

- The search was limited to the years 2013-2017.
- The search was also limited to the areas of Chemistry, Materials Science and Chemical Engineering.
- In the case of looking at individual universities the search was also limited to the UK region only (although collaborations between UK and other universities are also identified in the search).
- FWCI was calculated based on average citations for the institution in comparison to the field generally.

Chemical manufacturing key words: • Water quality • New catalysts • Sustainable feedstocks • Clean synthesis • Alternative solvents • Green technologies • New enzymes • Green intermediates • Ethylene • New organics • New inorganics	Wider supply chain key words: • Lightweighting • Energy storage • Recyclability • Life cycle analysis • Low carbon technologies • Air quality • Biomass • Carbon capture and storage
Specialty chemicals key words: • Adhesives/sealants • Dyes • paints/inks/pigments • Specialised healthcare • Fragrances/flavours • Pharmaceutical intermediates • Surfactants • Fertilisers	Materials key words: • Advanced materials • Smart materials • Smart coatings
Polymers and plastics key words: • New composites • Biopolymers • Synthetic monomers • Polymerisation techniques • Polymers	Technical consultancies key words: • Digitisation • Big data • Artificial intelligence • Automation

b) Citation Analysis: Comparison Between UK Research Base and International Comparator Nations

Table A3.1 Papers and citations analysis for key word search on chemical sub-sectors key challenges

Sub sector	UK		USA		Netherlands		France		Denmark		Germany		China	
	Papers	Citations/ paper	Papers	Citations/ paper	Papers	Citations/ paper	Papers	Citations/ paper	Papers	Citations/ paper	Papers	Citations/ paper	Papers	Citations/ paper
Chemical Manufacturing	5314	13	22957	14	1846	15	6409	10	844	11	8511	11	42446	9
Speciality chemicals	4847	9	17214	9	1329	9	8794	8	609	9	6953	8	36748	9
Polymers and plastics	1449	11	5367	11	359	11	1714	9	161	8	2074	9	11660	9
Materials	1181	12	5081	11	320	10	941	11	82	10	1782	11	5775	13
Technical consultancies	809	6	3489	5	245	7	437	5	90	8	1145	5	2869	3
Wider supply chain	2901	12	13840	12	1048	15	2406	11	603	11	3664	12	21671	9

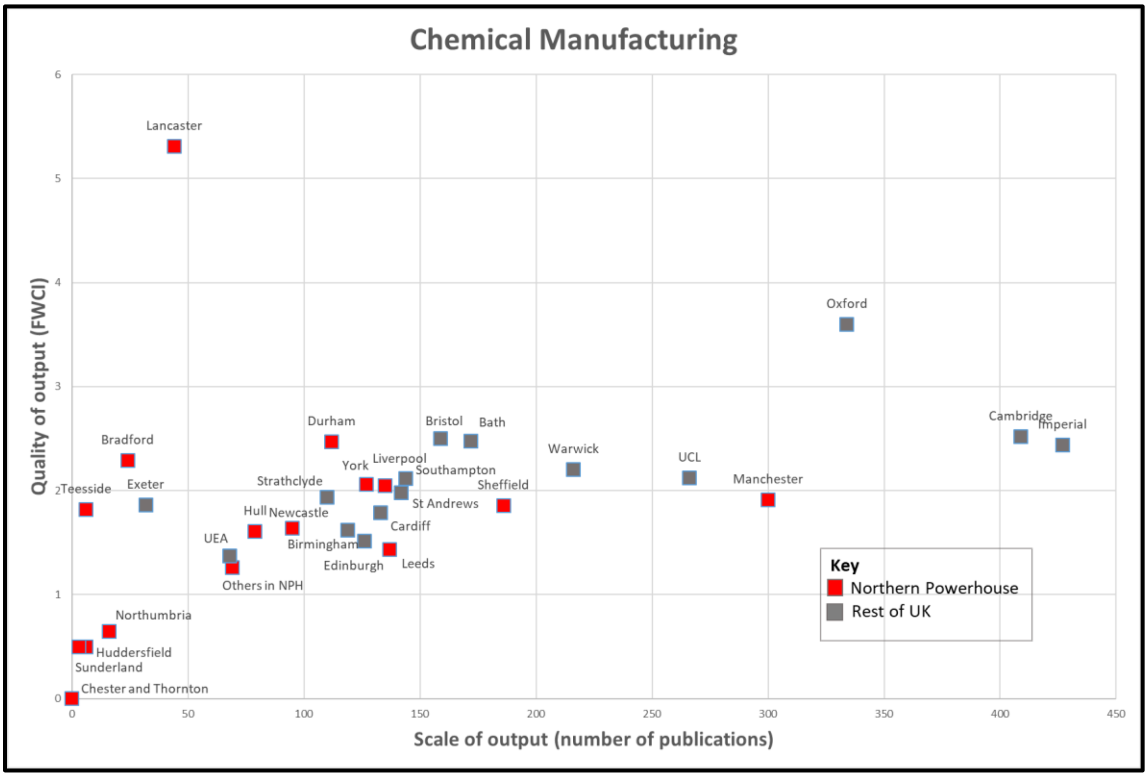
c) Citation Analysis: UK Comparison

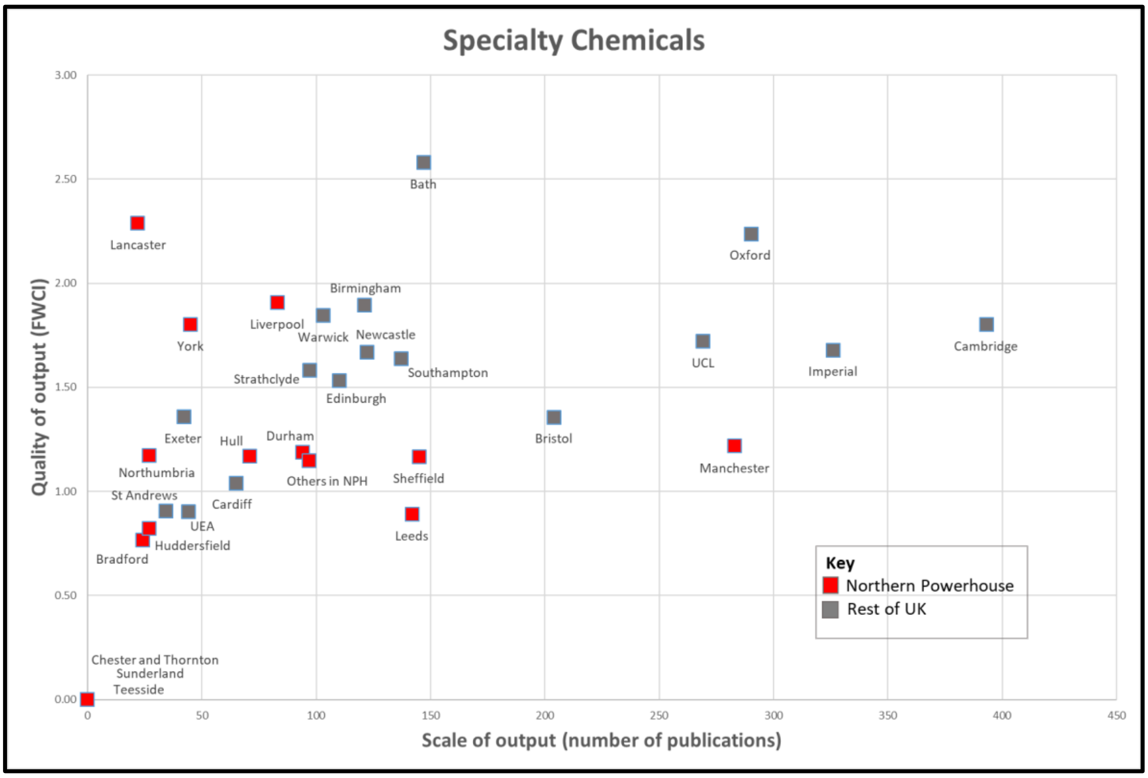
Table A3.2 Papers and Citations analysis for key word search on chemical sub-sectors key challenges

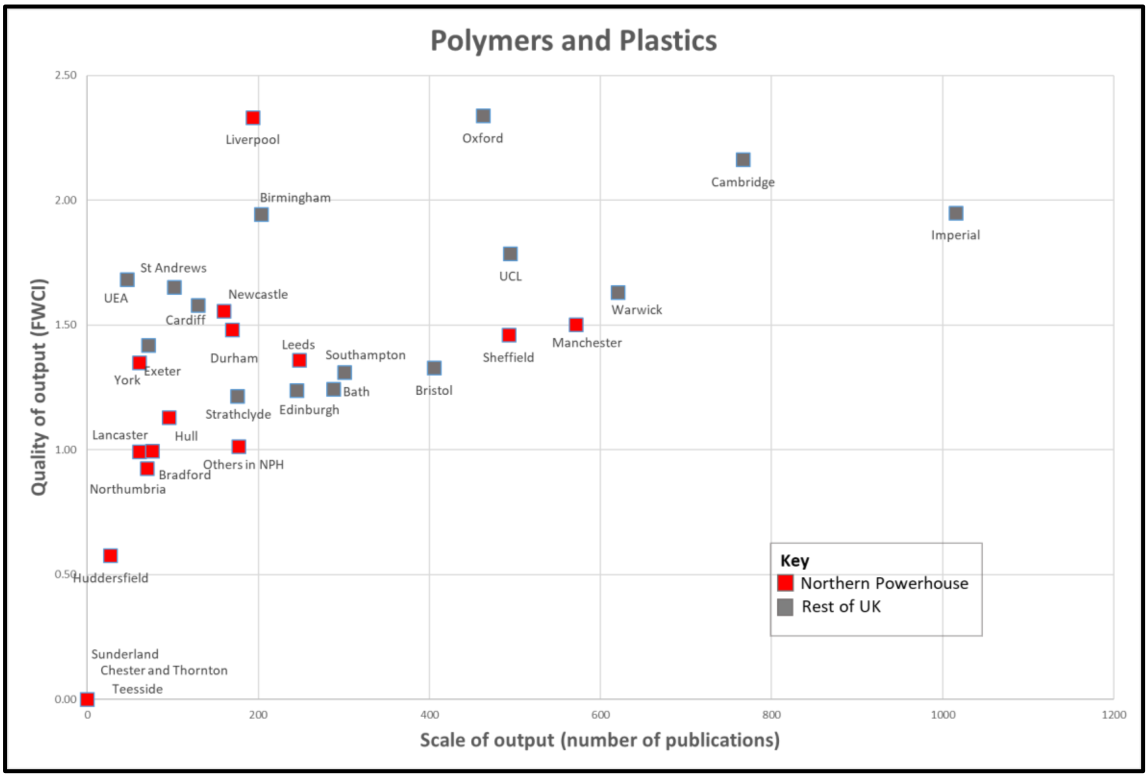
	Chemical Manufacturing		Specialty Chemicals		Polymers and Plastics		Materials		Technical Consultancies		Wider Supply Chain	
Institution	**Papers**	**FWCI**	**Papers**	**FWCI**	**Papers**	**FWCI**	**Papers**	**FWCI**	**Papers**	**FWCI**	**Papers**	**FWCI**
Durham	112	2.468017	94	1.186891	1702	1.478843	72	3.440107	214	11.0766	596	4.502756
Lancaster	44	5.312076	22	2.290024	410	0.992808	27	0.387012	2	0.241546	492	2.271524
Leeds	137	1.433707	142	0.890733	2279	1.357388	104	0.87689	92	2.564103	3248	3.232618
Liverpool	135	2.046434	83	1.907172	3061	2.330628	474	2.613158	64	2.318841	835	2.618577
Manchester	300	1.908458	283	1.217656	5816	1.501895	1053	1.985983	343	2.761675	2309	2.541568
Sheffield	186	1.853635	145	1.166221	4867	1.458229	631	2.206004	158	3.012967	416	0.987757
Newcastle	95	1.637078	122	1.670534	1684	1.554653	85	0.641248	90	3.26087	1051	2.531678
York	127	2.060172	45	1.802807	557	1.348766	204	2.924091	20	1.811594	1021	2.390134
N8 Research Partnership	**1136**	**2.793967**	**936**	**1.846581**	**20376**	**1.775954**	**2650**	**2.159669**	**983**	**9.800072**	**9968**	**3.501098**
Teesside	6	1.81592	0	0	0	0	0	0	0	0	0	0
Bradford	24	2.288557	24	0.767377	76	0.993159	8	0.877944	4	1.268116	4	2.119166
Chester and Thornton	0	0	0	0	0	0	0	0	0	0	0	0
Huddersfield	6	0.497512	27	0.823045	27	0.57443	0	0	7	1.138716	7	3.514135
Hull	79	1.607784	71	1.16835	96	1.12937	6	0.406124	3	1.207729	32	1.18424
Northumbria	16	0.643657	27	1.172558	70	0.924246	5	0.544684	5	3.115942	9	4.764661
Sunderland	3	0.497512	0	0	0	0	0	0	0	0	0	0
Others in NPH	69	1.258923	97	1.147045	177	1.012276	26	0.595403	9	0.885668	28	2.018253
Cambridge	409	2.517243	393	1.803246	767	2.161734	94	3.412659	52	4.919175	245	2.039962
Oxford	334	3.59773	290	2.239017	463	2.337526	48	2.150067	36	3.502415	125	3.348116
Bristol	159	2.500704	204	1.358671	406	1.326484	52	1.182537	29	2.411294	46	1.969217
UCL	266	2.119291	269	1.721806	495	1.784164	55	1.240523	50	1.398551	150	2.59397
Imperial	427	2.435597	326	1.680814	1016	1.948441	81	1.787298	43	3.201887	279	1.590603
Warwick	216	2.19942	103	1.845695	621	1.628621	36	3.252972	13	1.365663	63	1.954936
Cardiff	133	1.787678	65	1.039691	130	1.57823	8	0.734606	8	0.905797	46	1.727129
UEA	68	1.374012	44	0.902864	47	1.681385	4	1.110868	3	1.086957	40	1.583142
Southampton	144	2.117537	137	1.639836	301	1.309765	55	0.985122	23	2.772527	71	1.788504
Edinburgh	126	1.515044	110	1.534523	245	1.235945	19	1.62198	20	2.518116	63	1.852044
Birmingham	119	1.620469	121	1.895669	204	1.942683	39	2.712392	11	4.578393	119	1.532197
Strathclyde	110	1.934871	97	1.584836	176	1.213576	14	0.665497	13	2.146042	31	1.211718
St Andrews	142	1.98024	34	0.908765	102	1.649434	11	3.544353	6	3.26087	33	3.314109
Bath	172	2.475703	147	2.581306	288	1.24323	42	0.979475	11	0.889328	78	2.354629
Exeter	32	1.861007	42	1.358991	72	1.41761	11	2.56705	11	2.73386	44	3.301517

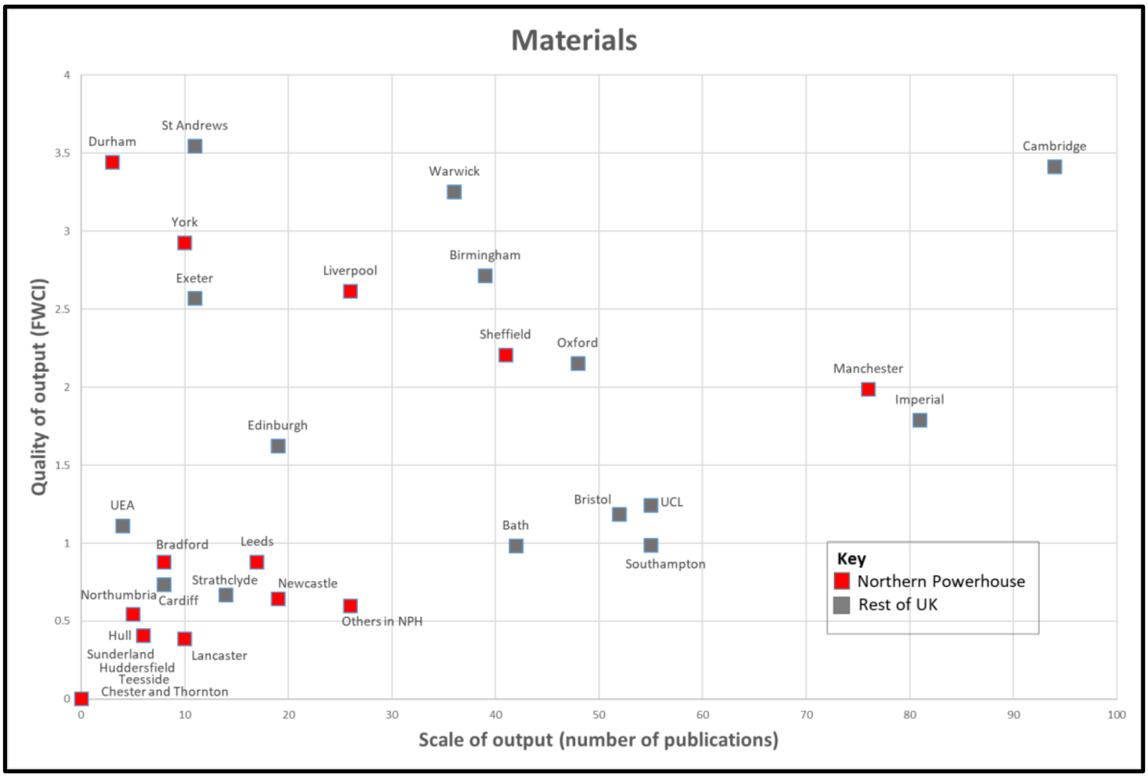
Research output versus research quality for chemical and process sector key challenges.

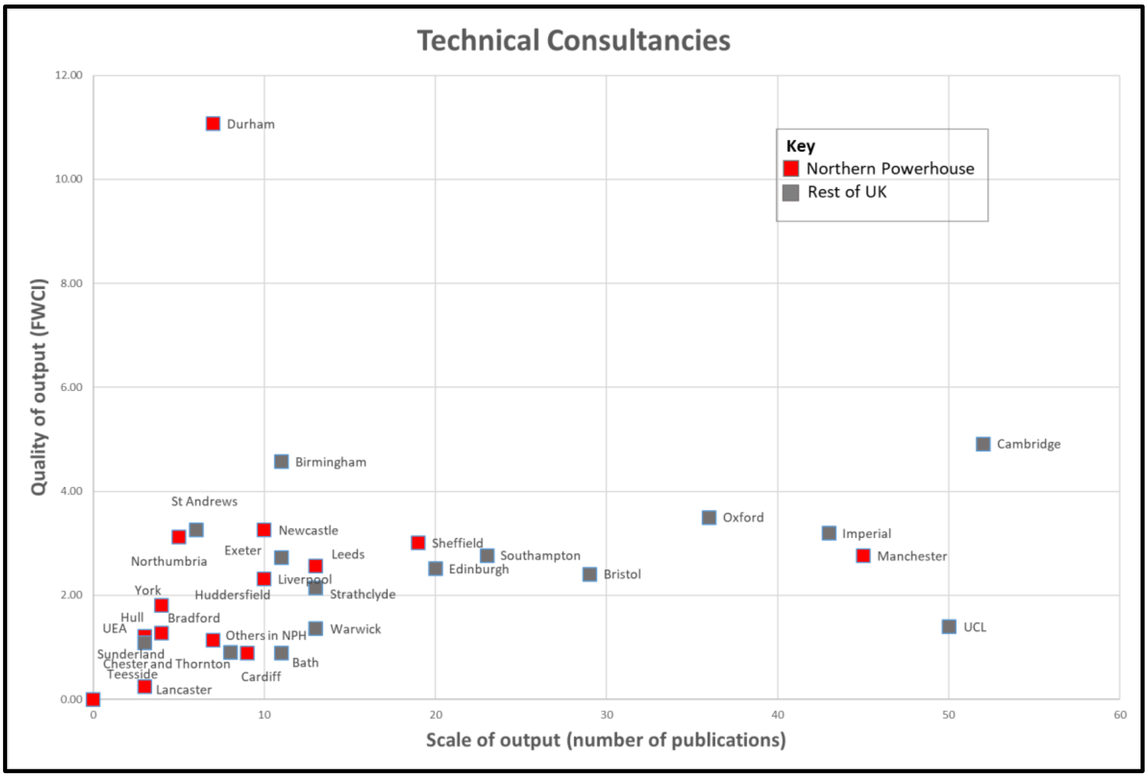
Analysed key words in publications 2013-2017 across the 6 key sub-sectors (Northern Powerhouse institutions highlighted in red).

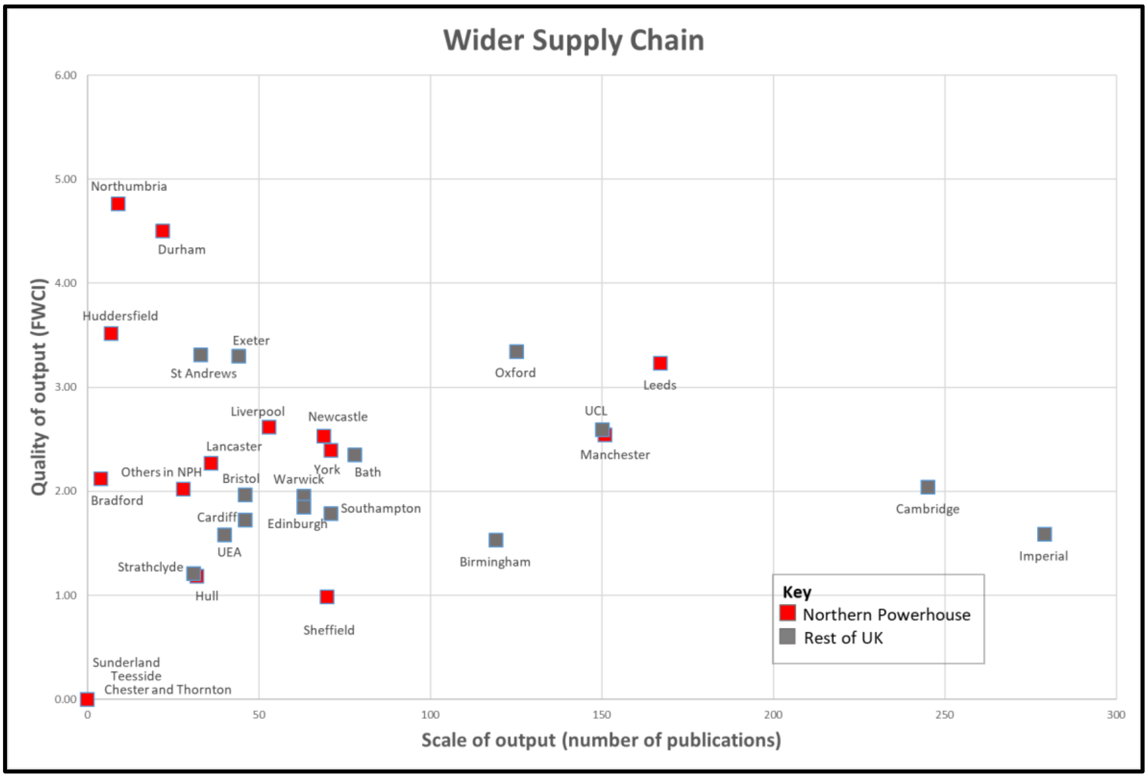





Polymers and Plastics
Quality of output (FWCI)
Scale of output (number of publications)
Liverpool
Oxford
Cambridge
Birmingham
Imperial
UCL
St Andrews
UEA
Newcastle
Cardiff
Warwick
Manchester
Leeds
Sheffield
Durham
Southampton
York
Exeter
Bath
Bristol
Edinburgh
Strathclyde
Lancaster
Hull
Others in NPH
Bradford
Northumbria
Huddersfield
Sunderland
Chester and Thornton
Teesside
Key
Northern Powerhouse
Rest of UK


Materials
Quality of output (FWCI)
Scale of output (number of publications)
St Andrews
Durham
Cambridge
Warwick
York
Birmingham
Exeter
Liverpool
Sheffield
Oxford
Manchester
Imperial
Edinburgh
UEA
Bristol
UCL
Bath
Bradford
Leeds
Southampton
Strathclyde
Newcastle
Northumbria
Cardiff
Others in NPH
Hull
Sunderland
Lancaster
Huddersfield
Teesside
Chester and Thornton
Key
Northern Powerhouse
Rest of UK


Technical Consultancies
Key
Northern Powerhouse
Rest of UK
Quality of output (FWCI)
Scale of output (number of publications)
Durham
Cambridge
Birmingham
St Andrews
Oxford
Newcastle
Imperial
Sheffield
Exeter
Leeds
Southampton
Manchester
Northumbria
Edinburgh
Bristol
Liverpool
York
Huddersfield
Strathclyde
Hull
Bradford
UEA
Others in NPH
Warwick
UCL
Sunderland
Chester and Thornton
Bath
Teesside
Cardiff
Lancaster
0.00
2.00
4.00
6.00
8.00
10.00
12.00
0
10
20
30
40
50
60


Wider Supply Chain
Quality of output (FWCI)
Scale of output (number of publications)
Northumbria
Durham
Huddersfield
Exeter
St Andrews
Oxford
Leeds
Liverpool
Newcastle
UCL
Lancaster
Manchester
York
Bath
Others in NPH
Bristol
Warwick
Bradford
Southampton
Cambridge
Cardiff
Edinburgh
UEA
Birmingham
Imperial
Strathclyde
Hull
Sheffield
Key
Northern Powerhouse
Rest of UK
Sunderland
Teesside
Chester and Thornton
0.00
1.00
2.00
3.00
4.00
5.00
6.00
0
50
100
150
200
250
300

Appendix 6: Research Spend Data Methodologies

a) ONS Data Methodology

ONS UK business enterprise research and development 2016, release date 21 November 2017 data accessed through https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/datasets/ukbusinessenterpriseresearchanddevelopment

Table 17 breaks R&D spend down by region and sector. Data from across the UK analysed for the chemical manufacturing sector.

17 **EXPENDITURE ON R&D PERFORMED IN UK BUSINESSES BY COUNTRY OR REGION: BROAD PRODUCT GROUPS, 2016**

Return to Main Menu

£ million

	TOTAL UK	England	North East	North West	Yorkshire and the Humber	East Midlands	West Midlands	East of England	London	South East	South West	Wales	Scotland	Northern Ireland
Area Code	K02000001	E92000001	E12000001	E12000002	E12000003	E12000004	E12000005	E12000006	E12000007	E12000008	E12000009	W92000004	S92000003	N92000002
TOTAL	**22,224**	**20,238**	**302**	**2,346**	**750**	**1,655**	**2,303**	**4,393**	**2,296**	**4,693**	**1,500**	**435**	**1,072**	**481**
Manufacturing: Total	**15,416**	**14,179**	**202**	**2,000**	**550**	**1,455**	**1,970**	**3,302**	**412**	**3,136**	**1,152**	**361**	**592**	**284**
Chemicals	**5,142**	**4,871**	98	698	232	155	35	1,771	253	1,575	54	58	167	47
Mechanical engineering	**1,022**	**914**	40	32	43	50	116	328	9	213	83	30	39	40
Electrical machinery	**1,592**	**1,298**	15	50	60	35	57	361	71	348	301	43	212	37
Transport	**3,775**	**3,702**	17	..	..	..	1,512	571	9	360	59	41	..	..
Aerospace	**1,905**	**1,700**	4	..	..	..	102	28	13	214	531	116	..	..
Other manufacturing	**1,981**	**1,693**	28	322	161	184	148	242	57	427	124	73	148	66
Services	**6,124**	**5,502**	**92**	**294**	**177**	**166**	**299**	**1,038**	**1,819**	**1,308**	**309**	**68**	**366**	**187**
Other: Total	**684**	**556**	**7**	**52**	**23**	**34**	**34**	**53**	**65**	**248**	**40**	**6**	**114**	**9**
Agriculture, hunting & forestry; Fishing	**132**	**123**	..	-	..	..	..	2	..	..	..	..	8	..
Extractive industries	**186**	**115**	-	-	2	..	..	..	..	..	..	1	67	3
Electricity, gas & water supply; Waste management	**156**	**130**	..	32	..	7	7	..	22	31	20	..	22	..
Construction	**211**	**187**	3	19	15	17	22	31	29	49	2	3	18	4

Source: Office for National Statistics

1 - denotes nil, figures unavailable or too small to display.
2 .. denotes disclosive figures.
3 Differences may occur between totals and the sum of their independently rounded components.
4 See list for detailed breakdown of broad product groups

b) Bureau van Dijk Orbis Data Methodology

The Bureau Van Dijk Orbis database **[8]** was analysed for companies which had declared R&D spend:

Data accessed 09/03/18, Data search was based on:

- Companies based in the UK
- Had declared R&D expenses in the last 5 years
- Had SIC codes within the defined chemical sector areas (defined in EMSI searches in Appendix 10 **[9]** also)
- SIC codes were manually assigned to sub-sectors as defined with the EMSI data
- Data broken down as: spend by region, spend by sector over the UK and spend by sector within each NUTS 1 region of the UK

c) Beauhurst

The Beauhurst searchable database **[10]** was accessed.

d) Innovate UK Funding Methodology

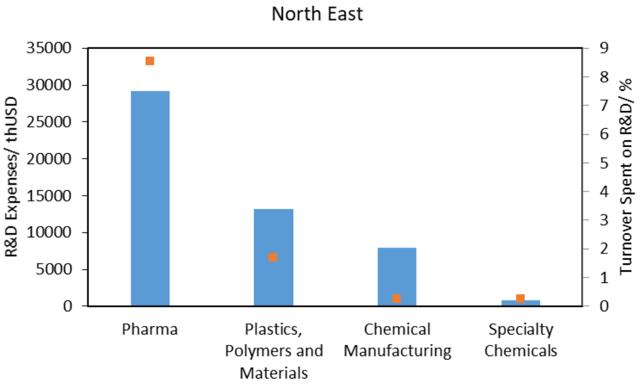
- Data accessed through https://www.gov.uk/government/publications/innovate-uk-funded-projects
- Data has been separated by region based on NUTS 1 codes, some companies did not display this information so were not included in the summary plots etc.
- The defined relevant sectors were Emerging and Enabling Technologies and Materials and Manufacturing.

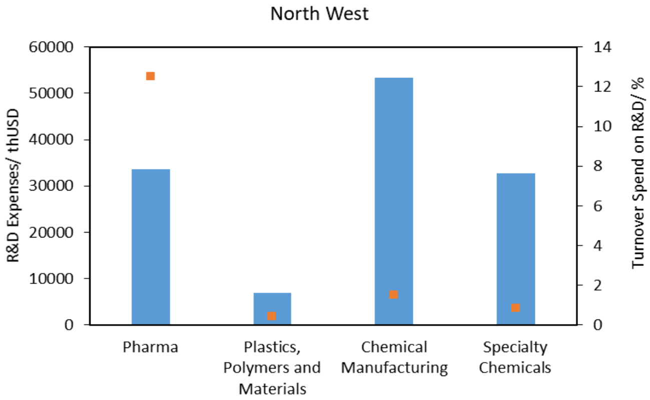
- Have looked at the distribution of funding across different enterprise sizes within the relevant sectors across the different regions in the UK.

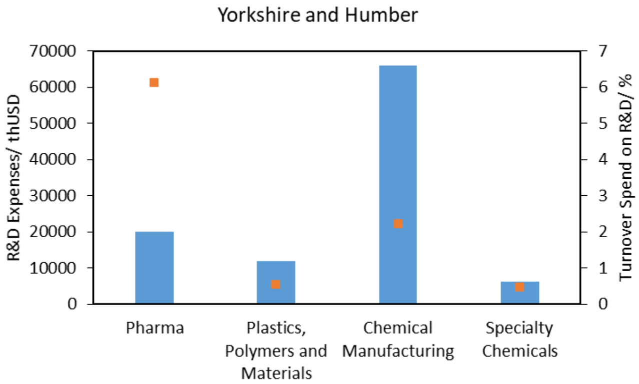
e) KTP Data

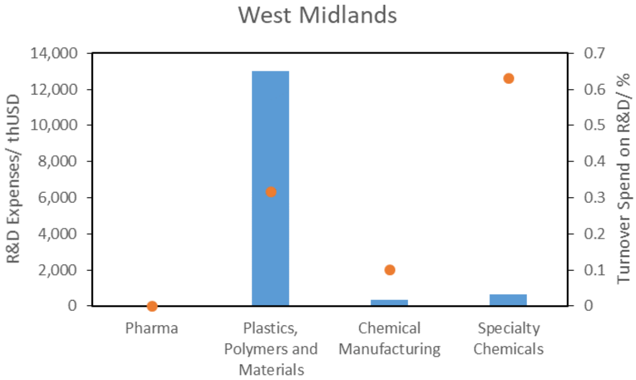
- Data sourced through https://info.ktponline.org.uk/action/search/current.aspx https://info.ktponline.org.uk/action/search/current.aspx
- Searches were undertaken in 3 sectors: Chemical sciences, advanced materials and nanotechnology.
- Company data was based on their defined region in the search database.
- University regions were allocated manually by the name of the university.

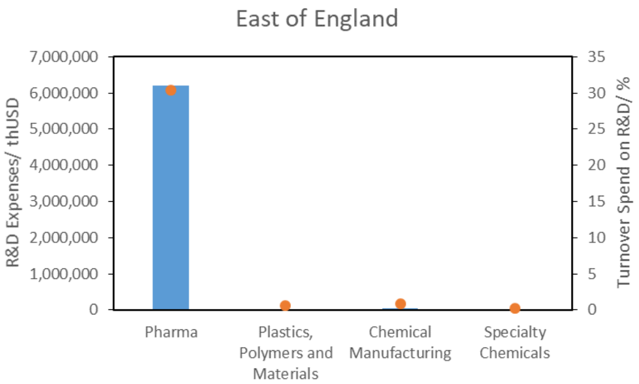
Appendix 7: Orbis Company Annual Accounts Research Spend Data

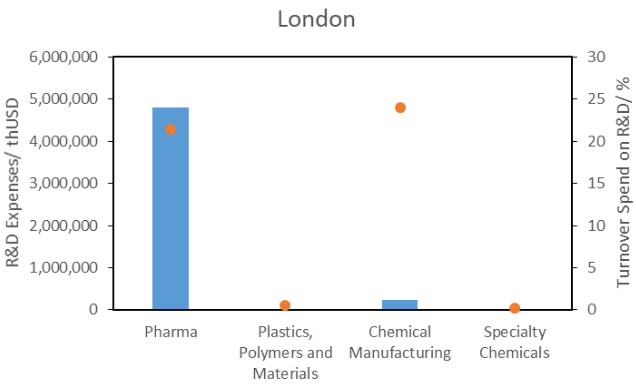


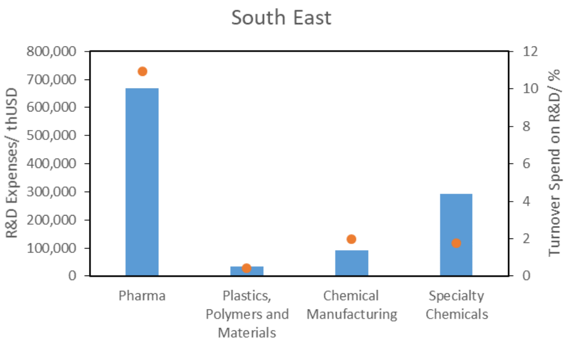


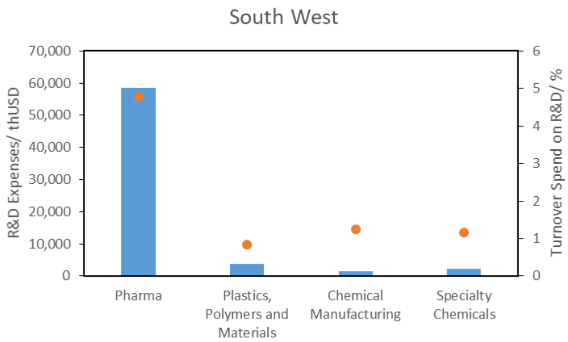


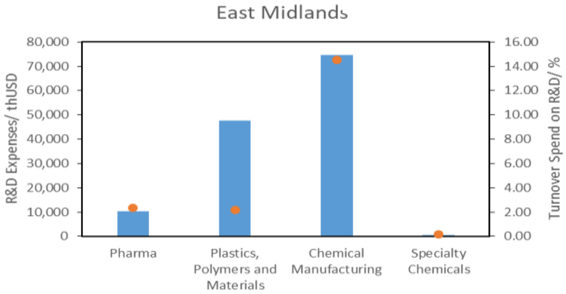










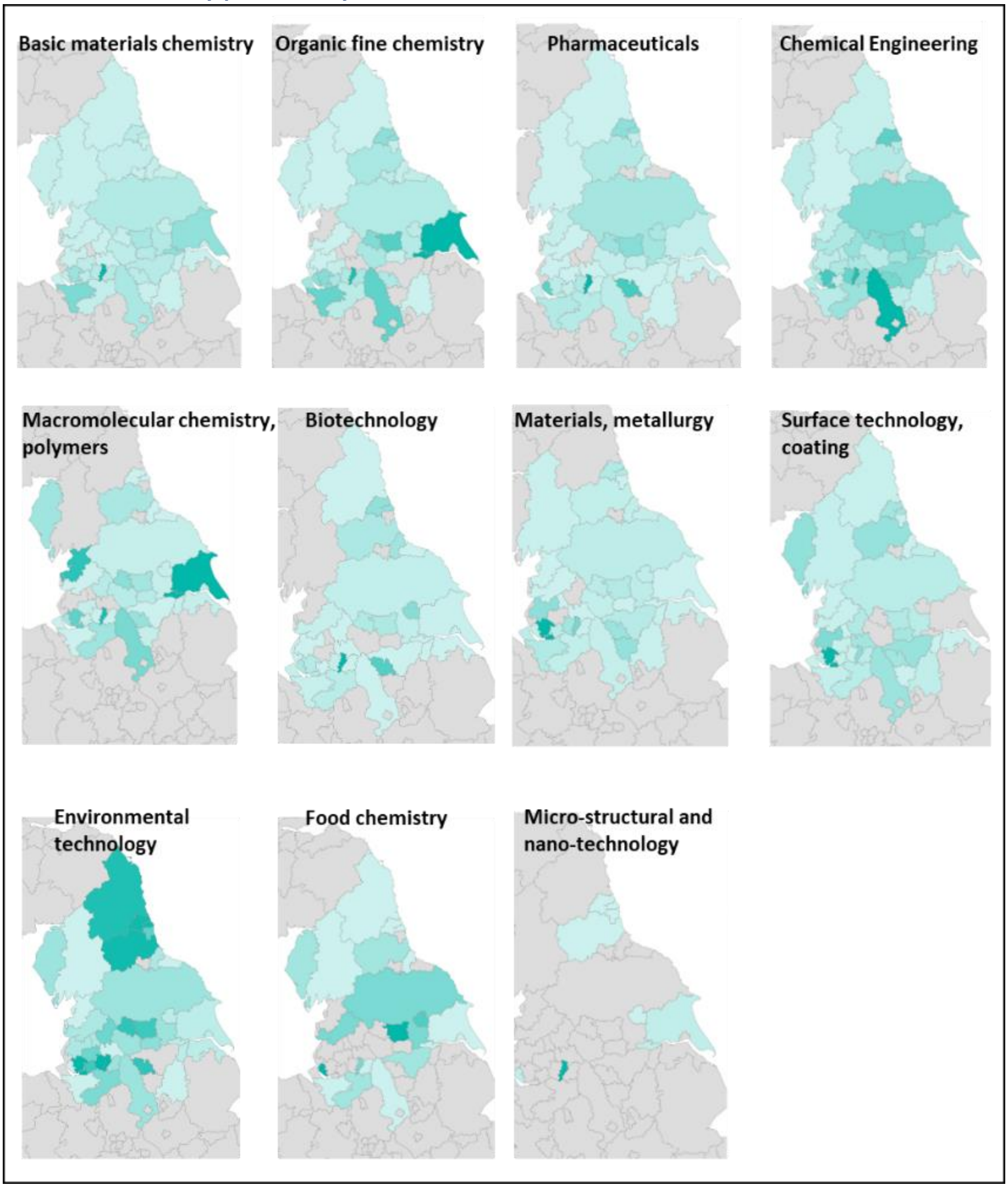


Appendix 8: Methodology and Patent Data Heat Maps for Key Chemical and Process Sector Technology Areas

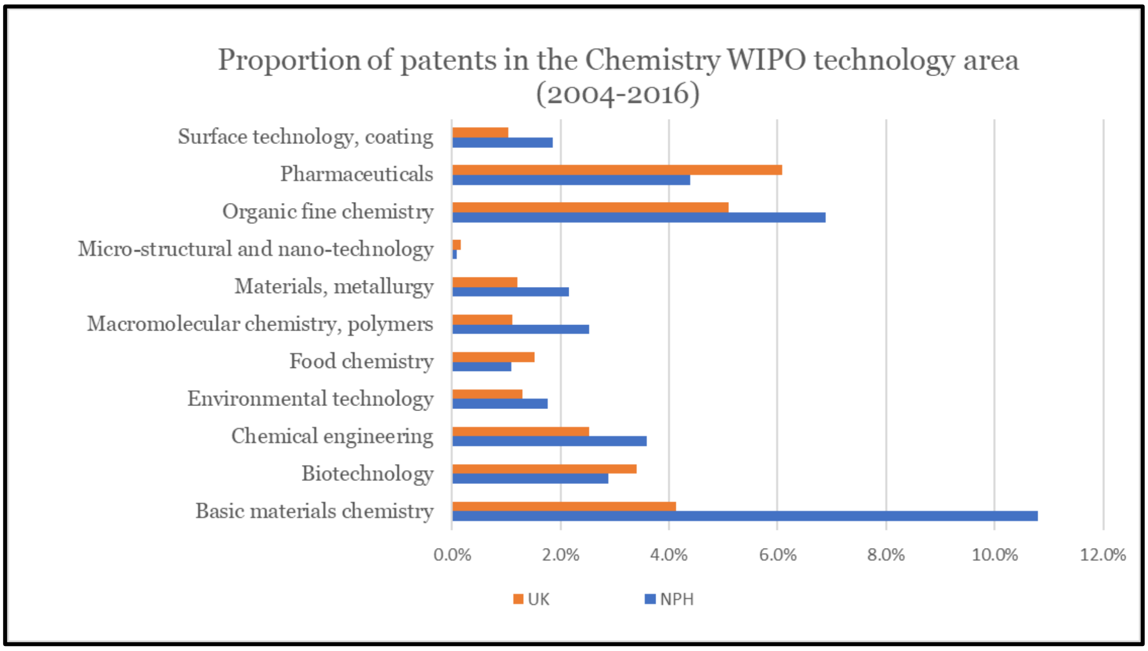
Data was accessed through the Technopolis core data portal and was based on core data provided by the EPO - PATSTAT. Worldwide Patent Statistical Database (spring 2017 version) **[11]**:

Methodological notes: 1) Since patents can be allocated to more than one WIPO technology area we have applied fractional counting to arrive to calculations that add up to the total number of (geo-located) patents (i.e. if a patent is allocated to N areas we assigned a weight of 1/N to each of them). 2) Geo-located patent information exists only for a small subset of patents (13.76%) where there is complete address information of applications and inventors, assuming that geo-located patents are randomly distributed, we give grossed estimates. 3) Patent application data has long time lags to publication in international databases, consider data for years up to 2013 to be complete (this is why we present data from 2004 onwards instead of 2007 onwards, to provide a 10-year window of reasonably complete data).

a) **Geo-location by patent subject area**



b) Patents within the Chemistry WIPO technology area (2004-2016) for UK and NPH



Northern Powerhouse SIA			United Kingdom	
Row Labels	**Percentage**		**Row Labels**	**Percentage**
Chemistry	**38.0%**		**Chemistry**	**27.6%**
Basic materials chemistry	10.8%		Basic materials chemistry	4.1%
Biotechnology	2.9%		Biotechnology	3.4%
Chemical engineering	3.6%		Chemical engineering	2.5%
Environmental technology	1.8%		Environmental technology	1.3%
Food chemistry	1.1%		Food chemistry	1.5%
Macromolecular chemistry, polymers	2.5%		Macromolecular chemistry, polymers	1.1%
Materials, metallurgy	2.1%		Materials, metallurgy	1.2%
Micro-structural and nano-technology	0.1%		Micro-structural and nano-technology	0.2%
Organic fine chemistry	6.9%		Organic fine chemistry	5.1%
Pharmaceuticals	4.4%		Pharmaceuticals	6.1%
Surface technology, coating	1.9%		Surface technology, coating	1.0%
Electrical engineering	**14.1%**		**Electrical engineering**	**26.7%**
Audio-visual technology	1.3%		Audio-visual technology	2.4%
Basic communication processes	0.2%		Basic communication processes	1.0%
Computer technology	2.4%		Computer technology	6.0%
Digital communication	1.2%		Digital communication	7.0%
Electrical machinery, apparatus, energy	6.3%		Electrical machinery, apparatus, energy	4.8%
IT methods for management	0.8%		IT methods for management	1.2%
Semiconductors	1.0%		Semiconductors	1.6%
Telecommunications	0.8%		Telecommunications	2.8%
Instruments	**15.6%**		**Instruments**	**17.2%**
Analysis of biological materials	1.1%		Analysis of biological materials	1.6%
Control	1.7%		Control	1.8%
Measurement	3.6%		Measurement	5.5%
Medical technology	8.4%		Medical technology	6.7%
Optics	0.8%		Optics	1.7%
Mechanical engineering	**23.4%**		**Mechanical engineering**	**20.1%**
Engines, pumps, turbines	3.9%		Engines, pumps, turbines	4.2%
Handling	3.5%		Handling	2.9%
Machine tools	2.5%		Machine tools	1.6%
Mechanical elements	3.5%		Mechanical elements	2.9%
Other special machines	3.4%		Other special machines	2.4%
Textile and paper machines	2.6%		Textile and paper machines	1.2%
Thermal processes and apparatus	1.0%		Thermal processes and apparatus	1.1%
Transport	3.0%		Transport	3.8%
Other fields	**8.9%**		**Other fields**	**8.3%**
Civil engineering	4.3%		Civil engineering	3.9%
Furniture, games	2.1%		Furniture, games	2.3%
Other consumer goods	2.5%		Other consumer goods	2.2%
Grand Total	100.0%		Grand Total	100.0%

Appendix 9: Innovation Base: National Innovation Centres

National Innovation Centres	
CPI	CPI is the process arm of the High Value Manufacturing Catapult (HVMC), focussing on technologies that are critical for the future of manufacturing, such as healthcare, materials and clean growth. Working with CPI gives companies access to its national innovation centres, which provide state-of-the-art laboratories for RD&I, process development and scale-up work. CPI currently has five National innovation centres in the North East region supporting formulation, printable electronics, graphene applications , biologics and industrial biotechnology and biorefining. It is also establishing a new National Centre for Healthcare Photonics with the help of Northeast Local Enterprise Partnership (NELEP). CPI works to reduce the risks associated with innovation for universities, SMEs and large corporates in the North East, helping to increase local productivity and economic growth. Since its inception 14 years ago, CPI has participated in the delivery of 964 projects, worth over £400m. In 2017, it had 605 engagements with SMEs, ran 171 RD&I projects, and worked with SMEs on CR&D projects worth £17.5m. Recent partnerships have helped to develop bioplastics, powder processes, engineered surfaces, advanced processing techniques and coatings for fuel cells, amongst many others. CPI also hosts the Knowledge Centre for Materials Chemistry, an innovation broker spread across UK universities that advances collaborations in the advanced materials and materials chemistry industries.
TWI	TWI is a world leading, not for profit independent research and technology organisation, established in 1946 it has over 850 staff and research centres in Cambridge, Middlesbrough, Rotherham and Port Talbot, as well as training facilities internationally. TWI is owned by its 700 industrial member companies, these represent over 4,500 different business locations globally and cover most industrial sectors. 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.
Materials Processing Institute	The Redcar based Materials Processing Institute is a research and innovation centre, with a seventy year track record in the development and commercialisation of technologies in advanced materials, low carbon energy and the circular economy. The Institute works internationally with multinational companies in the steel and minerals industries and supports SME growth through its SME Technology Centre. The has globally significant capabilities and assets, particularly for upscaling and commercialisation of new metals and metal processing technologies, including digital and industry 4.0 It is internationally renowned for its expertise in challenging processes, particularly those involving high temperatures, hostile environments and high specification materials. Many processing technologies that are the global industry standard for these sectors were developed at the Institute.
Sir Henry Royce Institute of	The Sir Henry Royce Institute of Materials Research and Innovation represents a £235m UK Government investment in materials research and innovation. The

Materials Research and Innovation	new institute will encompass 9 key areas of materials research grouped into four themes - Energy, Engineering, Functional and Soft Materials. The Manchester research and innovation centre will be supported by satellite centres or 'spokes' at the founding partners, comprising the universities of Sheffield, Leeds, Liverpool, Cambridge, Oxford and Imperial College.

Appendix 10: Sectoral Bodies

Sectoral Bodies	
North East Process Industries Cluster	NEPIC is the industry led and industry focussed cluster organisation representing 750 members and working on behalf of the chemical using industries in the North East of England.
Chemicals NW	Chemicals NW is the industry led support organisation for the North West chemical sector, representing over 160 businesses.
HCF CATCH	CATCH is an industry led partnership with 47 core member organisations and over 200 through the supply chain, which supports the process, energy, engineering and renewable industries in the Humber region. CATCH also supports skills and competency for industry through its 10-acre site that includes an industry scale operational process plant.
YCF	YCF is a membership organisation for companies in the manufacturing and process industries. They currently have over 45 full members and a number of associate member organisations. They represent the Yorkshire region and also run two national cluster groups; one for the cosmetics sector and one for the chemical sector.
Chemistry Growth Partnership	The Chemistry Growth Partnership is a joint industry/government initiative, led by industry, created in order to drive the activities recommended by the chemicals sector's strategy for delivering chemistry-fuelled growth of the UK economy (launched in October 2013). The partnership's 13 members include senior representatives from Croda, Contract Chemicals, SABIC, P&G, INEOS, BASF, Synthomer, Johnson Matthey, Shott Trinova, Thomas Swan, and GSK, along with Ministerial representation from BEIS and representation from Unite.
First for Pharma	First for Pharma represents the pharmaceutical manufacturers in the North East of England where there are 13 large pharmaceutical manufacturing sites in the North East, employing 2,600 people. They generate one third of the UK's pharmaceutical manufacturing GDP and 95% of their high-value products are exported globally. The value of pharmaceutical exports (over £2bn) is the highest in the UK per capita and is only marginally less than that of the North East's automotive sector. The sector is supported by a supply chain that is estimated to have a turnover in excess of £0.5bn.

Appendix 11: TTE Case Study

TTE is a technical training company that focuses on business and people transformation providing accredited courses, bespoke training programmes, apprenticeships and training centre design, operation and management. Their services ensure employees are competent and assist companies with localisation and nationalisation targets. ISO 9001 & 14001 certified, with excellent UK facilities, residential options for overseas learners/delegates and 24 hour welfare support. TTE provides services in the UK and Internationally. Operating for over 28 years, they have a proven track record in the oil & gas, process, manufacturing, engineering and utility sectors.

TTE has delivered process training courses/programmes to a number of NE businesses including Quorn, Chemoxy and CF Fertilisers.

TTE International's profits are donated to its parent company 'TTE Technical Training Group', a registered charity, who use this to provide Apprenticeships to students in Electrical, Mechanical, Process, Laboratory and Fabrication & Welding disciplines. TTE have been involved with the North East SIAC Consortium for the last 4 years and delivered the only pilot training scheme in the UK for the Science Manufacturing Technician (SMT) Apprenticeship Standard.

Whilst at TTE the apprentices achieve the mandatory knowledge qualification as outlined in the standard, the Diploma in Process Technology. This qualification is achieved alongside a bespoke training programme which gives the apprentices the hands-on experience of plant operation, with a high focus on safety. More recently, TTE were successful in being awarded the 2017 SIAC North East Consortium Apprenticeship delivery. This included 7 Employers and a total of 19 Apprentices. 12 apprentices are following a multi-skilled Electrical / Instrumentation Apprenticeship on the Science Industry Maintenance Technician Standard. The remaining 7 apprentices are Process discipline on the Science Manufacturing Technician Standard. The bespoke programme was developed in agreement with the Consortium and regular reviews meetings take place. All of the apprentices are currently attending TTE full-time for 1 academic year in which time they will achieve the Level 3 Technical Qualification (BTEC for E/I and City & Guilds 0610 Level 3 for Process). They also attend Outward Bound for 1 week to complement the 'Behaviours' and learn practical skills and gain hands-on experience in our fully-equipped workshop. Some of the companies that currently employ one of the process apprentices are Sabic, Lotte, Venator, CPI and Sembcorp.

TTE also offer residential apprenticeships and have provided these programmes to companies such as British Sugar, Northumbrian Water and Centrica.

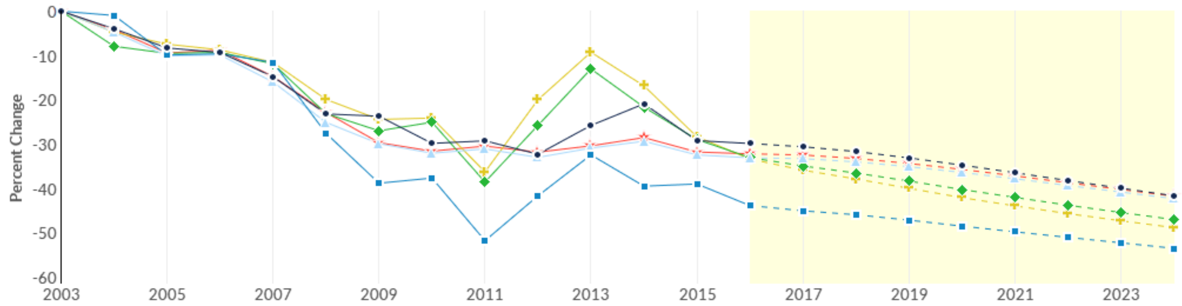
Appendix 12: Chemical Industry EMSI Overview - January 2018

Chemistry Industry EMSI Overview (January 2018) **[9]**. Chemical Industry definition includes ‘chemical manufacturing, speciality chemicals, pharmaceutical intermediaries, formulated performance products, polymers and plastics’. See Annex for detailed SIC code definition.

Northern Powerhouse area includes the North East, North West and Yorkshire and Humber regions.

94,733	-16.8%	£34,941
Jobs (2016)	% Change (2016-2024)	Avg. Wages Per Job (2016)
59% above National average	Nation: -14.1%	Nation: £32,869

Regional Trends



	Region	2016 Jobs	2024 Jobs	Change	% Change
●	Region	94,733	78,804	-15,929	-16.8%
●	Tees Valley	5,230	4,332	-898	-17.2%
●	England	229,057	197,530	-31,527	-13.8%
●	Tees Valley one hour drive time	16,087	12,727	-3,360	-20.9%
●	North East	16,404	12,593	-3,811	-23.2%
●	Nation	261,043	224,301	-36,742	-14.1%

- The employment base of the Chemical Industry in the Northern Powerhouse area is 59% above national average with over 94,730 people employed in the industry.
- Average wages stand at around £34,900
- The number of jobs in the sector is projected to fall by 16.8% compared to 14.1% nationally.
- Just under three quarters of the workforce is male and over half (57%) are aged under 45.
- 17% of the workforce is over the age of 55.

National Industry Gender Breakdown

Gender	2016 Jobs
Males	70.8%
Females	29.2%

National Industry Age Breakdown

Age	2016 Jobs
16-24	7.6%
25-34	24.6%
35-44	24.4%
45-54	26.9%
55-64	14.4%
65+	2.2%

Top Regional Businesses

Business Name	Industry Name
Ineos Chlor Ltd	Manufacture of other inorganic basic chemicals (2013)
Carclo Plc	Manufacture of builders' ware of plastic (2223)
Yorkshire Group Plc	Manufacture of dyes and pigments (2012)
Arran Isle Limited	Manufacture of plastic plates, sheets, tubes and profiles (2221)
Ineos Chlorvinyls Services Limited	Manufacture of other organic basic chemicals (2014)

Purchases from	In-region Purchases	Imported Purchases	Total Purchases
Manufacture of other organic basic chemicals	£841,101,474	£5,298,769	£846,400,242
Manufacture of plastics in primary forms	£679,517,358	£95,419,872	£774,937,230
Financial service activities, except insurance and pension funding	£171,049,162	£530,692,282	£701,741,444
Manufacture of other inorganic basic chemicals	£257,482,222	£0	£257,482,222
Retail sale in non-specialised stores with food, beverages or tobacco predominating	£101,712,383	£131,124,892	£232,837,275

Chemical Process Sector Detail

Description	2016 Jobs	2024 Jobs	2016 - 2024 Change	2016 - 2024 % Change	Avg. Wages Per Job	2016 Location Quotient
Manufacture of builders' ware of plastic	14,107	10,727	-3,380	-24%	£21,635	1.51
Manufacture of other plastic products	13,682	11,109	-2,573	-19%	£28,083	1.22
Manufacture of pharmaceutical preparations	11,576	9,650	-1,926	-17%	£42,397	1.85
Manufacture of plastic plates, sheets, tubes and profiles	8,495	6,700	-1,795	-21%	£28,603	1.46
Manufacture of plastic packing goods	6,580	5,045	-1,535	-23%	£31,990	1.32
Manufacture of paints, varnishes and similar coatings, printing ink and mastics	6,365	5,018	-1,347	-21%	£31,656	2.01
Manufacture of other organic basic chemicals	5,667	4,690	-977	-17%	£47,673	2.76
Manufacture of soap and detergents, cleaning and polishing preparations	4,943	5,002	59	1%	£42,841	1.97
Manufacture of other chemical products n.e.c.	4,922	4,607	-315	-6%	£46,525	1.81
Manufacture of plastics in primary forms	3,760	2,833	-927	-25%	£38,016	1.84
Manufacture of perfumes and toilet preparations	3,677	3,375	-302	-8%	£26,332	1.15
Manufacture of other inorganic basic chemicals	3,230	3,069	-161	-5%	£49,959	3.12
Manufacture of industrial gases	1,850	2,140	290	16%	£62,982	2.24
Manufacture of dyes and pigments	1,422	1,186	-236	-17%	£42,190	2.09
Manufacture of fertilisers and nitrogen compounds	1,359	1,211	-148	-11%	£40,747	2.97

Manufacture of pesticides and other agrochemical products	985	772	-213	-22%	£50,381	1.72
Manufacture of basic pharmaceutical products	725	439	-286	-39%	£41,241	0.59
Manufacture of glues	647	618	-29	-4%	£32,156	1.11
Manufacture of essential oils	546	502	-44	-8%	£42,992	1.06
Manufacture of man-made fibres	164	93	-71	-43%	£36,494	1.59
Manufacture of synthetic rubber in primary forms	22	11	-11	-50%	£44,815	0.62
Manufacture of explosives	<10	<10	Insf. Data	Insf. Data	Insf. Data	0.04

Top 10 occupations in Chemical Process by number employed

Description	2016 Jobs	Median Hourly Wages	Education Level
Production managers and directors in manufacturing	6,873	£20.17	Honours, Bachelor's degree
Chemical and related process operatives	6,462	£13.64	Level 2 NVQ; GCSE at grades A*-C
Plastics process operatives	6,202	£8.74	Level 2 NVQ; GCSE at grades A*-C
Sales accounts and business development managers	5,033	£19.32	Honours, Bachelor's degree
Elementary storage occupations	4,693	£8.77	Level 1 NVQ; GCSE at grades D-G
Glaziers, window fabricators and fitters	3,090	£8.87	Level 2 NVQ; GCSE at grades A*-C
Packers, bottlers, canners and fillers	2,919	£8.03	Level 1 NVQ; GCSE at grades D-G
Metal working production and maintenance fitters	2,422	£13.12	Level 3 NVQ; A Levels
Chemical scientists	2,389	£17.71	Honours, Bachelor's degree
Laboratory technicians	2,305	£9.85	Level 4 NVQ; Intermediate, DipHE, DipFE

Chemical Process occupations – largest projected fall in employment

Description	2016 Jobs	2024 Jobs	Change (2016 - 2024)	% Change (2016 - 2024)
Production managers and directors in manufacturing	6,873	5,881	-992	-14%
Elementary storage occupations	4,693	3,724	-969	-21%
Sales accounts and business development managers	5,033	4,132	-901	-18%
Plastics process operatives	6,202	5,452	-750	-12%
Glaziers, window fabricators and fitters	3,090	2,428	-662	-21%
Chemical and related process operatives	6,462	5,822	-640	-10%
Other administrative occupations n.e.c.	2,286	1,793	-493	-22%
Packers, bottlers, canners and fillers	2,919	2,438	-481	-16%
Book-keepers, payroll managers and wages clerks	1,522	1,166	-356	-23%
Metal working production and maintenance fitters	2,422	2,076	-346	-14%

Annex

Code	Description
2011	Manufacture of industrial gases
2012	Manufacture of dyes and pigments
2013	Manufacture of other inorganic basic chemicals
2014	Manufacture of other organic basic chemicals
2015	Manufacture of fertilisers and nitrogen compounds
2016	Manufacture of plastics in primary forms
2017	Manufacture of synthetic rubber in primary forms
2020	Manufacture of pesticides and other agrochemical products
2030	Manufacture of paints, varnishes and similar coatings, printing ink and mastics
2041	Manufacture of soap and detergents, cleaning and polishing preparations
2042	Manufacture of perfumes and toilet preparations
2051	Manufacture of explosives
2052	Manufacture of glues
2053	Manufacture of essential oils
2059	Manufacture of other chemical products n.e.c.
2060	Manufacture of man-made fibres
2110	Manufacture of basic pharmaceutical products
2120	Manufacture of pharmaceutical preparations
2221	Manufacture of plastic plates, sheets, tubes and profiles
2222	Manufacture of plastic packing goods
2223	Manufacture of builders’ ware of plastic
2229	Manufacture of other plastic products

Appendix 13: Business Characteristics of the UK Chemicals and Process Sector

the Bureau van Dijk ORBIS database **[8]** was utilised to identify a wide-ranging snapshot of the UK chemicals and process sector, based on 2016 and 2017 annual reports from Companies House. This identified 3,472 firms reporting data for turnover and employment figures. The sector was then divided by sub-sector, according to the registered SIC code. The analsys was undertaken on the UK sector as a whole rather than just within the Northernpowerhouse

Market Concentration

The top four (C4) and top seven (C7) largest firms within the chemicals and process sector as a whole were identified, then by sub-sector, in order to show concentration of ownership as a proxy for assessing maturity. See Table A13.1.

Table A13.1: The top 4 (C4) and top 7 (C7) Chemical and Process sector business data **[8]**.

(2016-17 Companies House report analysis)

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.		

Figures A13.1 to 4 summarise the relative turnovers reported for the C7 companies across the Chemical and polymers sector and three subsectors respectively.

Figure A13.1: C7 Companies Chemicals and Process Sector

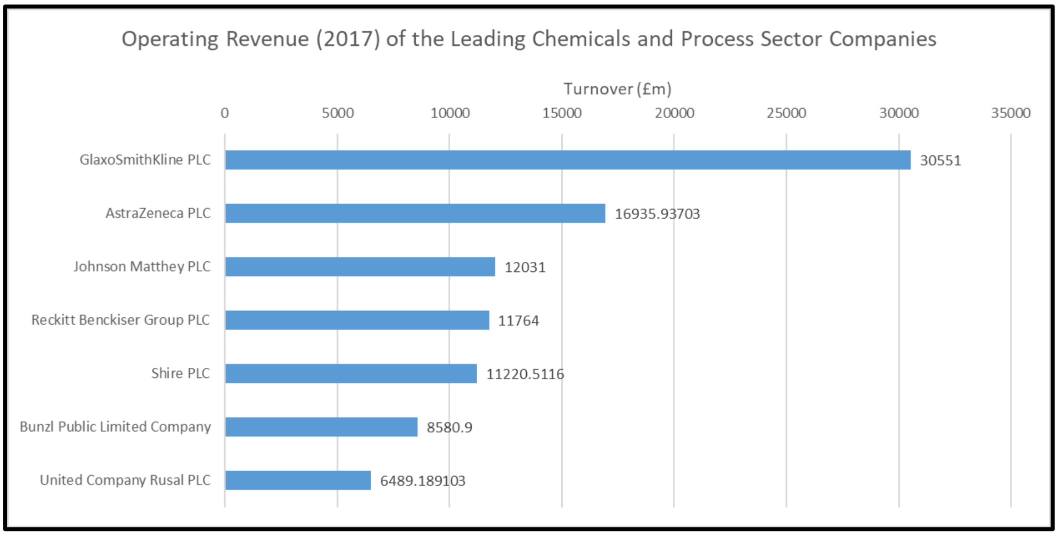


Figure A13.2: C7 Companies SIC 20 – Manufacture of chemicals and chemical products

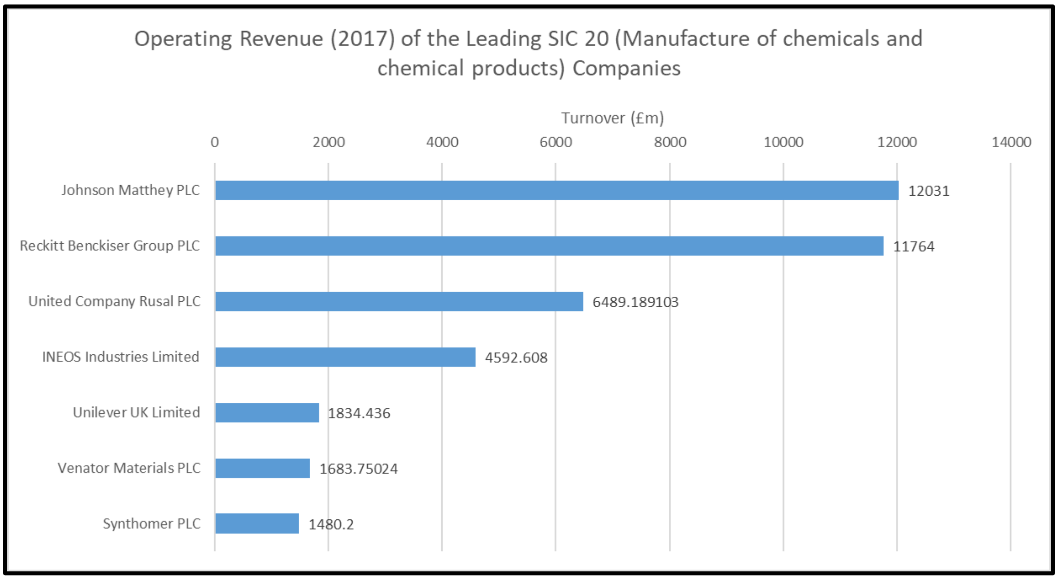


Figure A13.3: SIC 21 – Manufacture of basic pharmaceutical products/pharmaceutical preparations

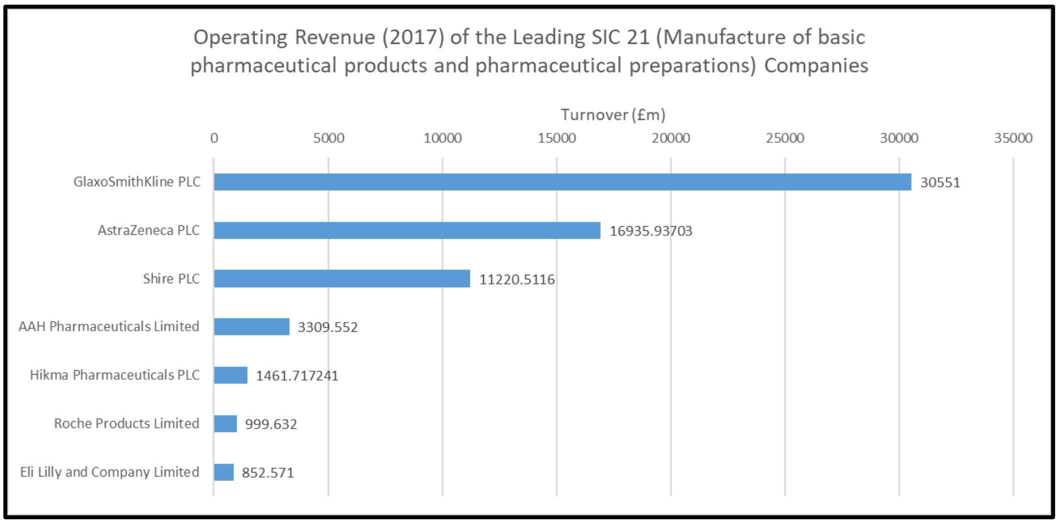
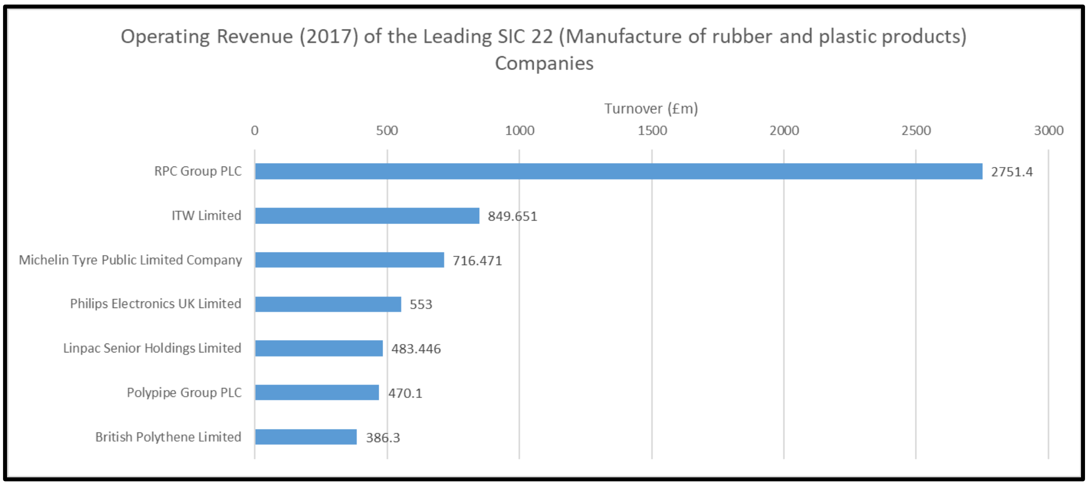


Figure A13.4: SIC 22 – Manufacture of rubber and plastic products



The market concentration in terms of turnover for the C4 and C7 firms of the chemicals and process sector are shown in Figure A13.5.

Figure A13.5: Market concentration of C4 and C7 companies in the chemicals and process sector [8]

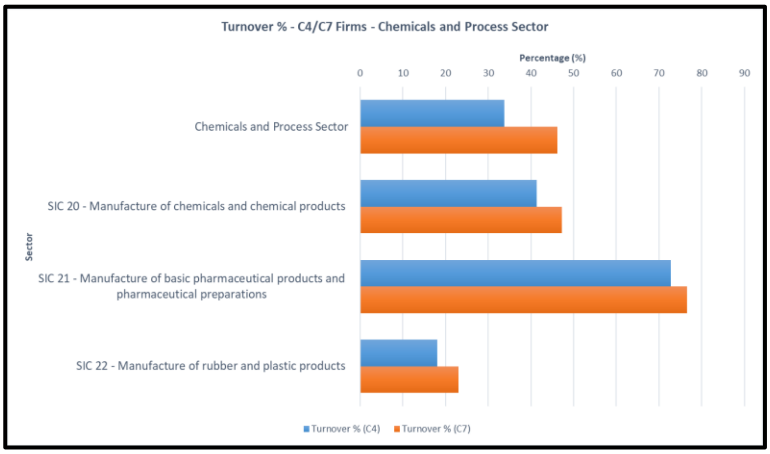
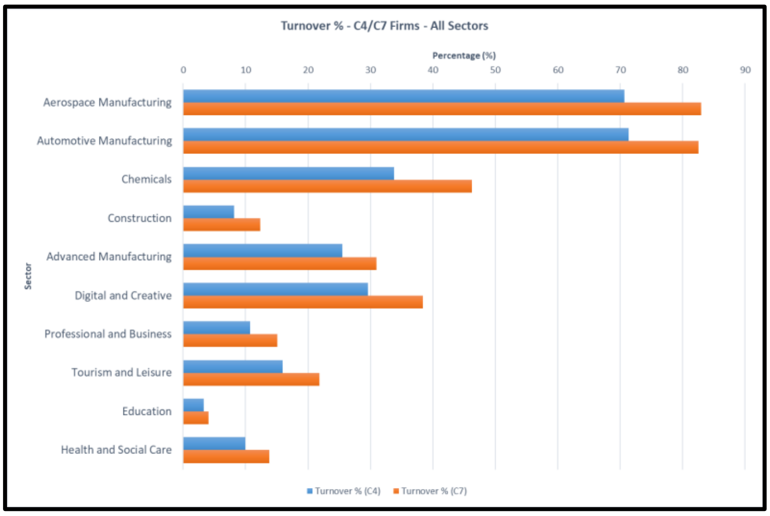


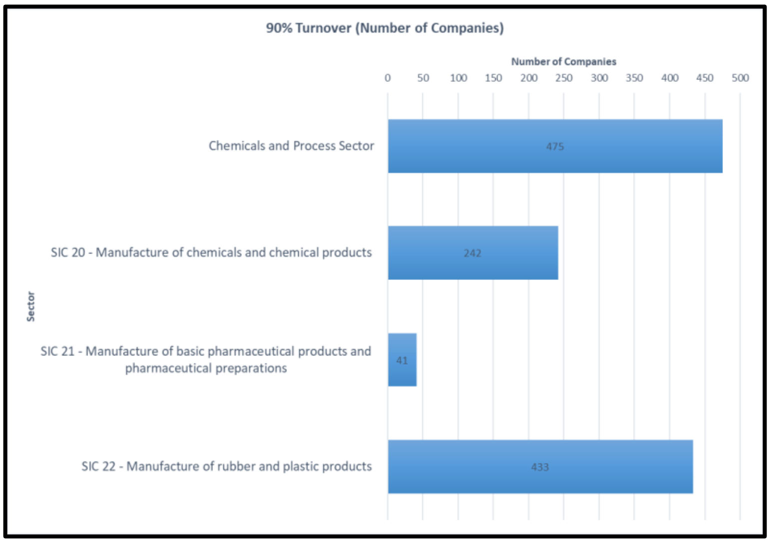
Figure A13.6 provides a comparison with other key sectors of the UK economy. Whilst the aerospace and automotive manufacturing sectors are more concentrated, clearly the chemicals and process sector is still very highly concentrated when compared to other industries.

Figure A13.6: Market concentration of C4 and C7 companies compared with other sectors [8]



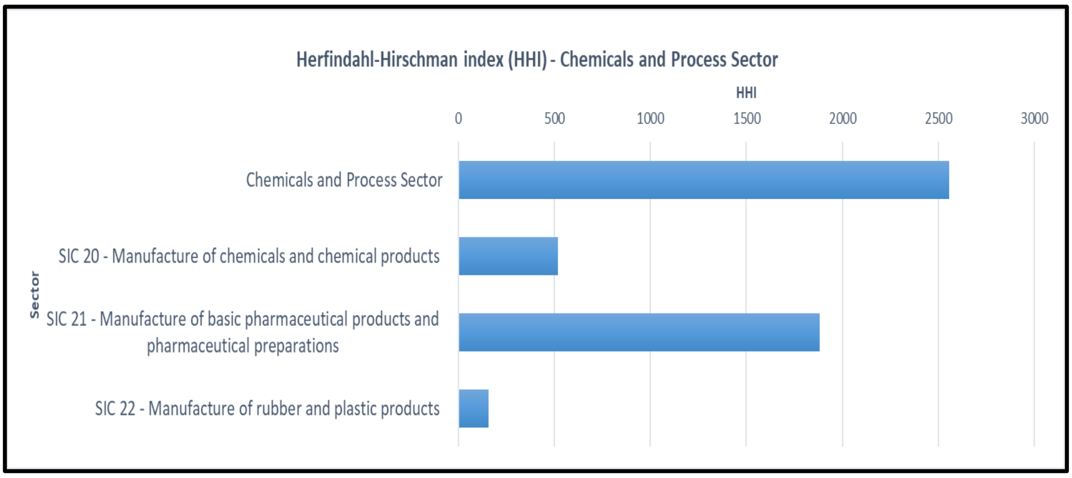
The number of firms accounting for 90% of turnover has been assessed as a further measure of market concentration The data is summarised in Figure A13.7. Across the chemical and processing sector, 475 firms account for 90% of total turnover. As a further measure of concentration, we see that, particularly with pharmaceuticals, relatively few firms account for 90% of turnover of the sub-sector. This compounds issues that have already been discussed.

Figure A13.7: Number of Companies accounting for 90% of Turnover [8]



The Herfindahl-Hirschman index (HHI) **[12]** is a commonly accepted measure of market concentration. The HHI takes into account the relative size distribution of the firms in a market. It approaches zero when a market is occupied by a large number of firms of relatively equal size and reaches its maximum of 10,000 points when a market is controlled by a single firm. Financial agencies generally consider markets in which the HHI is between 1,500 and 2,500 points to be moderately concentrated, and consider markets in which the HHI is in excess of 2,500 points to be highly concentrated. Figure A13.8 summarises the HHI indices across the UK chemicals and process sub-sectors. An HHI of 2557.08 indicates that the UK chemicals and process sector is highly concentrated. This is not particularly surprising, given the maturity and concentration we have presented earlier in this section.

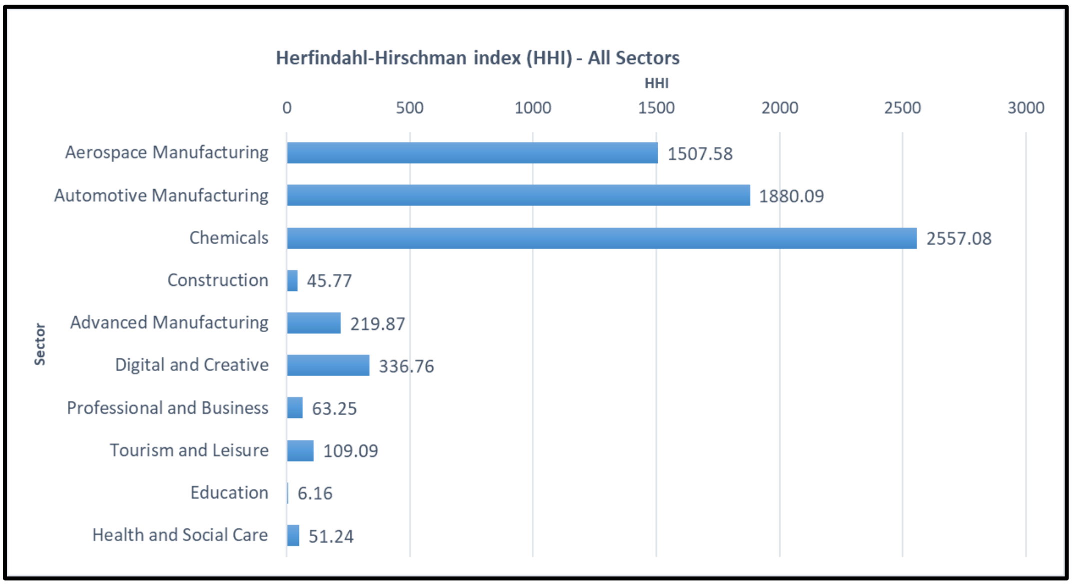
Figure A13.8: HHI for the chemicals and process sector and sub-sectors [8]



The higher the market concentration, the more towards a monopoly (price fixer rather than price taker) a market is likely to be. As expected, the sector is dominated by a small number of companies. 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 growth across the entire firm/sector but is concentrated in only select areas (highlighting the importance of place) and companies.

Figure A13.9 shows how this level of concentration compares with other key sectors of the UK economy. Clearly, the UK chemicals and process sector is very highly concentrated. The next section will look in more detail about the maturity of the UK chemicals and process sector.

Figure A13.9: HHI for the chemicals and process sector in comparison to other sectors [8]



Finally, market concentration in the C4/C7 companies has been measured by employment and compared with other sectors in Figure A13.10 and across the Chemicals and Process sub-sectors in Figure A13.11

Figure A13.10: C4/C7 Employment in comparison with other Sectors [8]

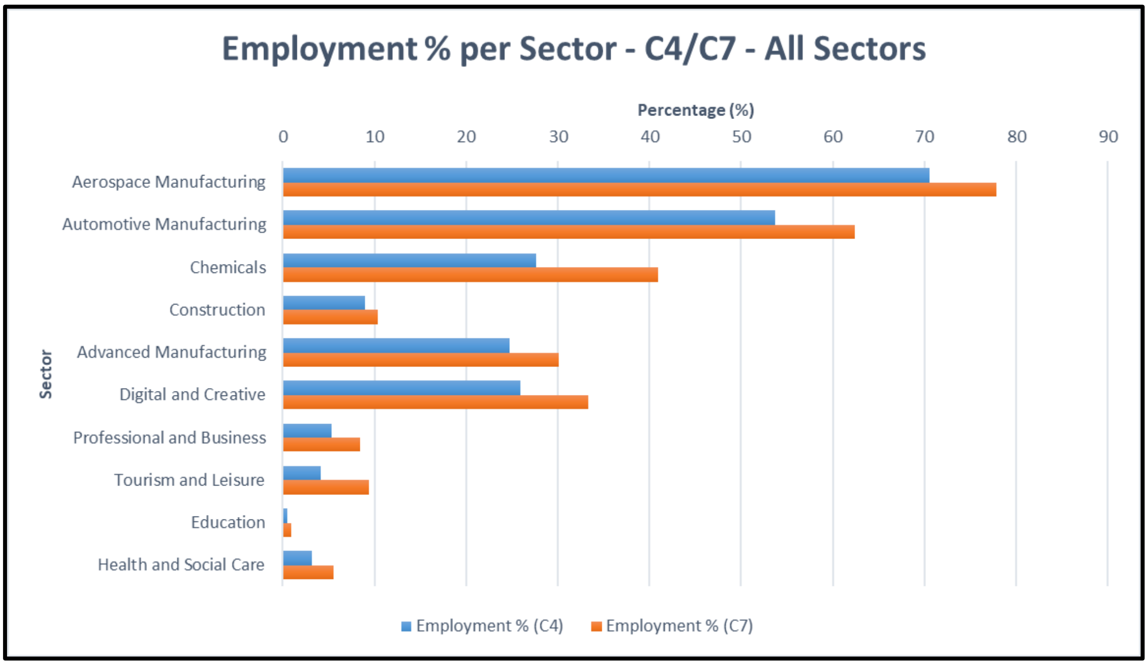
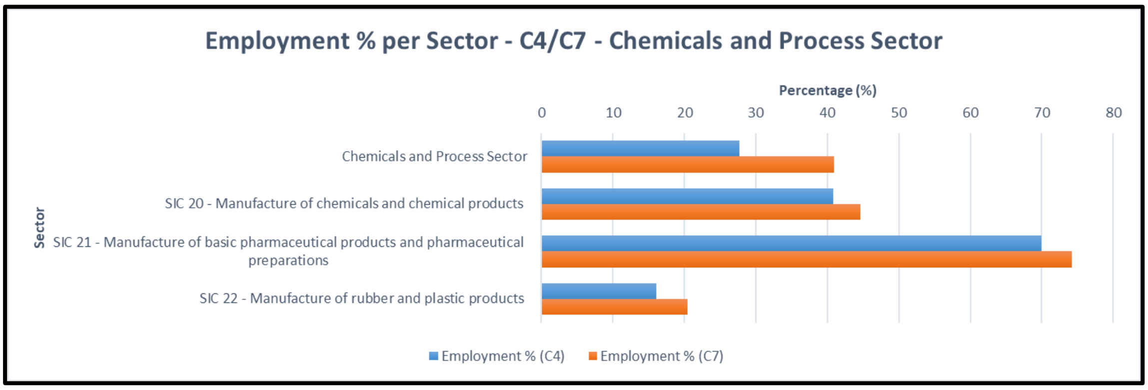


Figure A13.11: C4/C7 Employment for the chemicals and process sector and sub-sectors



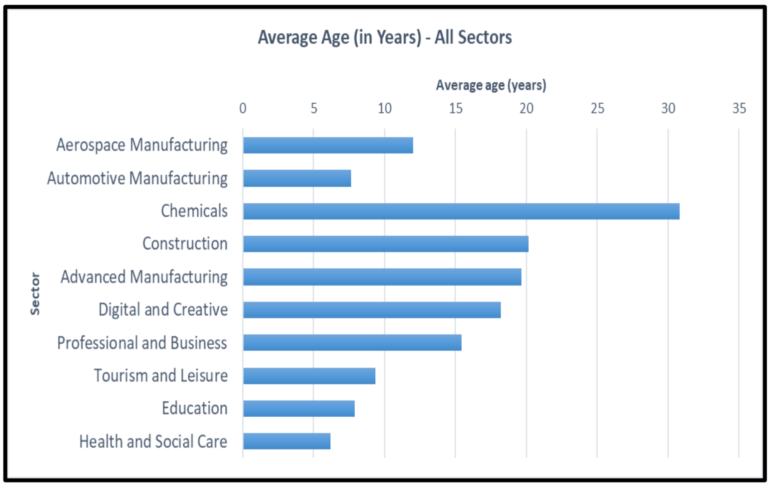
A high employment concentration indicates that employees are attracted, unsurprisingly, to the larger firms within a sector. The benefit of this for larger firms is that they are consistently able to attract the brightest and most capable workers, in order to drive future growth. However, the downside to this for mid-sized businesses and SMEs is that they will struggle to do this, as a result. This leads to sustainability issues for some firms who find it increasingly difficult both to retain staff and to attract new entrants.

Sector Maturity

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

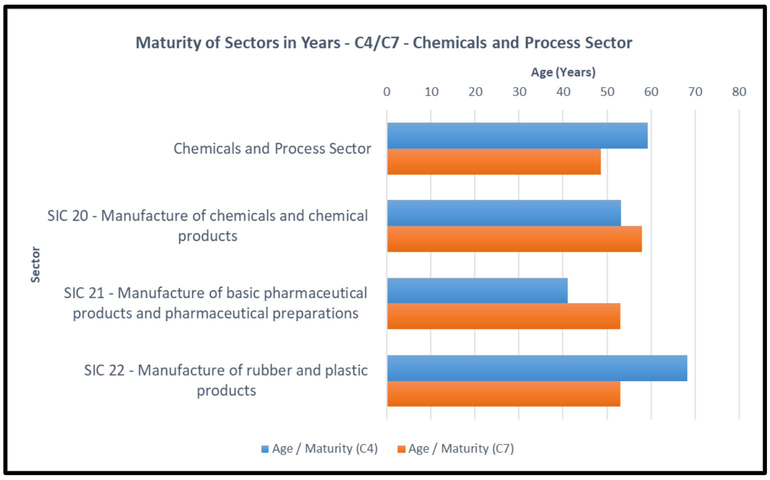
The maturity of the chemical and process sector and sub-sectors are shown in Figure A13.12, alongside a comparison with other key UK sectors. We can see that the average age of firms across the chemicals and process sector as well as the sub-sectors shows little variation. However, we can only gain insight as to what this level of maturity means when compared to other key sectors of the UK economy.

Figure A13.12: Maturity of chemicals and process sector compared to other key sectors [8]



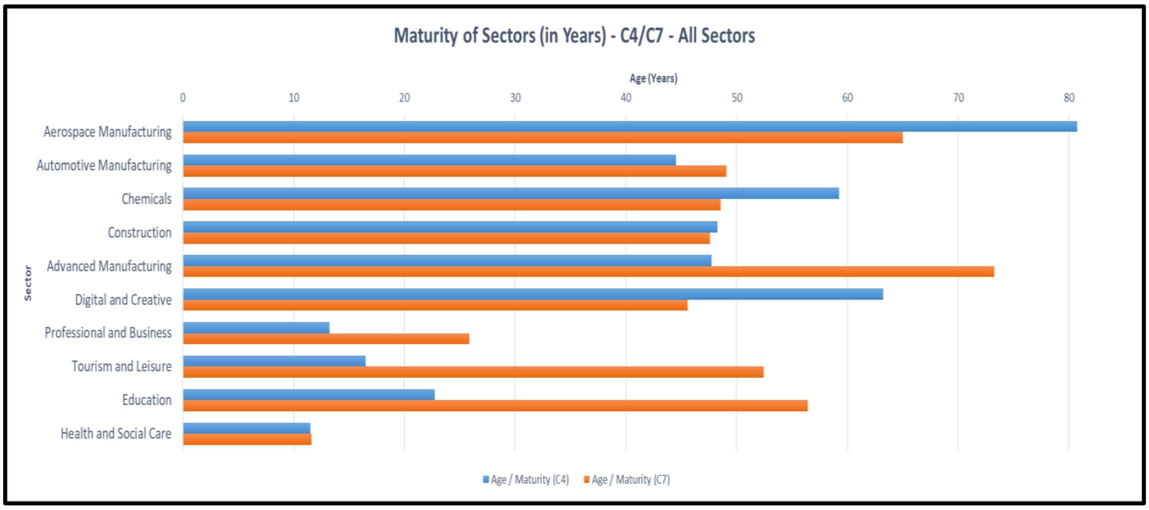
We have established that the chemicals and process sector on the whole is a relatively mature sector. Looking at the maturity of the top C4 and C7 firms across the sector, illustrated in Figure A13.13, we see that this trend continues, and in some cases is significantly above the average.

Figure A13.13: Maturity of C4 and C7 companies of chemicals and process sub-sectors [8]



Given that the average age of C4 / C7 firms across the sector is well above the average age for the sector as a whole (i.e. 31 years), Figure A13.14 shows how this compares with other key sectors of the UK economy**.**

Figure A13.14: Maturity of C4 and C7 companies compared with other key sectors [8]



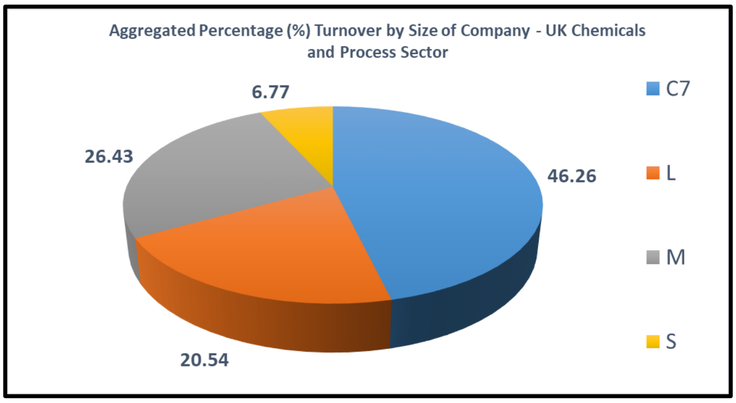
Key messages from this analysis are that there is a :

- Mature sector (average age across the sector of 31 years) and few new entrants; and
- Absorptive capacity likely to be lower than other sectors, leading to impact on innovation.

The Importance of Mid-Sized Businesses within the Sector

The Mid-sized Businesses Growth Review **[13]** uses a definition based on annual turnover of £25m-£500m. Figure A13.15 illustrates the sector breakdown by company size.

Figure A13.15: Aggregated percentage turnover by company size [8]



Whilst the large firms account for over two-thirds of turnover, the mid-sized firms still make a signicant 26.4% contribution to turnover for the sector **[8]**. Figure A13.16 shows the number of these firms and the relative turnover of the sector / sub-sectors. In terms of the mid-sized companies, there are a total of 652 across the sector, accounting for 26.42% of turnover. This also varies by sub-sector as shown in Figure A13.17

Figure A13.16: Number of mid-sized businesses by sub-sector [8]

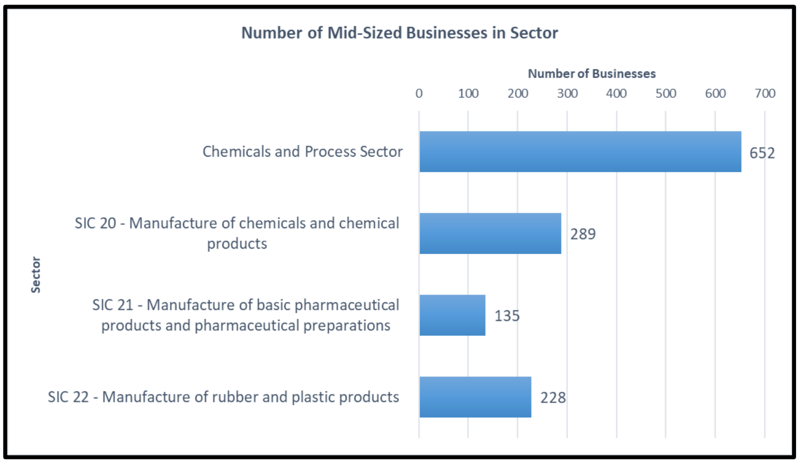
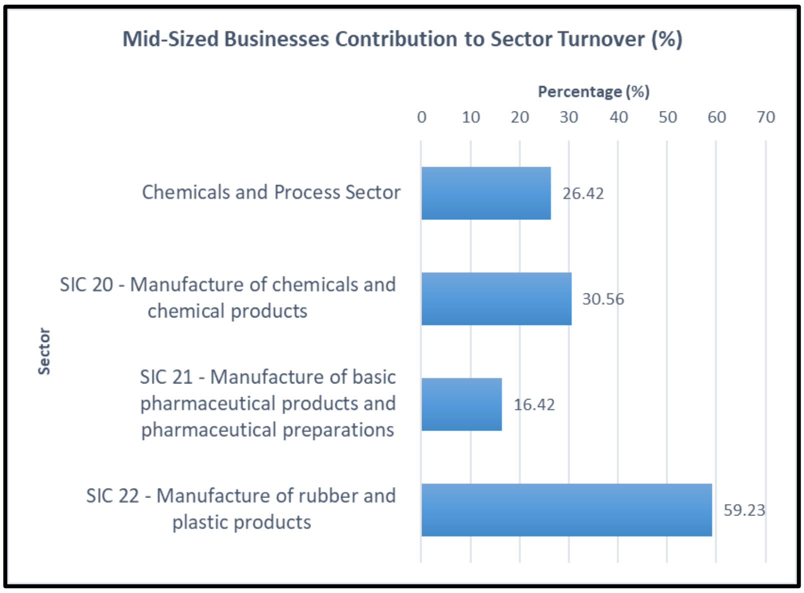
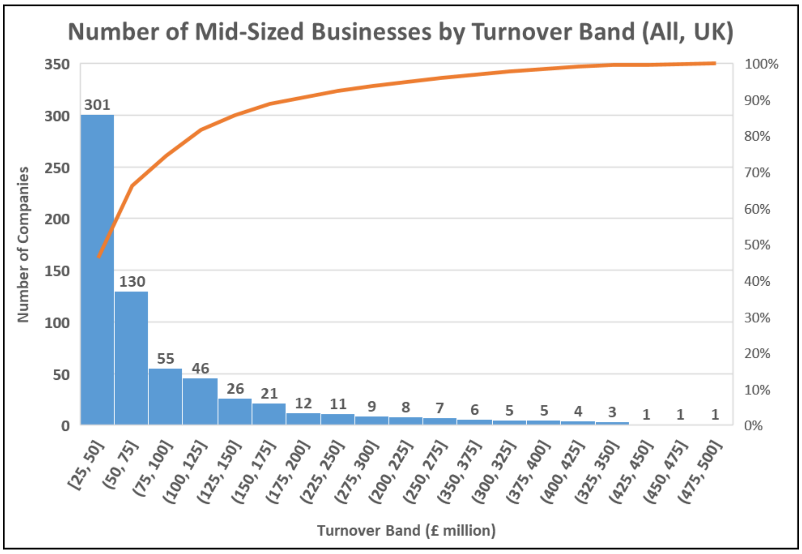


Figure A13.17: Mid-sized business contribution to sector turnover by sub-sector [8]



Breakdown of the mid-sized businesses by turnover is provided in Figure A13.18. The majority (65%) have turnovers less than £100m with relatively few businesses at the upper end of the range

Figure A13.18: Distribution of mid-sized businesses by turnover

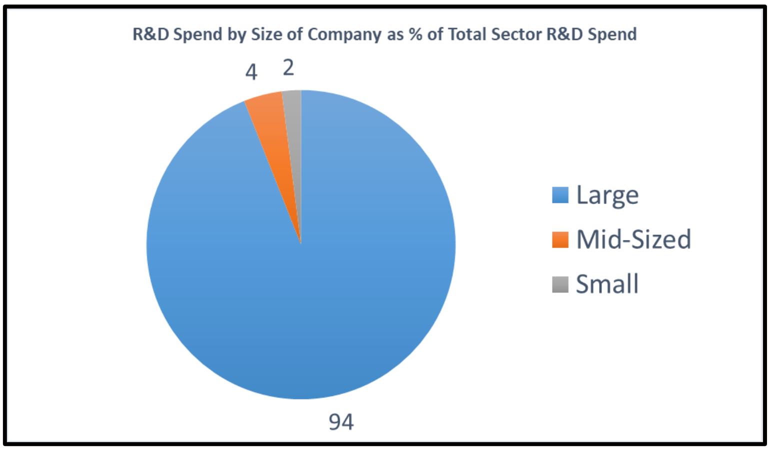


Mid-sized businesses have the following characteristics:

- 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.

Figure A13.19 shows that the vast majority of R&D is performed by large firms. Therefore, although mid-sized businesses account for 26.42% of turnover (figure A13.15), 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 thes mid size companies are of vital importance to the sector, but that this is not reflected in R&D performance.

Figure A13.19: R&D spend by size of firm [8]



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.

As noted in the analysis of R&D activity, the sector in the Northern Powerhouse is not exhibiting these characteristics. The following subsections focus on maturity and ownership structure of the sector to provide a rationale for this perceived underperformance.

Conclusions

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.

There is a need to curb this loss of market share/reduced export orientation and this could be potentially mitigated through import substitution and reshoring of key supply chain opportunities.

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.

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.

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 companies:
  - 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 companies:
  - Increased supply chain diversification;
  - Use supply chain/export diversification as a catalyst for innovation;
  - Address the absorptive incapacity of mid-sized companies 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.

Business Turnover Comparison of Northern Powerhouse with UK

Figures A13.20-22 compare the UK reported turnovers with companies reporting turnover in the NPH area. The NPH has a similar turnover profile to that across the UK in all three sub-sectors.

Figure A13.20: Turnover Comparison Manufacture of Chemicals and Chemical Products [14]

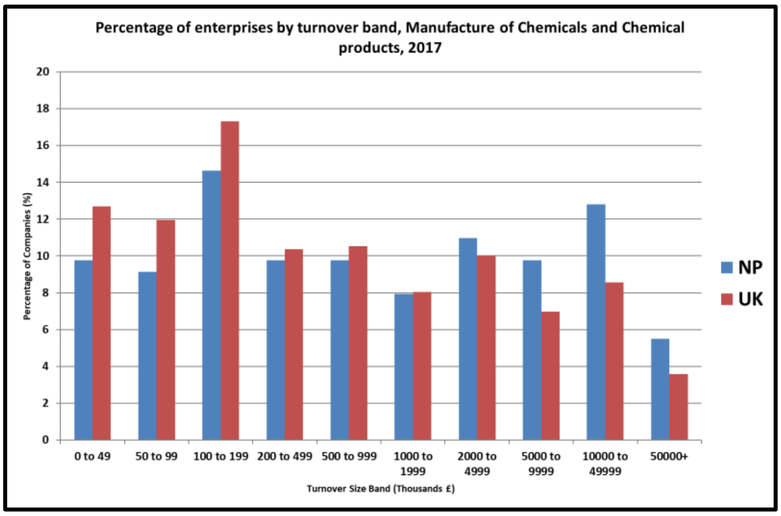


Figure A13.21: Turnover Comparison Manufacture of Basic Pharmaceutical Products and Pharmaceutical Preparations [14]

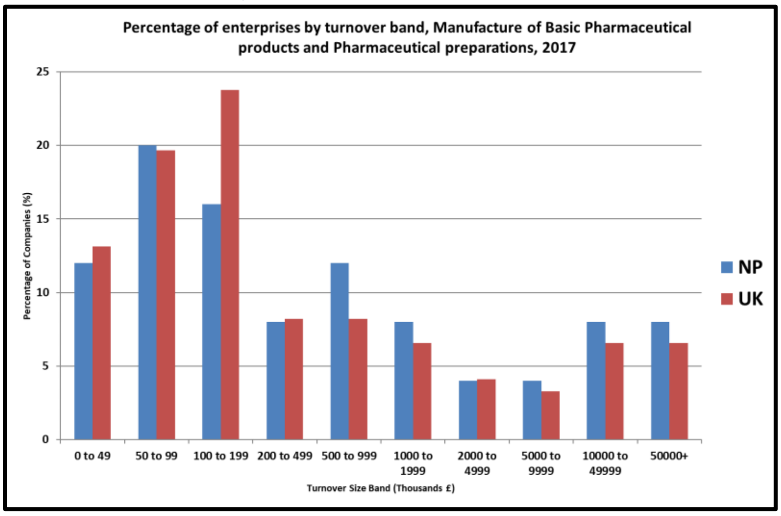
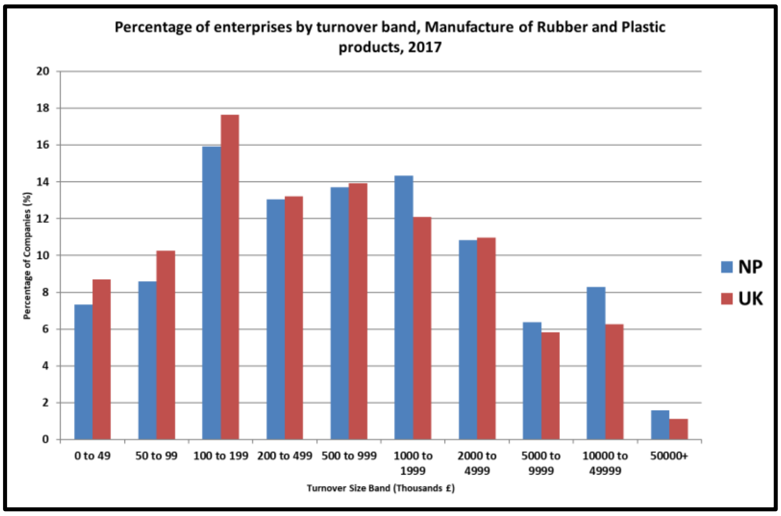


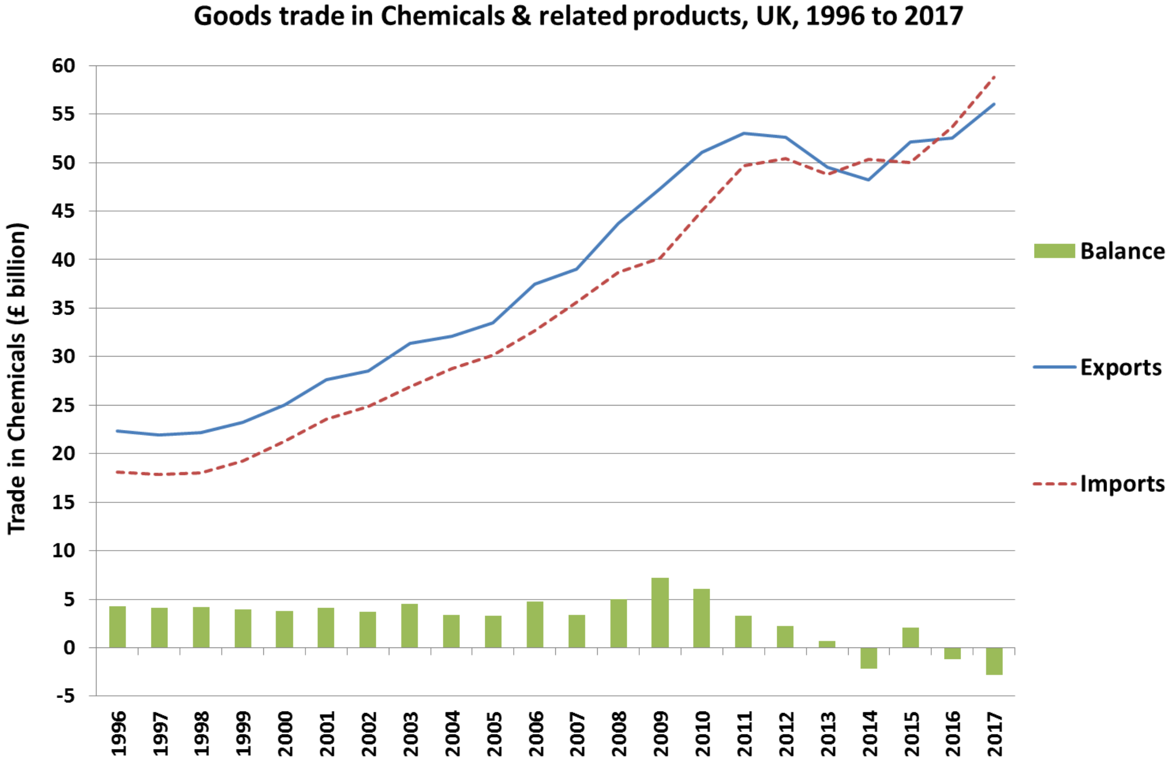
Figure A13.22: Turnover Comparison Manufacture of Rubber and Plastics Products [14]



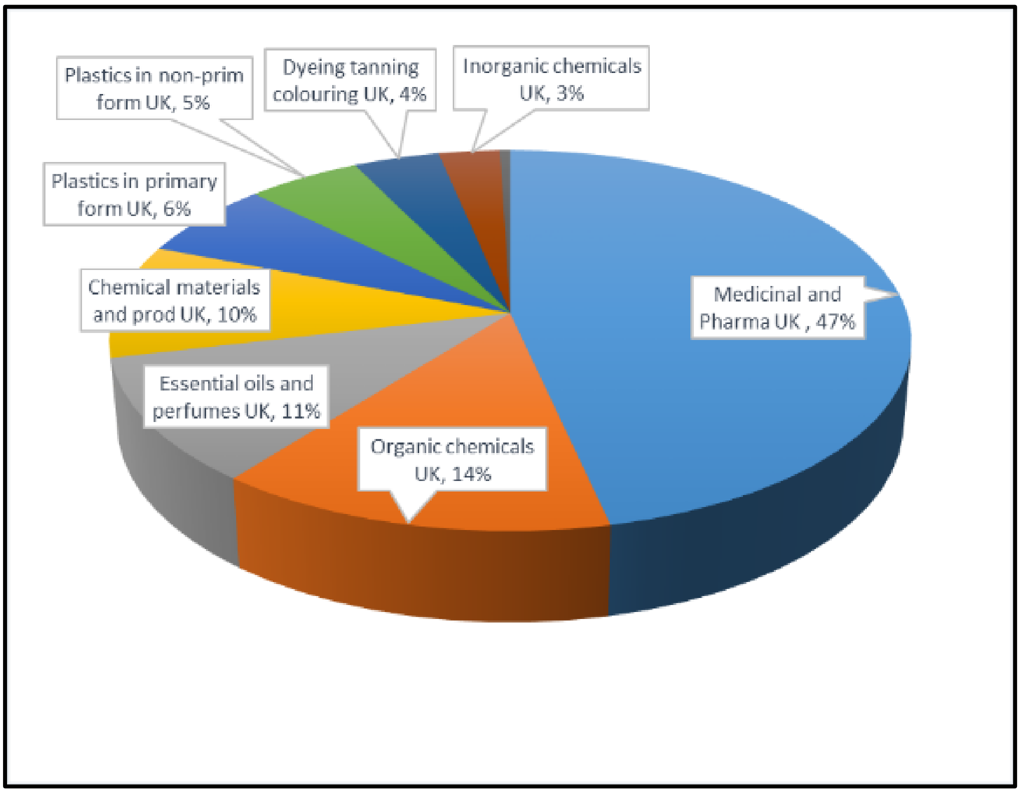
Appendix 14: Emerging Trade Figures

a) UK Chemical Sector Trends, 1996 to 2016

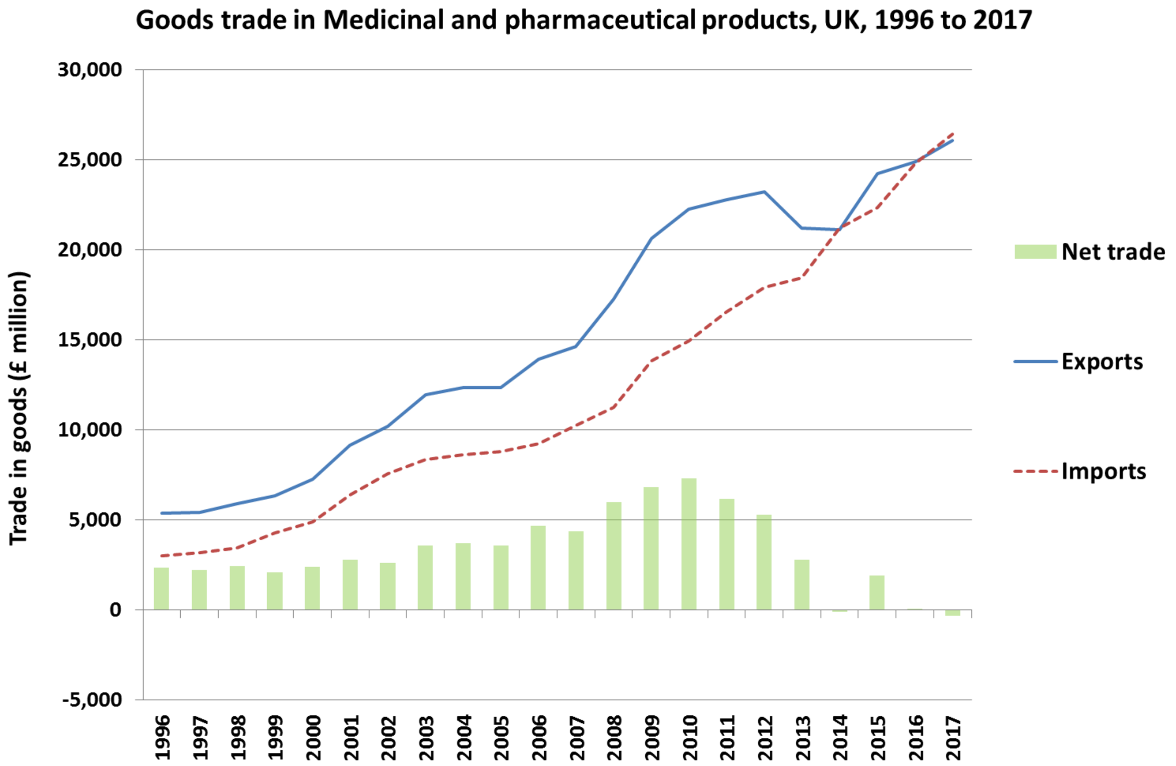
Source: HMRC Trade Statistics for this and all subsequent goods trade graphs **[15]** *SIC codes 20-22*

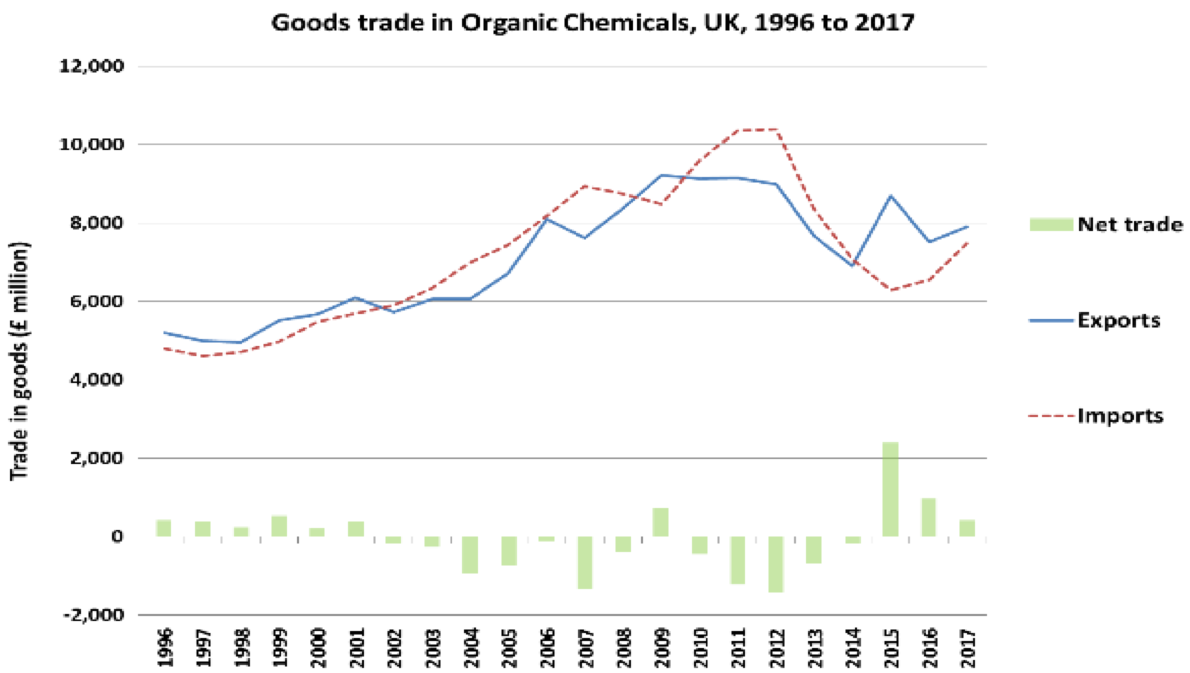


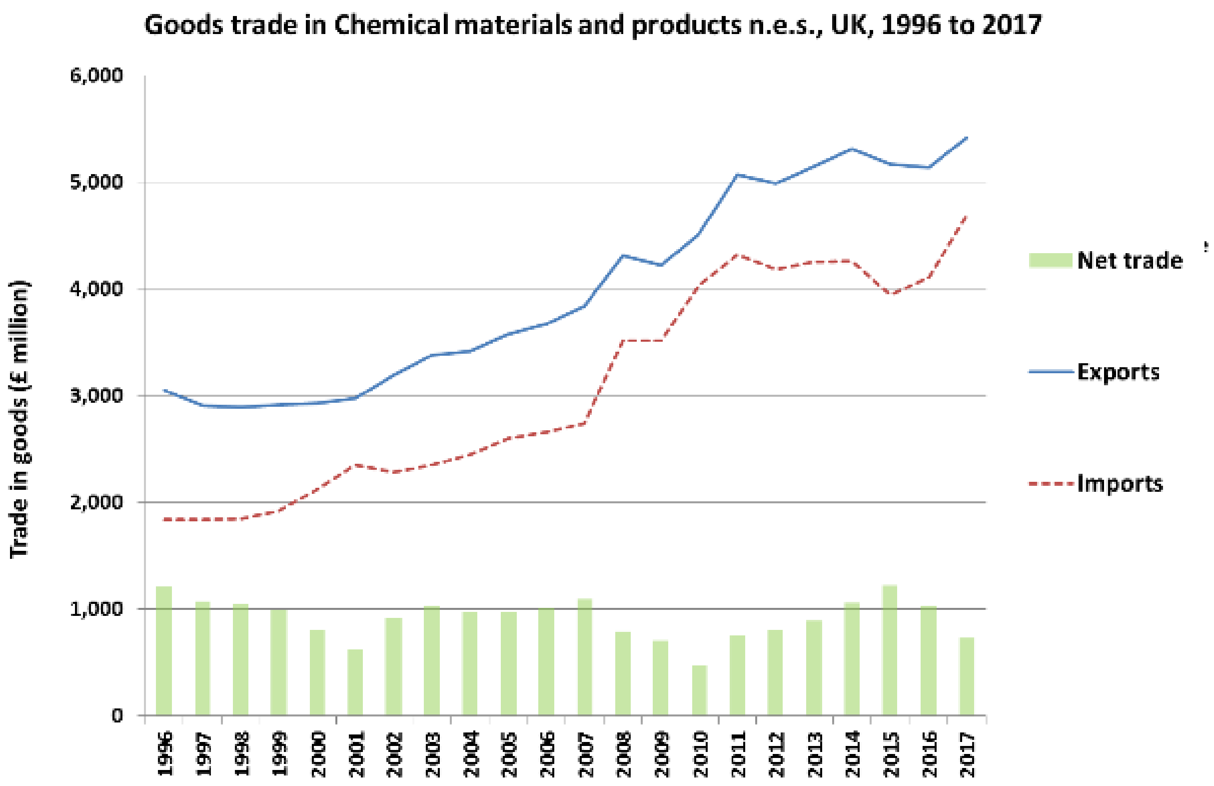
Share of Export Trade by Sub-sector 2017

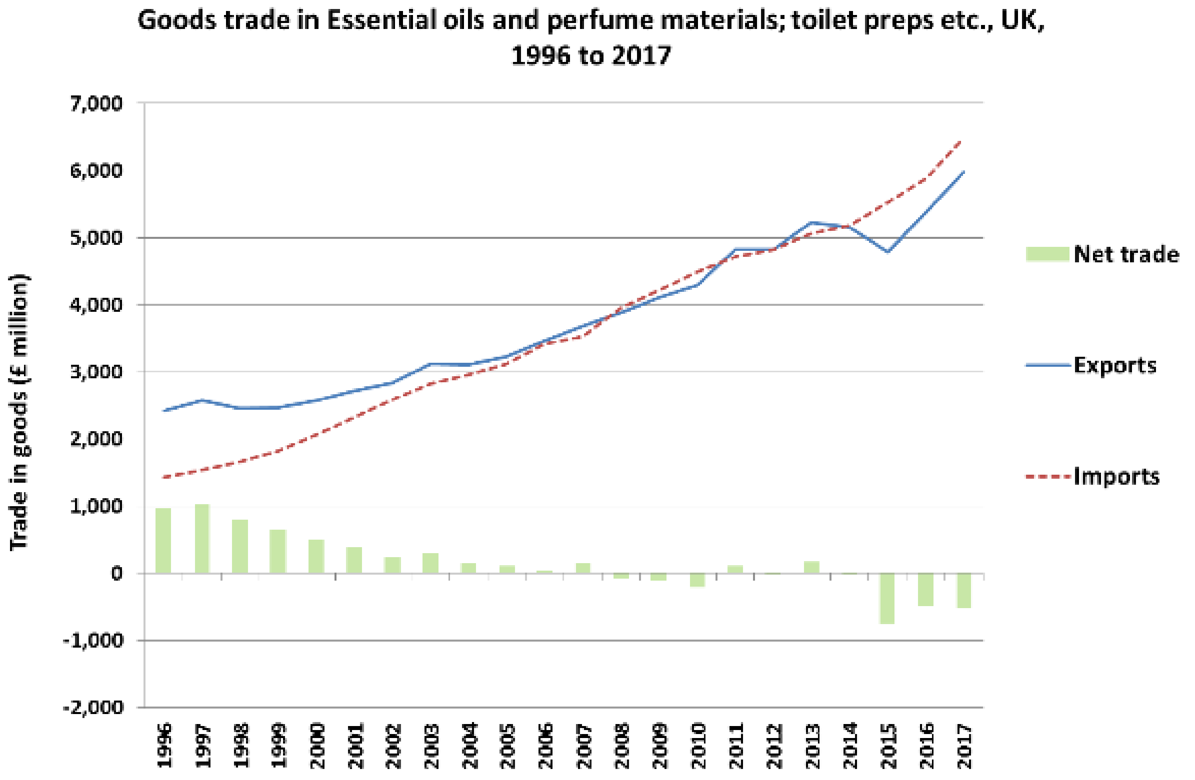


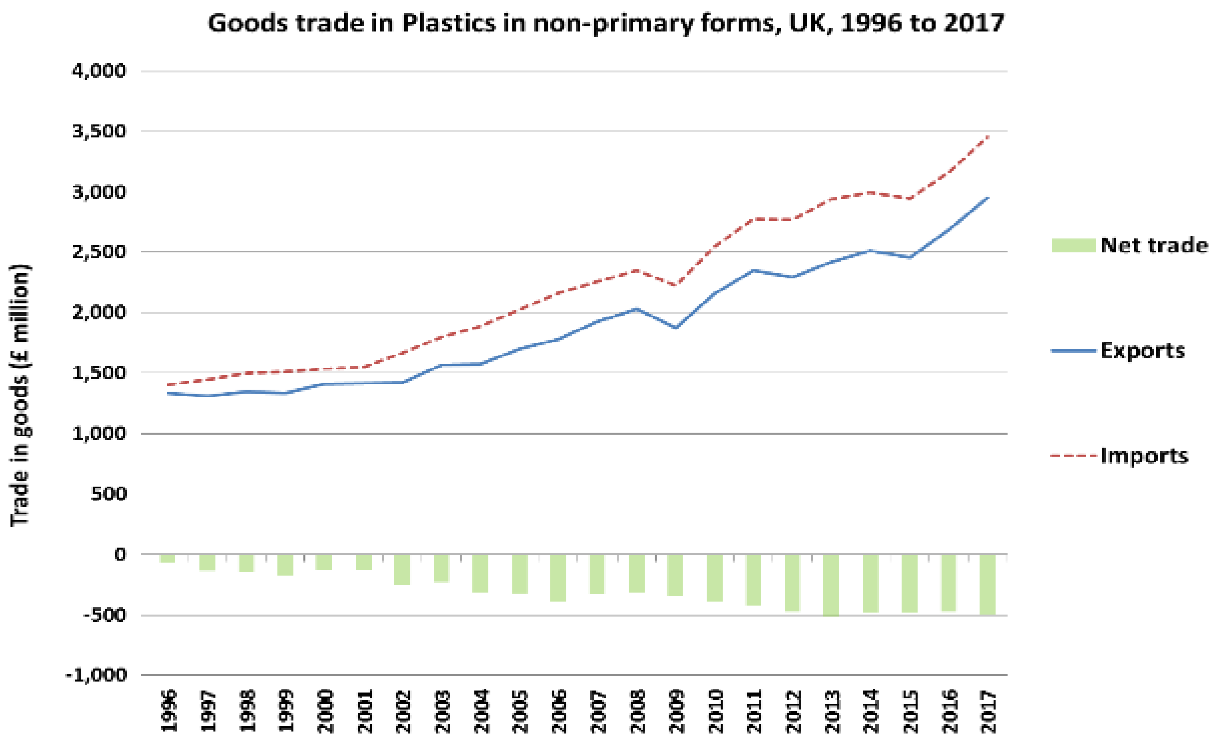
UK Chemicals Trade by Sub-sector

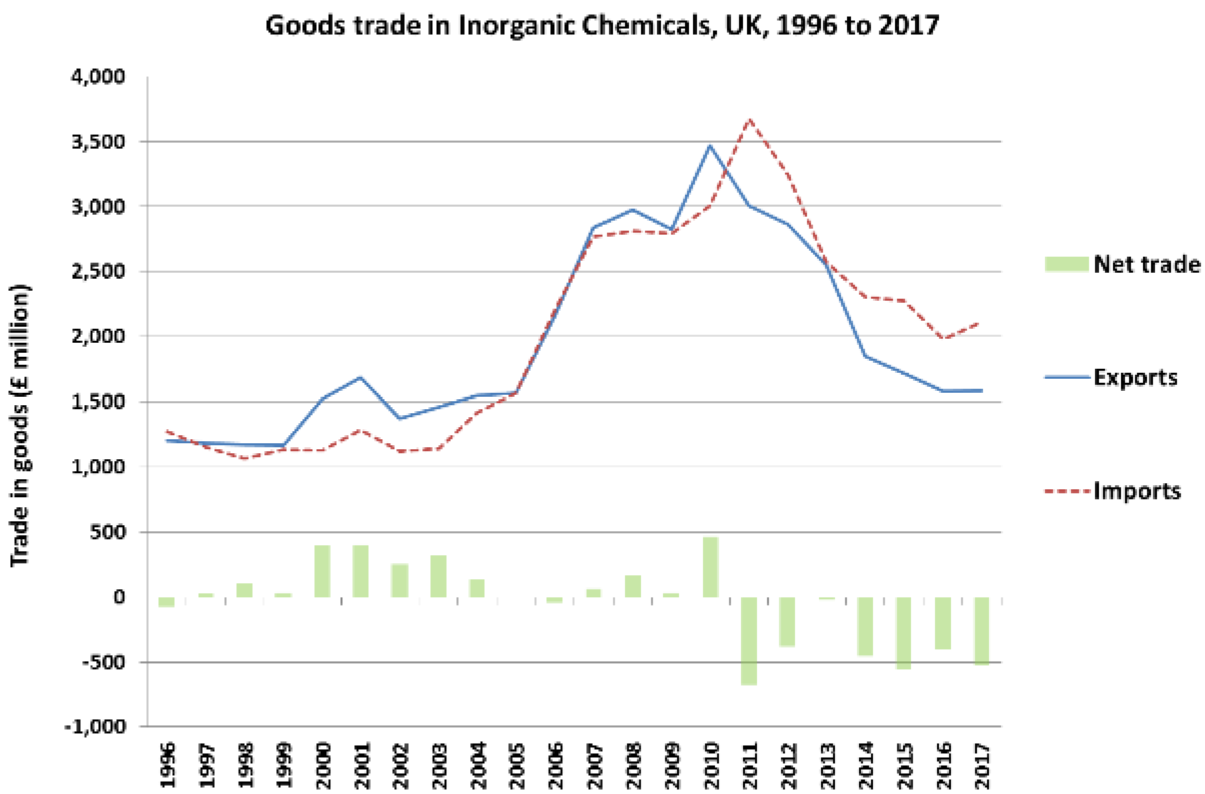


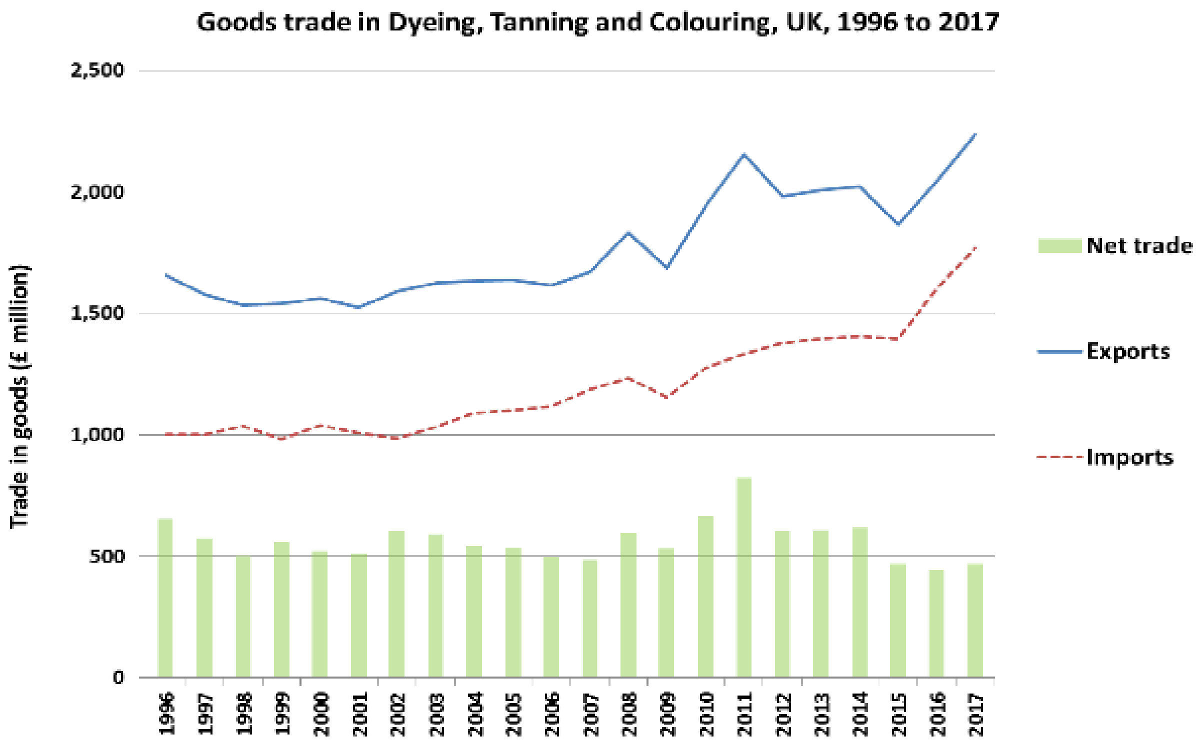


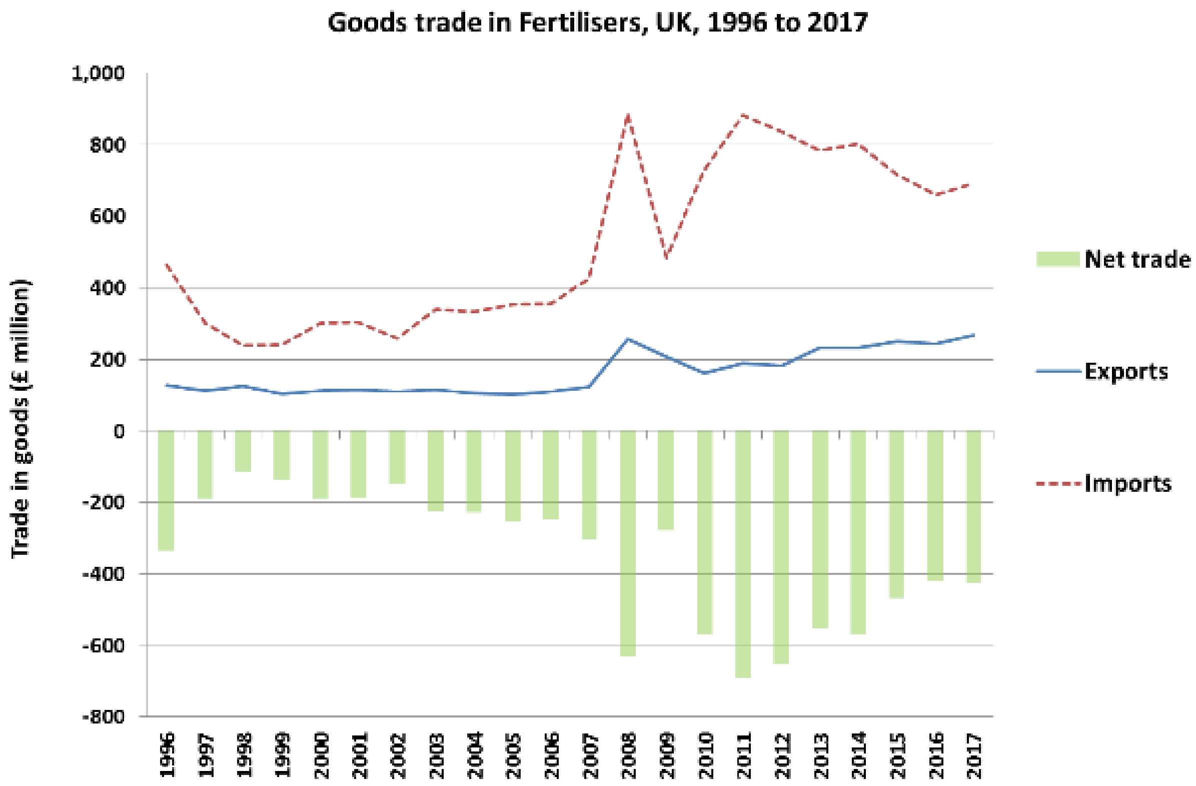

Goods trade in Chemical materials and products n.e.s., UK, 1996 to 2017
6,000
5,000
4,000
3,000
2,000
1,000
0
Trade in goods (£ million)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Net trade
Exports
Imports


Goods trade in Essential oils and perfume materials; toilet preps etc., UK, 1996 to 2017
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
Trade in goods (£ million)
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Net trade
Exports
Imports

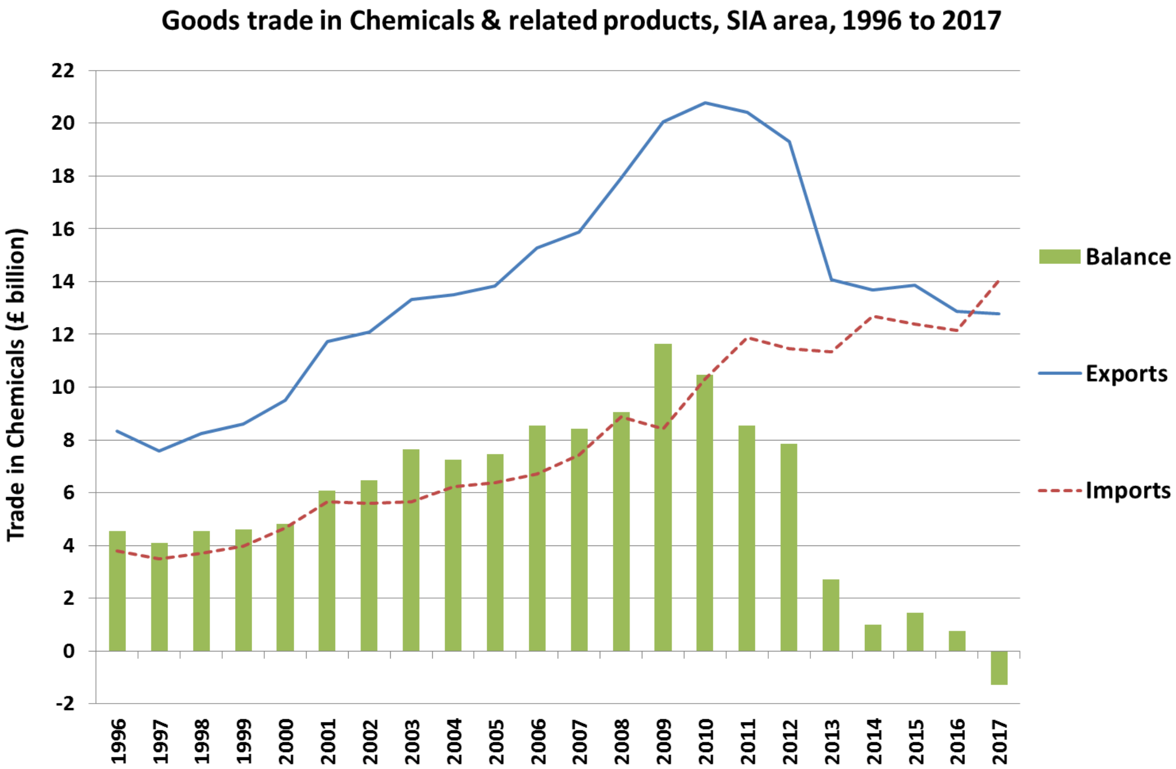

Goods trade in Plastics in non-primary forms, UK, 1996 to 2017
Trade in goods (£ million)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Net trade
Exports
Imports

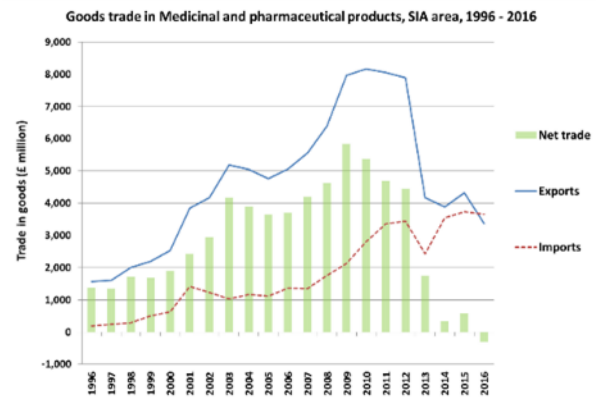

Goods trade in Inorganic Chemicals, UK, 1996 to 2017
Trade in goods (£ million)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Net trade
Exports
Imports

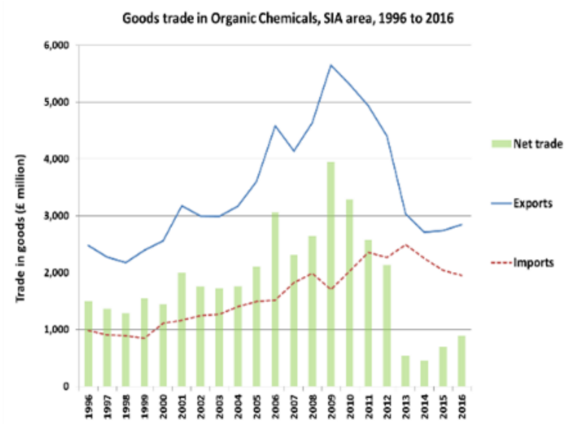

Goods trade in Dyeing, Tanning and Colouring, UK, 1996 to 2017
Trade in goods (£ million)
2,500
2,000
1,500
1,000
500
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Net trade
Exports
Imports

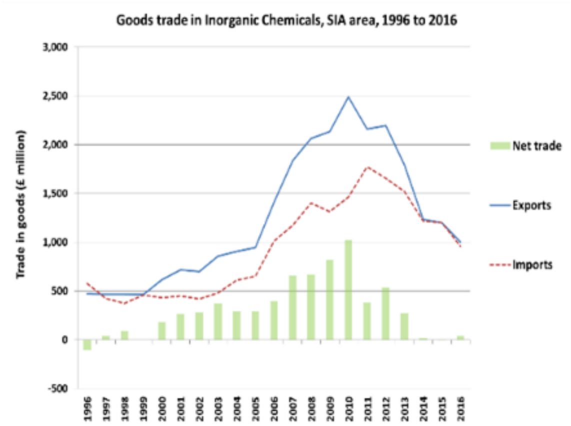

Goods trade in Fertilisers, UK, 1996 to 2017
Trade in goods (£ million)
1,000
800
600
400
200
0
-200
-400
-600
-800
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Net trade
Exports
Imports

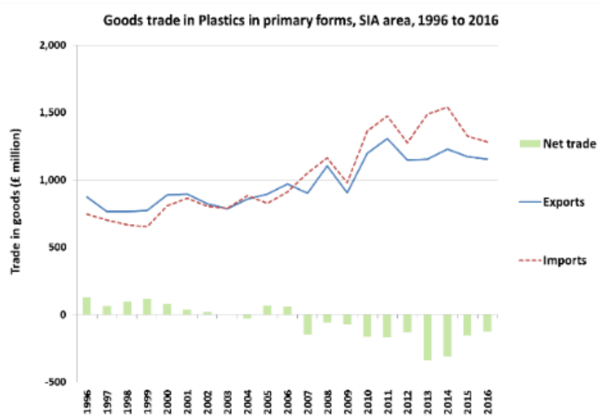
b) Northern Powerhouse Chemical Sector Trends, 1996 to 2016





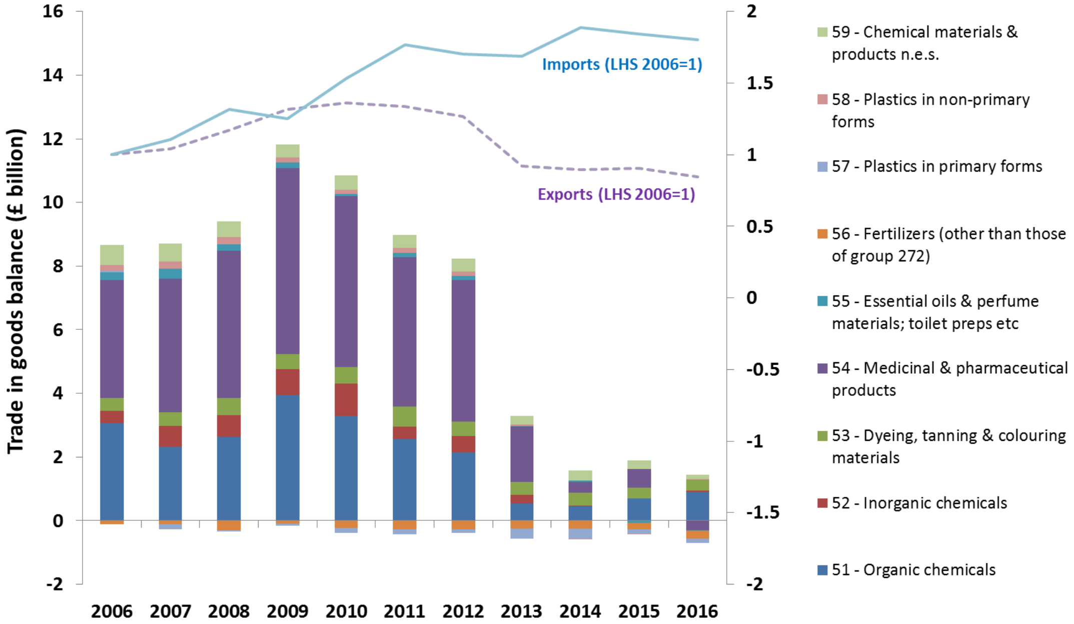






c) Components of change from peak positive trade balance

Change in Chemicals sector goods trade by sub-sector and by export and import indices (2006 = 1), 2006 to 2016

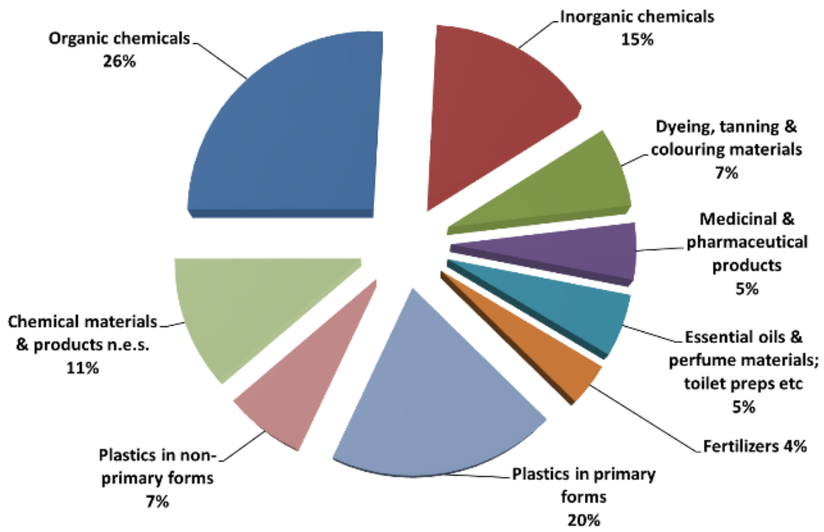


Chemical exports by LEP area, North of England, 2015

	Chemical exports (£m)	Total exports (£m)	Chemical exports % of total exports
Tees Valley	900	2,835	32
North Eastern	1,309	7,437	18
Liverpool City Region	690	2,314	30
Cheshire & Warrington	3,328	7,590	44
Humber	1,089	3,048	36
Greater Manchester	1,377	5,497	25
York, North Yorkshire and East Riding	375	1,692	22
Lancashire	1,210	3,011	40
Cumbria	244	726	34
Leeds City Region	3,017	8,192	37
Sheffield City Region	1,360	3,454	39
Total Northern Powerhouse LEPs	**14,899**	**45,796**	**33**

Source: HMRC **[15]**.

Imports in 1996



Key facts - imports

Chemical sector imports totalled £3.8bn in 1996.

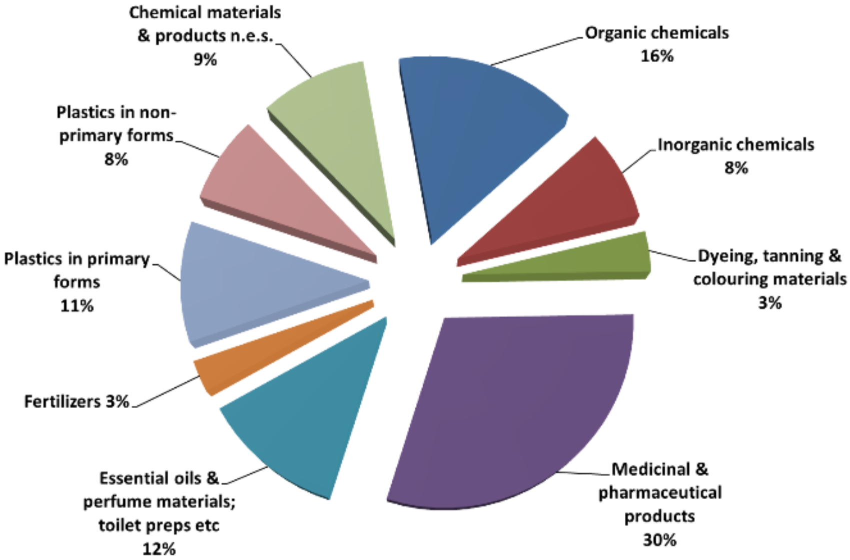
Imports totalled £12.1bn in 2016.

Imports were up by £8.3bn or 219% in nominal terms between 1996 and 2016.

Medical & pharmaceutical products were the fastest growing import – 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.

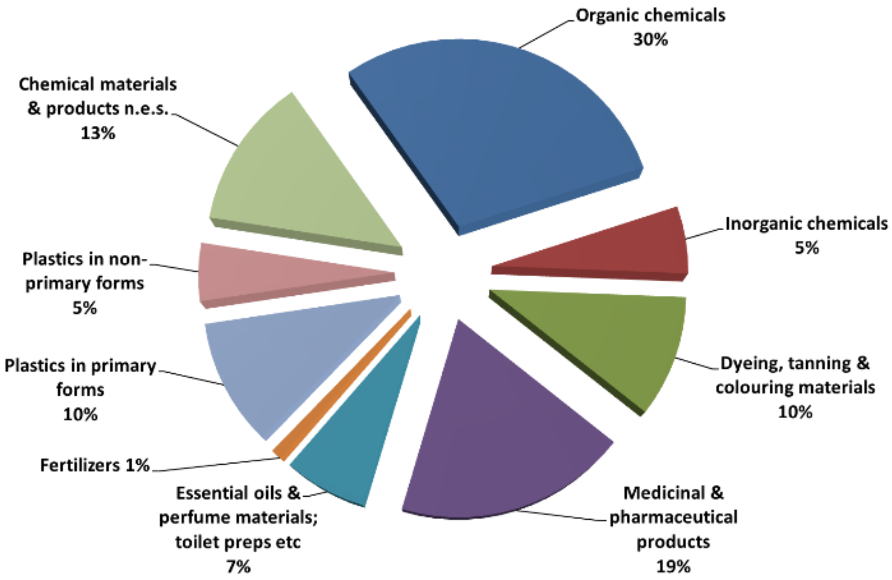
Organic chemicals accounted for the largest share of Chemical imports in 1996 at 26%. By 2016 this sub-sector accounted for just 16%.

Imports in 2016

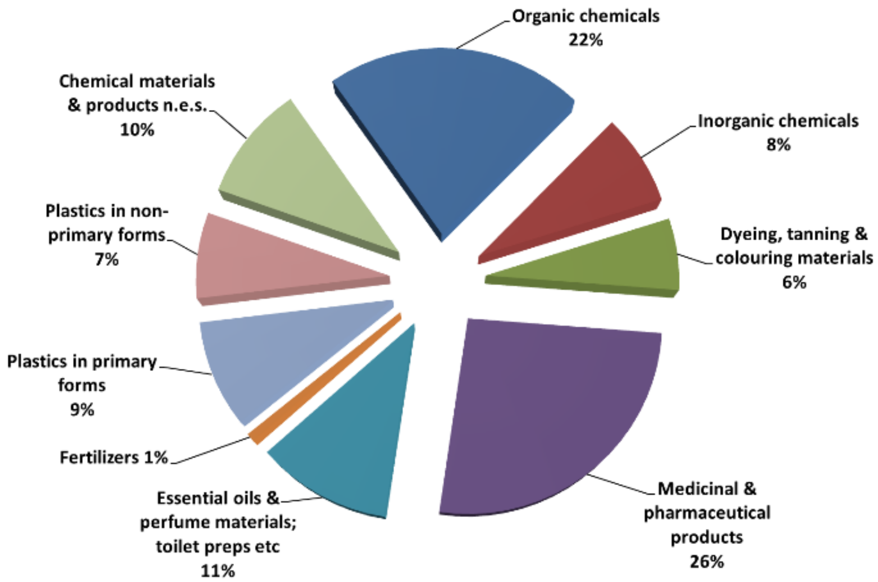


Source: HMRC Regional Trade Statistics **[15].**

Exports in 1996



Exports in 2016



Source: HMRC Regional Trade Statistics **[15]**.

Key facts - exports

Chemical sector exports totalled £8.3bn in 1996.

Exports totalled £12.9bn in 2016.

Exports were up by £4.5bn or 54% in nominal terms between 1996 and 2016.

Essential oils were the fastest growing export in percentage terms – up 155% between 1996 and 2016.

In numerical terms Medicinal & pharmaceutical products had the highest increase at £1.8bn, comprising 40% of the total rise in Chemicals between 1996 and 2016.

Organic chemicals accounted for the largest share of Chemical exports in 1996 at 30%. By 2016 this sub-sector accounted for just 22%.

d) Historic turnover for sector mapped to trade in same period

The Office for National Statistics Business Population Estimates **[16]** data (2010-2017) was used for SIC codes 20, 21 and 22, as described previously, in order to obtain a picture of the historic trend of turnover of the UK chemicals and process sector. The results are summarized in Figure A14.1. A clear conclusion is that the overall turnover of the sector is falling (-22.6% across the measured time period). The largest contributor to this decline is the manufacture of chemicals and chemical products (SIC 20) with pharmaceutical products (SIC 21) relatively stable during this period.

Fig A14.1 Turnover of the UK chemicals and process sector (2010-2017)

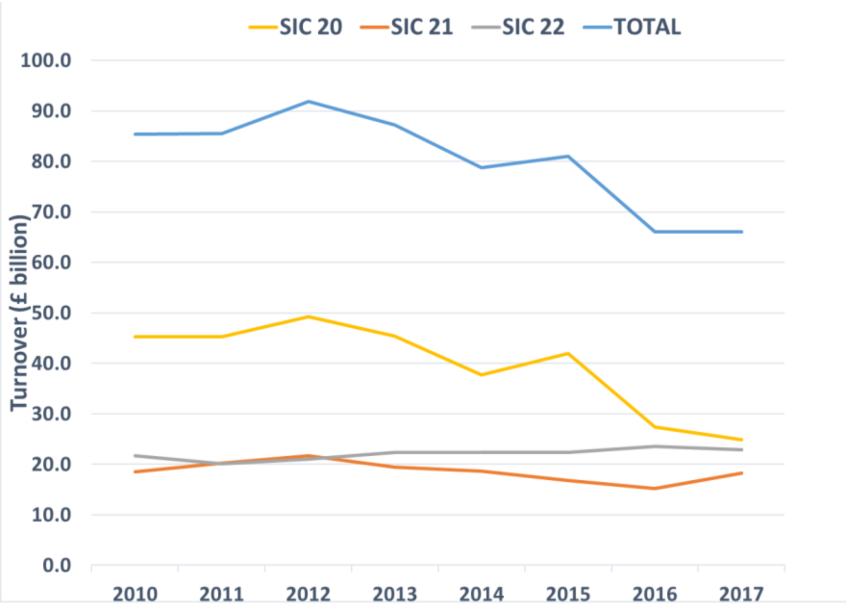
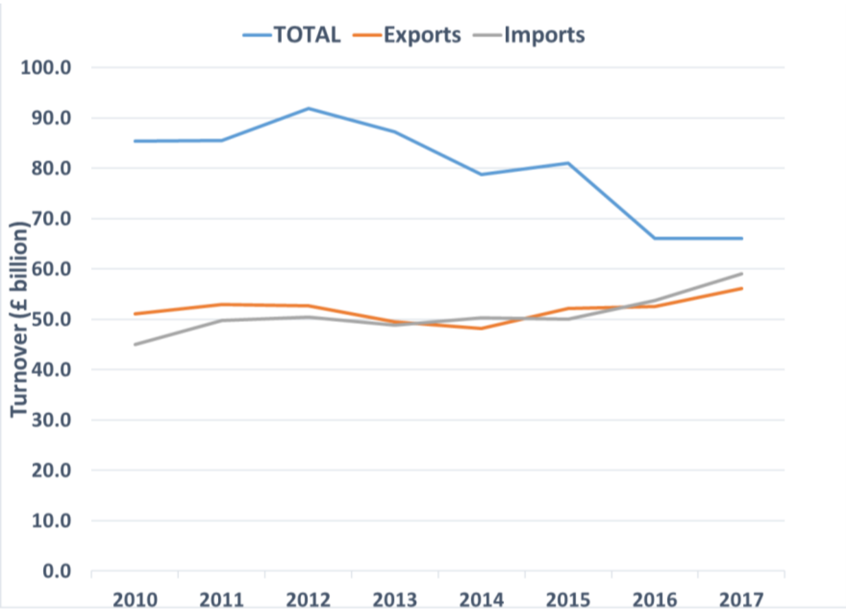


Figure A14.2 incorporates the trade figures over the same period from HMRC Regional Trade Statistics **[15]**

Figure A14.2 Turnover and Trade of Goods, UK Chemicals and Process sector 2010-2017



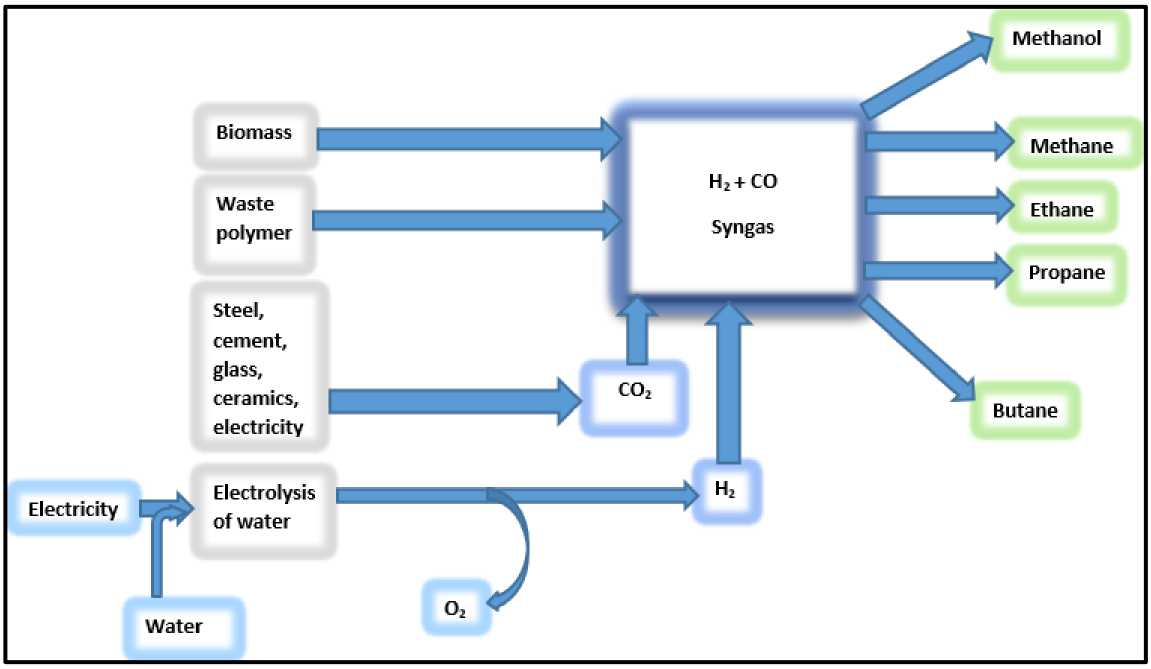
Comparing the two figures, we can see that not only is turnover in general decline, there is also a reduced balance of trade brought about by increased imports and lower exports-

Appendix 15: Key Innovation Priorities

a) Circular Economy Exemplars

Taking a detailed example within the sector, Figure 8.2 outlines a vision of how circular economy principles could be applied to bulk chemical manufacturing, providing the feedstocks to the manufacture of pharmaceutical intermediates, specialty chemicals, polymers, plastics and advanced materials.

Figure 8.2: The Circular Economy applied to Raw Materials for the Chemicals sector



The system hinges around the manufacture of “Syngas” a basic raw material for many chemicals. The Fischer Tropsch reaction converts syngas to methanol or alkanes (methane, ethane, propane, butane etc.). These can then be converted into finished products. For example, the conversion from ethane to ethylene and then onto polyethylene plastic. Alternatively, conversion to ethanol or ethylene oxide leads to the manufacture of surfactants, and so on.

The key to unlocking the circular economy in this area is the reuse and recycling of waste products from other processes. The key requirement is the availability of low cost, low energy, low carbon feedstocks.

The drive to lowest cost resource requires recycling of end products to feedstocks. For example, Biomass (wood, straw, etc.) can be converted to syngas **[17]**. Similarly there are processes that can pyrolyse waste plastics and polymers to this critical intermediate. Whilst the chemistry is known, these processes are not as yet running at scale. Key issues include:

- Purity of inputs and waste streams (e.g. PVC contamination in polyethylene and polypropylene will generate hydrochloric acid which corrodes steel plant).
- Robust and efficient membrane technologies used in the electrolysis of water to hydrogen
- Detailed understanding of the economics of each process step i.e. yield of products, energy cost and capital cost of plant. This has to be related to the understanding of the full cost impact in comparison with conventional petrochemical feedstocks. In short to medium term, the consideration of tax and behavioural nudge incentives might be necessary to drive behaviour.

Figures A15.1 and A15.2 provide further examples which exemplify the functioning of a circular economy with respect to the Bio-economy and also for the polymers and plastics sector

Figure A15.1: Outline of a Circular Economy [18]

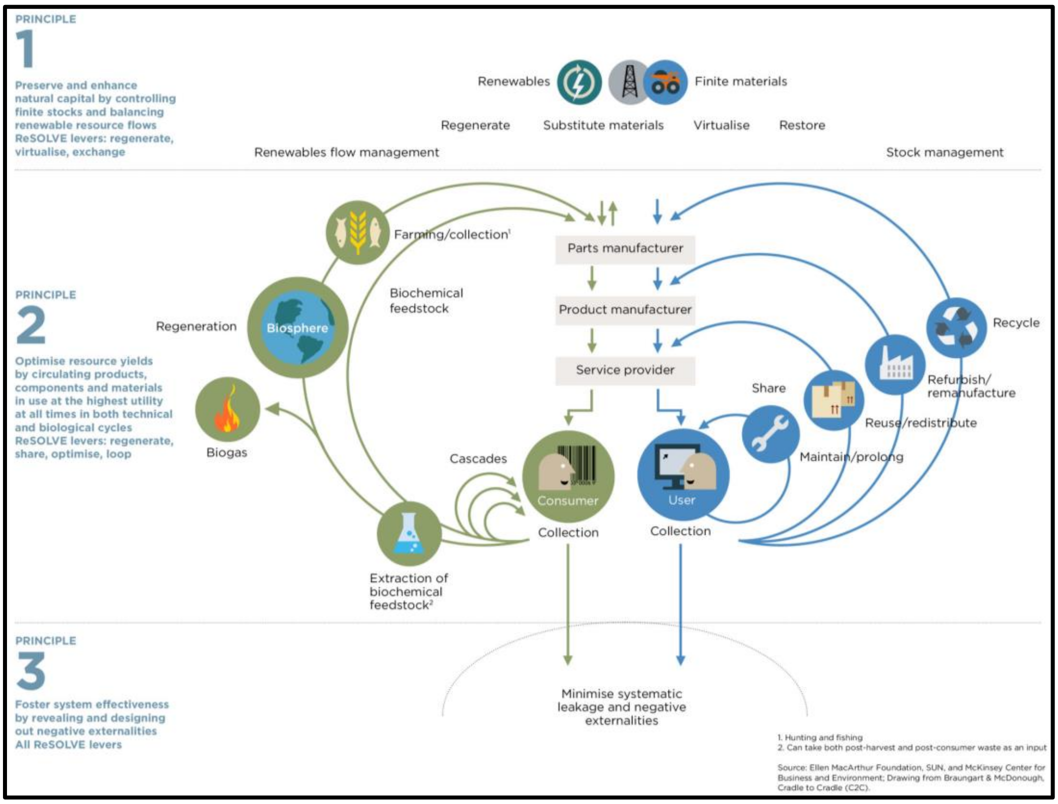
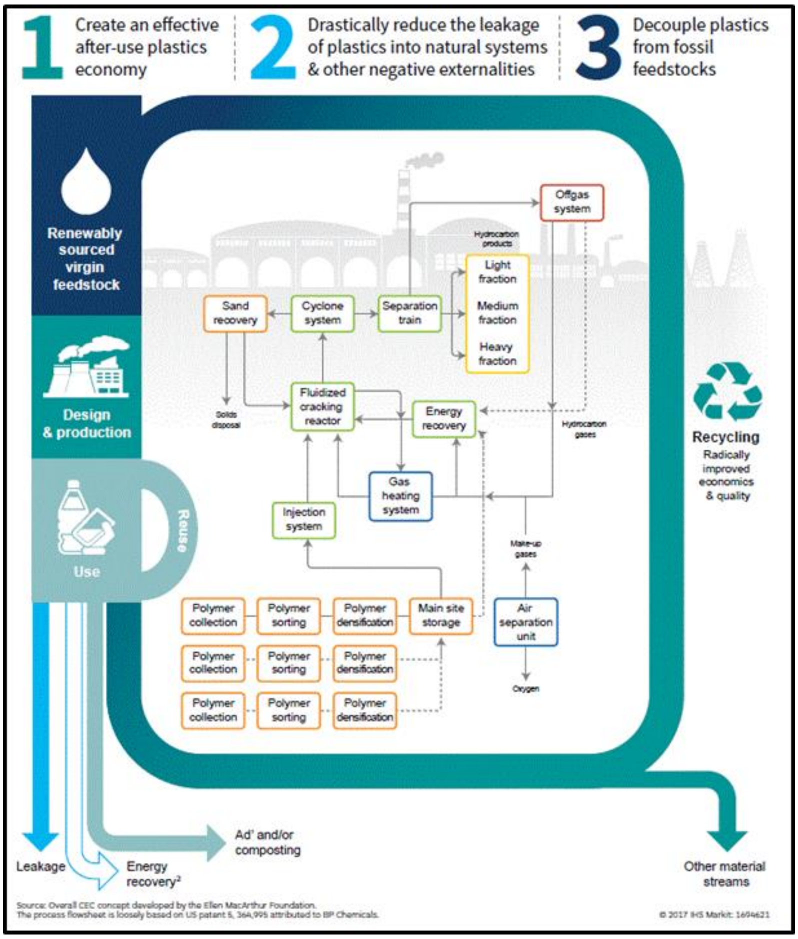


Figure A15.2: Polymer and Plastics Sector Circular Economy [19]



Appendix 16: International Benchmarking Technopolis Report (Analytical Support)

Science and Innovation Audits

Northern Powerhouse Chemicals & Process Sector

Analytical support

June 2018

TABLE OF CONTENTS

1 Introduction

This draft report was prepared for Northern Powerhouse Chemicals in response to their SIA Wave 3 request for international benchmarking exercise to identify key competitor cities and regions and its competitive advantages, with respect to the chemical sectors and its innovation ecosystem. The following sections are organised into analyses of the six suggested regions:

1. Rheinhessen-Pfalz;
2. Antwerp/Rotterdam;
3. Geleen;
4. Gulf Coast (USA);
5. Singapore; and
6. South Korea.

The final section provides a comparative analysis between the six regions and the Northern Powerhouse. Annex A presents the definition of the SIC codes mentioned in the text.

2 Rheinhessen-Pfalz

2.1 Chemical and process sector

Rheinhessen-Pfalz (also "Rhine-Hesse-Palatinate") is one of the three ancient districts of Rhineland-Palatinate, a state in Germany, located in the south of the state. Therefore, the information collected as part of this note refers rather to Rhineland-Palatinate. The population of the state is around 4,050,000. The largest airport in Rhineland-Palatinate is Frankfurt-Hahn Airport (not to be confused with Frankfurt Airport). About 861km of motorway run through Rhineland-Palatinate and the state is part of the German high-speed railway network (ICE).

Figure 1 – Rhineland-Palatinate in the German federation

Source: Rheinland-Pfalz (2016) Exceptional. Rhineland-Palatinate. The Center of Innovation

The chemical industry is the most important industrial sector in Rhineland-Palatinate. The structure of the chemical sector is not only shaped by the well-known major companies, such as BASF, Boehringer Ingelheim and Michelin, it is also shaped by many small and medium-sized companies. Around nine out of ten chemical companies employ less than five hundred people, more than half of them even fewer than one hundred. This structure has had a very positive effect on a stable economic development in Rhineland-Palatinate and has allowed the location to be better prepared for future economic crises. A large majority of the chemical products are delivered to other industrial sectors for further processing. Therefore, the chemical sector in Rhineland-Palatinate is essential for many value chains in the state economy, turning chemistry into a key industry. Furthermore, the chemical sector in Rhineland-Palatinate is also very important at the national level (in Germany) and many chemical companies have become global players. The broad range of products also includes advanced medicines, environmentally compatible paint and varnish as well as high-performance materials for generating energy from wind and sun, making the chemical sector an important player in the climate change protection.

More than 2,300 chemical companies operate in the state of Rhineland-Palatinate (of which more than 900 are based in the province of Rheinhessen-Pfalz)[1]. The chemical sector accounts for approximately 33 % of the total manufacturing turnover in the state and employs up to 100,000 employees (in the SIC sectors 20, 21, 22 and 23). The average salary for the SIC code 20 in Rhineland-Palatinate was €64,400 annually in 2015 and €38,100 for the SIC 22.

Companies operating in the SIC 20 and SIC 21 sub-sectors are on average significantly larger (117 employees, 276 employees respectively) than those in the SIC 22 and SIC 23 sub-sectors (35 employees, 19 employees respectively). The locations of the companies are concentrated along the Rhine River between Lahnstein, Mainz / Ingelheim, Worms and Ludwigshafen. Other centres are in Bad Kreuznach and Pirmasens. BASF SE (i.e. Badische Aniline & Sodafabrik or Baden Aniline and Soda Factory), in Ludwigshafen, is the largest chemical producer in the world and dominates the sector in the region. BASF operates in a variety of markets. Its business is organised in the segments of chemicals, plastics, performance products, functional solutions, agricultural solutions and oil & gas. BASF in Ludwigshafen, a highly integrated complex, employs 39,000 employees[2]. Other major producers in the area are Boehringer Ingelheim, Abbott, Raschig and Abbvie.

The German chemical industry association estimates that by 2030 there will be 6.4 million fewer people in the labour market compared to 2013[3] Therefore, the demographic trend is seen as a major challenge for the chemical sector in Germany. The sector has taken steps to keep pace with changing labour market conditions and the companies in the chemical sector now offer over 50 different vocational training courses to attract a younger workforce.

Statistical indicators – Rheinland-Pfalz (incl. Rheinhessen-Pfalz), Germany

Indicators on the chemical sector	SIC 20	SIC 21	SIC 22	SIC 23	Notes
Number of companies	461	49	818	987	Eurostat, 2015 (sbs_r_nuts06_r2)
Employment + share of the manufacturing total in brackets	53,734 (16.2%)	13,512 (4.1%)	28,470 (8.6%)	18,809 (5.7%)	Eurostat, 2015 (sbs_r_nuts06_r2)

[1] Eurostat, sbs_r_nuts06_r2 indicator, see a separate table on all available indicators across the focus regions.
[2] Information available at: https://www.basf.com/de/en/company/about-us/sites/ludwigshafen.html.
[3] Verband der Chemischen Industrie e. V. (2013) *AMBITIONS. ACHIEVEMENTS. SOLUTIONS. Sustainability in the Chemical Industry in Germany*

Growth rate of employment (%)	-0.4%	0.7%	-0.9%	0.5%	Eurostat, 2015 (sbs_r_nuts06_r2)
Output - Turnover	The chemical sector accounts for approximately 33 % of the total manufacturing turnover in the state.				Ad-hoc reports, referenced in text
Turnover (all Germany) (€m)	163,386	50,810	84,516	47,522	Eurostat, 2015 (sbs_na_sca_r2)
Gross value added per employee (all Germany) (thousand €)	119	125	61	67	Eurostat, 2015 (sbs_na_sca_r2)
Export activity (all Germany) (thousand €)	65,906,401	37,350,181	27,329,154	10,922,416	Eurostat, 2015 (ext_tec07)
Supply chain integration	A large majority of the chemical products are delivered to other industrial sectors for further processing.				Ad-hoc reports, referenced in text
Wages (€m)	3,462.5	895.9	1,085.9	827.3	Eurostat, 2015 (sbs_r_nuts06_r2)
Average wage/salary (€)	64,438	68,304	38,142	43,984	Own calculation, based on Eurostat data
Skills levels (all Germany)	The German chemical industry lacks skilled personnel and was running at 87 percent utilisation in 2017. The sector had to recently revise its forecast upward for production this year.				https://global.handelsblatt.com/companies/german-economy-faces-shortages-as-economy-reaches-capacity-limits-895822
Age profile	A major challenge is demographic ageing. There are too few young people entering the workforce in Germany.				https://www.chemiehoch3.de/fileadmin/user_upload/downloads/CHEMIE3-NH-Publikation-EN.pdf
Average size of enterprise	117 employees	276 employees	35 employees	19 employees	Own calculation, based on Eurostat data
Ownership structure	N/A	N/A	N/A	N/A	

2.2 Policy agenda

Over the last few years, innovation policy in Rhineland-Palatinate has been regarded as part of the economic and science policy. In 2005, a major initiative "Knowledge Creates the Future" (or Initiative Wissenschaft Zukunft)[4] was launched by the State Government, which aims at fostering research excellence and innovation. In 2014, the State Government adopted the Innovation Strategy of Rhineland-Palatinate[5], the objective of which is to strengthen the innovation capacity as well as the ability to compete of Rhineland-Palatinate. The document presents five strategic aims:

- Research and technological development at universities, universities of applied sciences and research institutes will remain central
- SMEs shall expand their R&D projects through targeted support and accelerate the market launch of their inventions
- An intensification of knowledge & technology transfer should contribute to a knowledge-based development of the economy

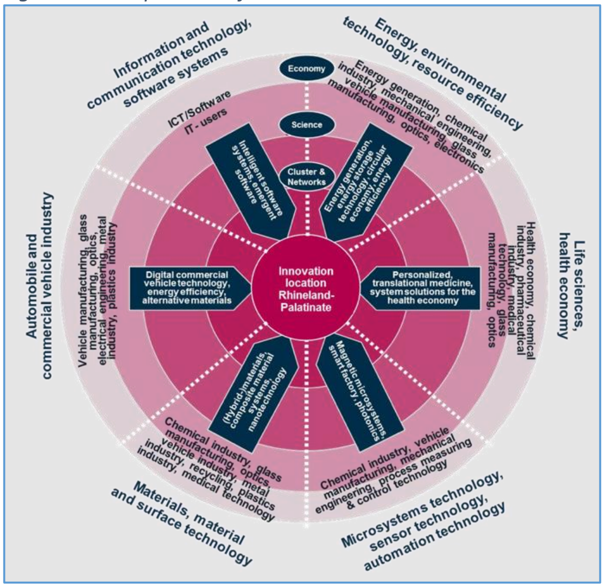
[4] More information online at: https://mwwk.rlp.de/de/themen/wissenschaft/hochschulfinanzierung/wissen-schafft-zukunft.

[5] Rheinland-Pfalz (2014) *Innovation Strategy: Rhineland-Palatinate*

- Facilities for business start-ups in Rhineland-Palatinate should be improved in order to improve the potential for a technology driven foundation of enterprises
- Collaboration, networking and innovative capability in Rhineland-Palatinate through encouragement of networks and clusters should be supported

The figure below illustrates the position of the chemical sector within the policy agenda of the Innovation Strategy.

Figure 2 – The position of the chemical sector in the Rhineland-Palatinate Innovation Strategy



Source: Rheinland-Pfalz (2014) Innovation Strategy: Rhineland-Palatinate

The innovation policymaking of Rhineland-Palatinate is characterised by a multilevel governance. The State is the main implementing body of the innovation strategy, and operates according to frameworks enacted at both federal and European levels. The German Basic Law gives the states considerable autonomy in R&D policy. This is particularly the case for higher education policy. At the regional innovation policy level, two ministries play a central role in innovation policymaking. The Ministry for Economic Affairs, Traffic, Regional Planning and viniculture (MWVLW)[6] is, among other areas, responsible for regional economic and innovation policies, industrial policy as well as funding and promotion, in order to strengthen the economy in the region. The Ministry for Science, Further Education and Culture (MWWK)[7] is responsible for science and research policy as well as education policy and culture. An important agency, which administers public support measures, in the field of start-ups, innovations, company expansions or municipal infrastructure, is the Investitions- und Strukturbank Rheinland-Pfalz (ISB)[8].

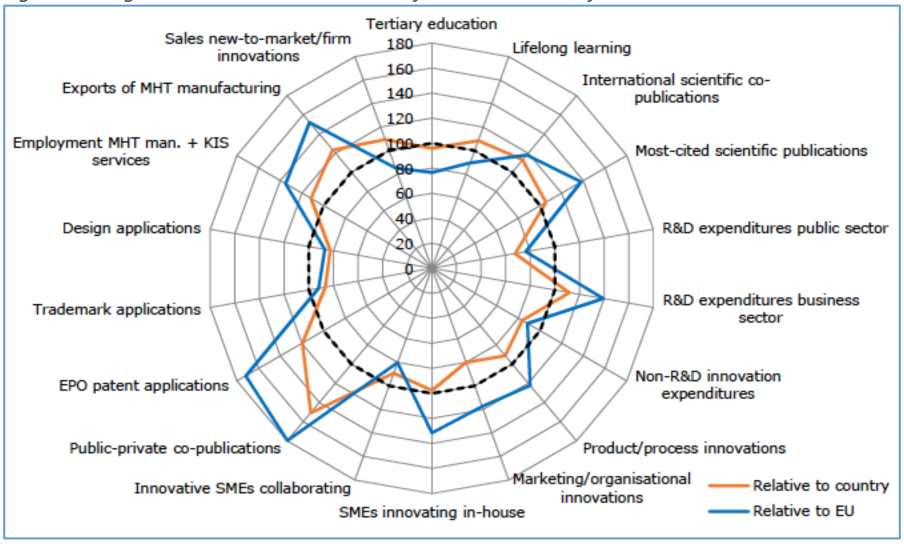
2.3 Innovation ecosystem

According to the Regional Innovation Scoreboard 2017 (see figure below)[9], **Rheinhessen-Pfalz** is characterised as an "Innovation leader", but the overall RTDI intensity (expressed in R&D expenditures) in Rhineland-Palatinate is low compared to other German regions. The EU Regional

[6] Official website at: https://mwvlw.rlp.de/de/startseite/
[7] Official website at: https://mwwk.rlp.de/de/startseite/
[8] Official website at: https://isb.rlp.de/home.html
[9] European Commission (2017) *Regional Innovation Scoreboard 2017*

Innovation Scoreboard concluded that the innovation performance of the economy should be increased. In particular, SMEs shall expand their R&D projects and the launch of new inventions.

Figure 3 - Regional Innovation Scoreboard for Rheinhessen-Pfalz



Source: EU Regional Innovation Scoreboard 2017

The innovative capacities of Rhineland-Palatinate have grown in recent years and the state is now in the middle of the ranking among the German states. The innovation ecosystem comprises four universities and seven state universities of applied sciences (Fachhochschulen) and there are some outstanding research units, such as three Max Planck institutes, three Fraunhofer institutes, one institute of the Helmholtz Society and five institutions of the Leibniz Association. Both businesses and research organisations are key to innovations. Yet the innovative power of SMEs faces the structural challenge of small company sizes and low research and development capacities.

2.4 Additional commentary on low-carbon solutions and circular economy

There are specific examples of initiatives and projects that focus on low-carbon solutions, circular economy, bio-based products etc. in Rhineland-Palatinate:

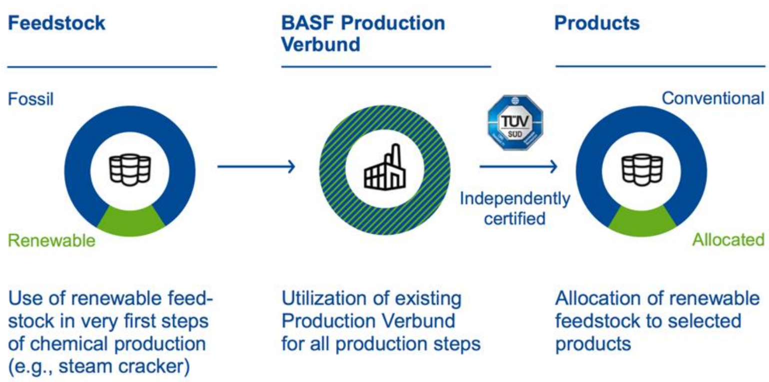
- As early as 2008, the Government of Rhineland-Palatinate adopted a strategy for a circular economy[10]. Rhineland-Palatinate has strong agriculture and forestry sectors. Therefore, as such, it offers high potential for energetic and material use of biomass and a number of projects and facilities in this field have been already implemented and established.
- The regional Operational Programme for ERDF aims explicitly (among others) at fostering the shift towards CO2 emissions reduction in all sectors of the economy[11].
- Rhineland Palatinate is a signatory party to The Memorandum of Understanding (MOU) on Subnational Global Climate Leadership[12] under which the state aims to reduce GHG emissions by 40% by 2020 compared to 1990 and by 90% by 2050[13].

[10] Rheinland-Pfalz (2008) *The Circular Economy State of Rhineland-Palatinate*
[11] More information available at: https://efre.rlp.de/fileadmin/efre/F%C3%B6rderperiode_2014-2020/Download-Center/Vereinbarungen_Operationelles_Programm/2014-10-27_-_Genehmigtes_OP_2014-2020_-_Deckblatt_erg%C3%A4nzt.pdf (in German)
[12] More information available at: http://under2mou.org/the-mou/.
[13] More information available at: http://under2mou.org/wp-content/uploads/2015/05/Rhineland-Palatinate-Appendix-English.pdf

- BASF SE in Ludwigshafen focuses on renewable raw materials at all stages of the value chain. It has also developed an independently certified biomass balance approach that allows a proportion of fossil feedstock to be replaced by renewable feedstock. The box below provides more information on this approach.

BASF's biomass balance approach

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-naphtha, together with fossil resources, already at the beginning in production. The renewable raw materials are then allocated to the respective sales products using a novel certification method (developed in collaboration with TÜV). The certified products thus contribute to sustainable development by saving fossil resources and reducing greenhouse gas emissions.



The share of the renewable feedstock (replacing the required quantities of fossil feedstock) can range from 25 to 100 percent, depending on the customer, whilst maintaining the product characteristics identical to those of the fossil equivalent.

There are a number of benefits stemming from this approach:

- It is a driver for the use of renewable resources
- It helps save fossil resources and reduce greenhouse gas emissions
- It has an independent certification
- It provides the same product quality with the same properties

More information available at: https://www.basf.com/en/company/sustainability/environment/resources-and-ecosystems/renewable-raw-materials/biomass-balance.html

2.5 References

European Commission (2017) Regional Innovation Scoreboard 2017

European Commission (2012) Analysis of policies in chemical regions to support the competitiveness of the chemicals industry

Rheinland-Pfalz (2014) Innovation Strategy: Rhineland-Palatinate

Rheinland-Pfalz (2016) Exceptional. Rhineland-Palatinate. The Center of Innovation

Rheinland-Pfalz (2008) The Circular Economy State of Rhineland-Palatinate

Rheinland-Pfalz (2012) Welcome to Rheinland-Pfalz

Verband der Chemischen Industrie e. V. (2013) AMBITIONS. ACHIEVEMENTS. SOLUTIONS. Sustainability in the Chemical Industry in Germany

3 Antwerp and Rotterdam

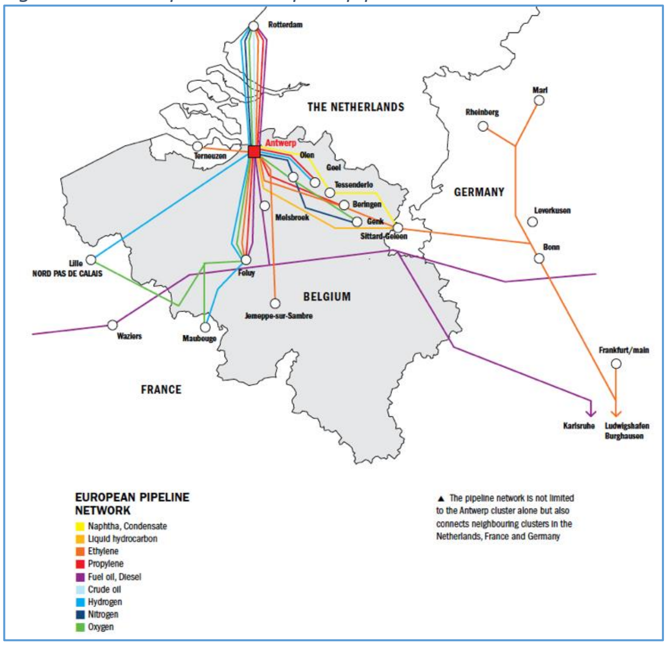
3.1 Chemical and process sector

Antwerp is the northernmost province of the Flemish Region (Flanders) in Belgium. It borders on North Brabant province of the Netherlands and the Belgian provinces of Limburg (bordering the Dutch province of Limburg), Flemish Brabant and East Flanders. Its capital, Antwerp, comprises the Port of Antwerp, the economic heart of the Antwerp province. Antwerp is the largest chemical cluster in Europe and the second largest worldwide (after Houston in the United States). 10 out of the world's top 20 chemicals companies have major facilities in Antwerp. The port is the main hub for the European pipeline network. Almost 500 chemical companies operate in the province of Antwerp[14], generating an annual turnover of €54 billion and providing direct and indirect employment across the whole of Flanders for some 180,000 people (77,000 direct employment in the SIC sectors 20, 21, 22 and 23 and some 100,000 indirect employment, of which 46% have a higher degree)[15].

The workforce in the chemical sector in Belgium is ageing. The chemical sector has launched a number of initiatives to attract young people to specialise in chemical process techniques, which resulted in a significant increase in the number of students enrolled in educational courses related to chemical process techniques[16]. Companies in the sub-sectors SIC 20 and SIC 21 tend to be larger on average (in terms of numbers of employees) than those in the sub-sectors SIC 22 and SIC 23. The average salary for the SIC code 20 in Antwerp was €73,646 annually in 2015, which is almost twice as high as the average salary for the SIC code 23 (€39,846). The petrochemical sector in Belgium lacks engineers, but also welders and machine operators to maintain the pipeline infrastructure.

Several chemical factories and oil refineries were established at the port, such as Bayer, BASF, Evonik, FRX Polymers, Monsanto Company. Pharmaceutical companies include Genzyme, Soudal and Ravago. The chemical sector is highly integrated in the value chain and the production spans diverse stages from feedstocks, building stocks, commodities, intermediates to final products. The chemical companies generate 25% of the industry added value in the country, twice the average of the EU[17]. Business Expenditures on R&D (BERD) represent €4.469 billion in 2015, of which the chemical and pharmaceutical sector led the way with 41%[18]. The Port of Antwerp is an essential element in the European pipeline network (see the image below).

Figure 4 - Antwerp in the European pipeline network



Source: Port of Antwerp (2015) Port of Antwerp: Europe's leading integrated oil and chemical cluster

[14] Eurostat, sbs_r_nuts06_r2 indicator, see a separate table on all available indicators across the focus regions.
[15] Beckx, F. (2016) *Europe's leading chemical and life sciences industry is looking for talent*, Essencia and Eurostat data.
[16] Essencia (2017) *Sustainable development report 2017 of the Belgian chemicals, plastics and life sciences industry*.
[17] Port of Antwerp (2015) *Port of Antwerp: Europe's leading integrated oil and chemical cluster*
[18] Geerts, N., Van Langenhove, M., Viaene, P. and Verdoodt, P. (2017) *STI in Flanders*

In the economy of Flanders, the biotechnology sector is seen as one of the most important strategic sectors and significant attention has been given to its development over recent decades. While the Flemish biotech industry is largely specialised on the medical sector, the region is also well equipped to play a significant international role in the industrial biotechnology sector, which is at the core of the knowledge-intensive bio-based economy. A fifth of Flemish biotech companies are involved in industrial biotech activities, with a focus on bioprocessing technologies of enzymes, chemicals, bio-based materials and biofuels. Flanders hosts the largest integrated bio-energy production complex in Europe, Ghent Bio-economy Valley (GBEV)[19].

Statistical indicators – Antwerp, Belgium

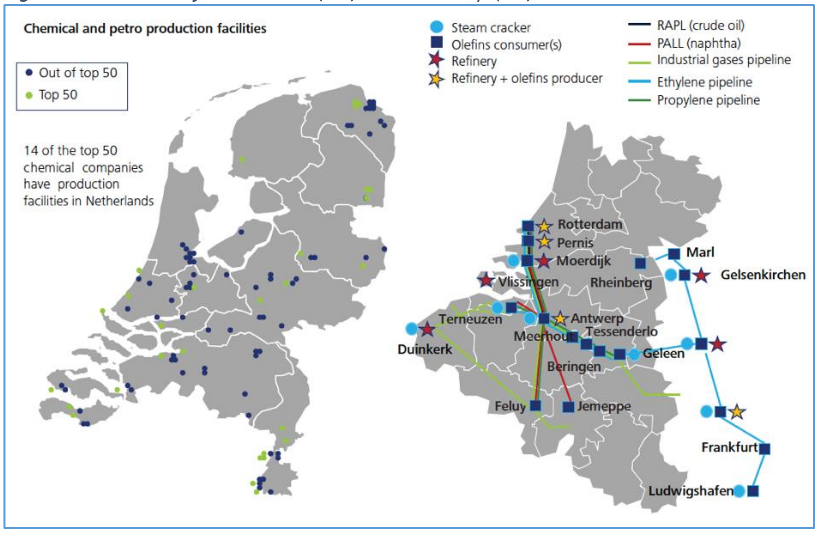
Indicators on the chemical sector	SIC 20	SIC 21	SIC 22	SIC 23	Notes
Number of companies	122	17	125	215	Eurostat, 2015 (sbs_r_nuts06_r2)
Employment + share of the manufacturing total in brackets	17,728 (17.4%)	9,123 (9%)	3,082 (3%)	3,506 (3.4%)	Eurostat, 2015 (sbs_r_nuts06_r2)
Growth rate of employment (%)	5.2%	1.3%	-4.7%	-3.3%	Eurostat, 2015 (sbs_r_nuts06_r2)
Output - Turnover	The sector in Antwerp comprises 500 companies which generate an annual turnover of €54 billion.				Ad-hoc reports, referenced in text
Turnover (all Belgium) (€m)	37,291	15,925	7,083	9,008	Eurostat, 2015 (sbs_na_sca_r2)
Gross value added per employee (all Belgium) (thousand €)	199	261	89	91	Eurostat, 2015 (sbs_na_sca_r2)
Export activity (all Belgium) (thousand €)	20,237,001	11,535,762	4,570,291	2,421,340	Eurostat, 2015 (ext_tec07)
Supply chain integration	N/A	N/A	N/A	N/A	
Wages (€m)	1,305.6	639.8	127.7	139.7	Eurostat, 2015 (sbs_r_nuts06_r2)
Average wage/salary (€)	73,646	70,130	41,434	39,846	Own calculation, based on Eurostat data
Skills levels	Almost one employer in two in Belgium recognises that talent shortages are having a negative impact on the ability to serve their clients. Technicians and skilled workers are of particular importance, for instance, to Belgium's chemical and petrochemical industry, which needs not only engineers but also welders and machine operators to maintain the equipment and pipelines. Yet, they are the most difficult positions to fill, which does not bode well for business in Belgium.				http://www.amcham.be/policy/labor-market/talent-gap
Age profile	In 2015, almost 25,000 jobs in the chemicals, plastics and life sciences industry in Belgium were held by employees aged over 50, representing more than one-quarter of the workforce. Over the last ten years, this ratio has risen from 18% to 28%.				https://www.essensciaforsustainability.be/wp-content/uploads/pdf/essenscia_sdr17_full.pdf

[19] Information available online at: https://www.flanders.bio/en/news/.

Average size of enterprise	145 employees	537 employees	25 employees	16 employees	Own calculation, based on Eurostat data
Ownership structure	N/A	N/A	N/A	N/A	

Rotterdam is a city in the Netherlands, in South Holland within the Rhine–Meuse–Scheldt river delta at the North Sea. Being the second largest city in the Netherlands, Rotterdam is the largest post in Europe, with the rivers Meuse and Rhine providing excellent access to the hinterland upstream reaching to Basel, Switzerland and into France. The port's main activities are petrochemical industries and general cargo handling and transhipment. It is also home to the regional headquarters of a chemical company called LyondellBasell, a commodities trading company Glencore and a pharmaceutical company Pfizer. The chemical and process sector in the province of Zuid-Holland comprises more than 830 companies. Companies operating in the sub-sectors SIC 20 and SIC 21 tend to be larger on average (by number of employees) than those in SIC 22 and SIC 23 sectors. All the companies together directly employ some 16,500 people. The average salary for the SIC code 20 in Zuid-Holland was €61,500 annually in 2015. The average wage in the SIC 23 sub-sector was €43,000 annually in 2015. The Rotterdam port itself hosts 45 chemical companies, five oil refineries, four palm oil refineries, five biofuel producers, two biochemical factories and various power stations. The main chemical product clusters are olefins, aromatics, polyurethane, polyester and chlorine. Compared to the Limburg region (see a separate regional profile prepared by Technopolis), Rotterdam is more focused on base chemicals, while Limburg specialises more in life sciences. Both Rotterdam and Antwerp are part of the international the Antwerp-Rotterdam-Rhine-Ruhr Area (ARRRA) chemical clusters (see figure below). VNCI and Deloitte predicted in 2012 that the ports of Rotterdam and Antwerp, together with the northwest European chemical cluster will be by 2030-2050 Europe's hub for oil, gas, bio-based feedstock and waste. Energy and feedstock will be imported from all over the world, and the ARRRA is the natural access point[20].

Figure 5 - Position of Rotterdam (NL) and Antwerp (BE) within ARRRA chemical cluster



Source: VNCI and Deloitte (2012) The Chemical Industry in the Netherlands: World leading today and in 2030–2050.

Statistical indicators – Zuid-Holland (incl. Rotterdam), The Netherlands

[20] VNCI and Deloitte (2012) *The Chemical Industry in the Netherlands: World leading today and in 2030–2050.*

Indicators on the chemical sector	SIC 20	SIC 21	SIC 22	SIC 23	Notes
Number of companies	179	50	224	379	Eurostat, 2015 (sbs_r_nuts06_r2)
Employment + share of the manufacturing total in brackets	8,813 (8.3%)	2,690 (2.5%)	2,329 (2.2%)	2,658 (2.5%)	Eurostat, 2015 (sbs_r_nuts06_r2)
Growth rate of employment (%)	-1.3%	0.3%	5.7%	-7.2%	Eurostat, 2015 (sbs_r_nuts06_r2)
Output - Turnover	The main chemical product clusters are olefins, aromatics, polyurethane, polyester and chlorine.				Ad-hoc reports, referenced in text
Turnover (all the Netherlands) (€m)	46,826	5,803	8,998	5,609	Eurostat, 2015 (sbs_na_sca_r2)
Gross value added per employee (all the Netherlands) (thousand €)	191	159	87	81	Eurostat, 2015 (sbs_na_sca_r2)
Export activity (all the Netherlands) (thousand €)	21,874,968	6,272,927	4,416,912	1,182,369	Eurostat, 2015 (ext_tec07)
Supply chain integration	N/A	N/A	N/A	N/A	
Wages (€m)	542.3	149.3	N/A	114.0	Eurostat, 2015 (sbs_r_nuts06_r2)
Average wage/salary (€)	61,534	55,502	N/A	42,889	Own calculation, based on Eurostat data
Skills levels	There is an ageing workforce in the Dutch chemical sector, which is tackled by public-private skills planning.				http://www.chemlandscape.cefic.org/wp-content/uploads/pdfs/Netherlands-70.pdf
Age profile					
Average size of enterprise	49 employees	54 employees	10 employees	7 employees	Own calculation, based on Eurostat data
Ownership structure	N/A	N/A	N/A	N/A	

3.2 Policy agenda

The innovation policy of the region of Flanders (including Antwerp) is driven by Science and Technology. There is a high level of awareness in the Flemish Government of the importance of research and innovation as a necessary condition for maintaining wealth and well-being in Flanders. The science and technology policy has been developed since 1990s and a large degree of continuity can be observed over the past 10-15 years. Flemish public and private stakeholders committed themselves to strive towards the 3% R&D expenditure/GDP target. The "Flanders in Action"[21] future plan aims to rank Flanders among the Top 5 EU regions by 2020. It defines several thematic breakthroughs, one of which is the "Innovatiecentrum Vlaanderen"/"Innovation Centre Flanders"[22]. Flanders has also put forward the following cluster domains for a smart specialisation strategy in which

[21] More information available at: http://www.vlaandereninactie.be/.

[22] Technopolis (2016) *Regional Innovation Report: Flanders (Production related biotechnology)*

R&D is to be strengthened and the transformation of knowledge into economic and societal valorisation is to be promoted:

- Sustainable chemistry
- Specialised manufacturing
- Personalised health care
- Specialised logistics
- Specialised agro-foods
- Integrated construction-environment-energy cluster
- Smart systems
- Creative industries and services

The Department for Economy, Science and Innovation of the Government of Flanders (EWI)[23] is the principal policymaking in the domain of STI policy in Flanders. The Flemish Advisory Council for Innovation and Enterprise (Vlaamse Adviesraad voor Innoveren en Ondernemen or VARIO)[24] is the advisory body of the Flemish Government and the Flemish Parliament for science and innovation policy. The VARIO offers advice on the complete innovation chain, from fundamental scientific research at universities, to applied research aiming at valorisation and the transformation of industry, the services sector and Flemish entrepreneurship. The VARIO can do this on its own initiative, upon request of the Flemish Government or upon request of the Flemish Parliament. Whereas the Flemish Government's departments prepare, monitor and evaluate public policy, a number of agencies are charged with the implementation of the policy decisions. In the STI field, these agencies are:

- VLAIO: Flanders Innovation and Entrepreneurship
- FWO: Research Foundation Flanders
- PMV: Flanders Holding Company (to a limited degree)
- LRM: Investment Company LRM

In the **Netherlands**, innovation policy is primarily the responsibility of the national government, where the largest budgets are spent, and where most often decisions on (semi-) public research institutes are made. R&D support is mostly based on generic instruments, such as tax benefits and research subsidies managed by the Dutch organisation for scientific research (NOW). The Dutch provinces (including **South Holland**) have no formal role in research- or higher education policy, though they do have an informal role in the Dutch consensus-oriented consultative culture in these areas. Since 2010, the involvement of the national government in regional economic policy has been gradually phased out. Innovation policy is now absorbed into the national top sectors approach, and is based on making use of existing strengths instead of trying to develop laggard regions. Triple helix consortia have been put in place for the high priority sectors included in the top sectors policy.

A number of relevant policy documents adopted at both national and regional levels exist that cover South Holland. The Roadmap Next Economy (commissioned by the Rotterdam The Hague Metropolitan Area)[25] recognises the role of the chemical sector for the region and its potential in the transition towards a distributed, collaborative and circular economy. In 2014, the Dutch Government adopted the Adaptive Agenda Southern Randstad 2040[26] which aims at ensuring that the Southern Randstad[27] will still be in the top 10 of global competitive regions in 2040 with an even stronger

[23] Official website at: https://www.ewi-vlaanderen.be/.
[24] More information available at: https://www.vario.be/en/.
[25] Metropolitan Region Rotterdam The Hague (2016) *The Roadmap Next Economy*
[26] Dutch Government (2014) *Adaptive Agenda Southern Randstad 2040*
[27] The Randstad is a megalopolis in the central-western Netherlands consisting primarily of the four largest Dutch cities (Amsterdam, Rotterdam, The Hague and Utrecht) and their surrounding areas.

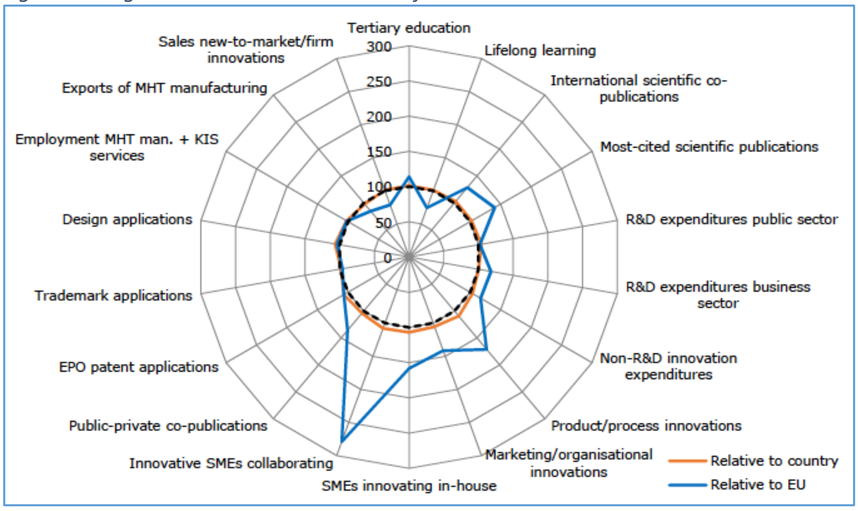
position. The importance of the chemical sector and the Port of Rotterdam is highlighted in the document. The S3 regional strategy for the Western Netherlands[28] includes the Rotterdam's chemical sector as one of the nine top industrial sectors. The nine areas of smart specialisation for West Netherlands are:

- Agri-food
- Chemicals
- Creative industry
- Energy
- High tech
- Life sciences and health
- Logistics
- Horticulture and propagation materials
- Water

3.3 Innovation ecosystem

The region of **Flanders** is an Innovation Leader, according to the Regional Scoreboard 2017 (see figure below)[29].

Figure 6 - Regional Innovation Scoreboard for Flanders



Source: EU Regional Innovation Scoreboard 2017

A dense network of universities, complemented by market-driven strategic research centres in selected fields, drives the knowledge-intensive economy. There are incentives from the Belgian and Flemish governments to stimulate innovation, ranging from investment incentives through tax-related schemes on to employment, training and R&D advantages, as well as facilitating access to bank credit.

A wide range of actors and stakeholders are involved in the Flemish STI landscape: public administrations and agencies, advisory bodies, knowledge institutes and centres, universities, university colleges, scientific institutes, public research organisations, various networks active in STI,

[28] European Commission (2014) *RIS3: Strategy for Smart Specialisation Western Netherlands: Final Version*
[29] European Commission (2017) *Regional Innovation Scoreboard 2017*

university hospitals, other research centres, data collection institutions, incubation centres, science and technology parks, technology transfer offices, other intermediaries and many private companies and professional (technology and other) organisations.

The Flemish Government, through the VLAIO agency, supports clusters in Flanders with a goal to unlock unused economic potential and increase competitiveness through active and sustainable collaboration between all cluster members. 50 % of the funding come in the form of public subsidy. One of the clusters is Catalisti[30], the cluster for Chemistry and Plastics, established to primarily serve companies in Flanders by building partnerships between individual companies as well as with research institutions, sector associations and governments. The box below provides more detail on the cluster.

Catalisti – The Spearhead Cluster for Chemistry and Plastics in Flanders

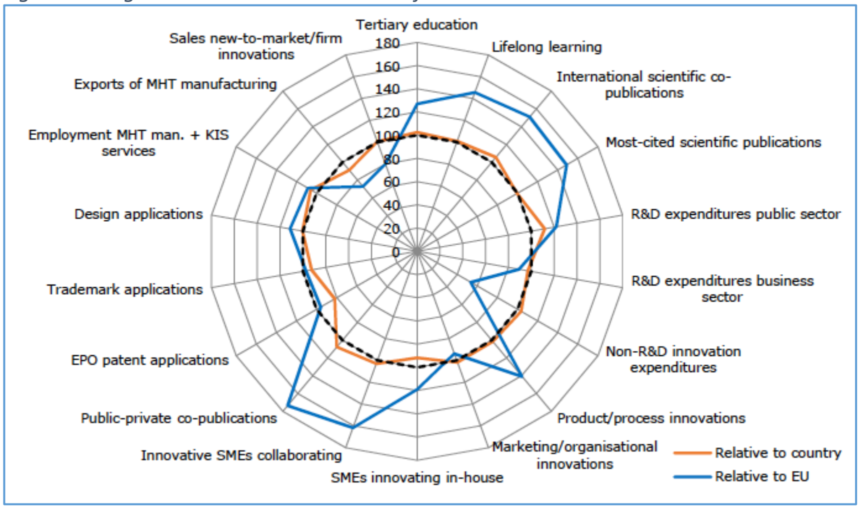
Officially started at the end of 2016 under the new name, the Catalisti cluster was set up to stimulate sustainable innovations in chemical and plastics sectors by means of intensive and cross-sectoral partnerships between small and large companies, research institutions and government organisations. Nearly a hundred companies and all Flemish universities participate in the project, together with the VITO (Flemish Institute for Technological Research) and some other research organisations. The task of the cluster is to find and offer solutions for major societal challenges. International cooperation is necessary because these societal challenges do not limit themselves to the borders of Flanders. The activities of the cluster span from applied research, to proof of concept to pre-production while following the "Triple F principle" of operation (see figure below).

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. The recent years have shown that this open model of collaboration can yield significant results and create a leverage effect for investments. The initial joint investment of the government and the participating companies was €25 million, which is estimated to have resulted in an economic added value of more than €575 million, or an economic leverage effect of 26.

More information available at: http://catalisti.be (in Dutch)

The region of **South Holland** (Zuid-Holland) is an Innovation Leader (see below).

Figure 7 - Regional Innovation Scoreboard for Zuid-Holland



Source: EU Regional Innovation Scoreboard 2017

[30] More information available at: http://catalisti.be/.

Thanks to substantial investments in innovation, above-average business dynamics and increasing labour productivity, South Holland has enormously improved its innovative strength. The province set up the regional development organisation, InnovationQuarter[31] offering three investment funds (a € 137 million budget in total). It provides funding for start-ups and SMEs in the sectors Cleantech, High Tech & Smart Industry, Safety & Security, Horticulture, Life Sciences & Health and Water & Maritime. Furthermore, it assists foreign investors that want to settle in the province and organises cooperation between innovative entrepreneurs, knowledge institutes and the government. It is one of the most active investors in the Netherlands.

The province boasts various centres of knowledge and expertise, including three research universities in the cities Leiden, Delft and Rotterdam. There are also various universities of applied sciences (Hogescholen). Non-university public research institutes in the region include, for example, the TNO research laboratories (in Delft and Leiden), Estec (European Space Agency in Noordwijkerhout) and UNESCO-IHE (in Delft). There are also a number of private research centres including Unilever Research Vlaardingen, Shell Rijswijk, DSM Delft and a large number of smaller research-intensive companies. Life Sciences is a specific strength of the universities of Leiden and Delft.

Other important regional organisations include Medical Delta, a consortium of life sciences, health and technology partners in the Netherlands, and Knowledge Alliance Rhine – Waal, a German – Dutch collaboration between different research and educational institutions from the Euregion Rhine – Waal.

3.4 Additional commentary on low-carbon solutions and circular economy

There are specific examples of initiatives and projects that focus on low-carbon solutions, circular economy, bio-based products etc. in the regions of Antwerp / Rotterdam:

- The ERDF Operational Programme Flanders (2014 – 2020) includes six thematic objectives, of which one is supporting the shift towards a low-carbon economy in all sectors.
- In its Vision 2050[32] the Flemish Government presents its long-term strategy. In order for the Vision 2050 objectives to succeed, the government works on seven transition priorities enabling the necessary changes to be made faster. The circular economy is one of these seven priorities. Circular Flanders is the result of an evolution in policy that has been going on since 2006.
- Antwerp Port Authority has teamed up with gas infrastructure operator Fluxy's to explore opportunities for carbon capture, storage and reuse at the port. The port has also installed a new refinery off gas unit with a saturated gas train and an unsaturated gas train to convert the off-gas from the refinery into low-cost petrochemical feedstock, replacing the oil-based naphtha feedstock[33].
- The S3 regional strategy for the Western Netherlands[34] explicitly points out the need to support low-carbon economy and city development.
- Circular Economy is one of the priorities for South Holland and the province aims to be completely energy-neutral by 2050[35].
- The bio-based economy in the Netherlands is recognised as an interesting topic, but not yet an explicit spearhead in policy. Several important facilities are located in South-Holland: BPF, Biotech Campus Delft, Delft, Veenweideinnovation center, Port of Rotterdam.

---

[31] More information available at: https://www.innovationquarter.nl/.

[32] Flemish Government (2016) *Vision 2050.*

[33] Information available at: http://www.portofantwerp.com/en/news/energy-transition-port-antwerp-and-fluxys-team-co2-capture

[34] European Commission (2014) *RIS3: Strategy for Smart Specialisation Western Netherlands: Final Version*

[35] More information available at: http://www.zuid-holland.eu/europe/circular-economy/

- The Port of Rotterdam has a facility that transforms non-recyclable waste into "green" methanol to fuel the chemical industry and transportation sector.
- ExxonMobil designed an aromatics plant to receive feedstock from nine refineries and chemical plants. This, has enabled this plant to become the largest and one of the most profitable in the region[36].

3.5 References

Beckx, F. (2016) Europe's leading chemical and life sciences industry is looking for talent, Essencia

Dutch Government (2014) Adaptive Agenda Southern Randstad 2040

Essencia (2017) Sustainable development report 2017 of the Belgian chemicals, plastics and life sciences industry

European Commission (2014) RIS3: Strategy for Smart Specialisation Western Netherlands: Final Version

European Commission (2017) Regional Innovation Scoreboard 2017

Flemish Government (2016) *Vision 2050*

Geerts, N., Van Langenhove, M., Viaene, P. and Verdoodt, P. (2017) *STI in Flanders*

Metropolitan Region Rotterdam The Hague (2016) *The Roadmap Next Economy*

Port of Antwerp (2015) Port of Antwerp: Europe's leading integrated oil and chemical cluster

Port of Rotterdam (2016) Facts and Figures on the Rotterdam Energy Port and Petrochemical Cluster

Technopolis (2016) Regional Innovation Report: Flanders (Production related biotechnology)

VNCI and Deloitte (2012) The Chemical Industry in the Netherlands: World leading today and in 2030–2050

4 Geleen

4.1 Chemical and process sector

Geleen is a city in the southern part of the province of Limburg, the southernmost of the 12 provinces of the Netherlands. It is part of the municipality of Sittard-Geleen, with a population of approximately 96,000. Sittard-Geleen is the third largest Limburg's municipality. The city is well linked to the rest of the country, but also to the neighbouring countries by two railway lines and two motorways.

The social and economic trends that affected the province in recent decades generated a process of change and renewal which has enabled Limburg to transform its peripheral location into a highly globalised regional nexus, linking the Netherlands to the Ruhr metropolitan area and the southern part of the Benelux region. Airports of Maastricht Aachen, Brussels, Düsseldorf, Köln-Bonn and Liège are located within a circle of 100 km.

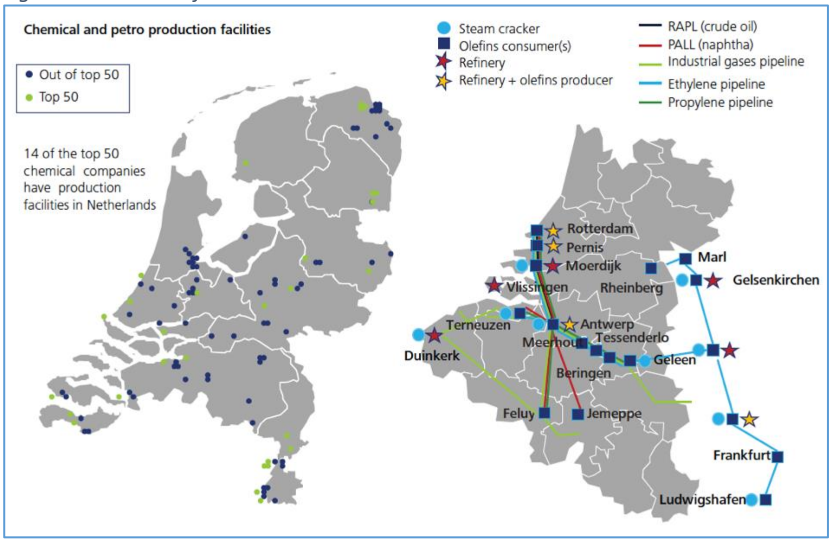
Limburg forms part of the Antwerp-Rotterdam-Rhine-Ruhr Area (ARRRA), one of the strongest chemical clusters in the world. This cluster is responsible for a huge array of products that supply the competitive European manufacturing industry for both domestic and export markets. More than 470 chemical companies operate in the province of Limburg. The chemical sector employs some 13,500

[36] Information available at: http://corporate.exxonmobil.com/en/company/news-and-updates/speeches/innovation-and-the-evolution-of-chemical-feedstocks

people in the SIC sectors 20, 21, 22 and 23. The average salary for the SIC code 20 in Limburg was €68,000 annually in 2015.

In 2015, chemical industry represented 20% of the total value of exports of the Limburg region[37]. Nearly 22% of the added value that the chemical industry in the Netherlands generated in 2015 came from Limburg. With an added value of €1.6 billion, the chemical sector represented one-fifth of the total industrial added value generated in Limburg in 2014 (with a prospect to grow to €2.4 billion in 2020). Nationally, this share does not exceed 7%. The chemical sector in Limburg features 15,000 jobs accounting for 20% of total industrial employment in the region[38].

Figure 8 - Position of Sittard-Geleen within ARRRA chemical cluster



Source: VNCI and Deloitte (2012) The Chemical Industry in the Netherlands: World leading today and in 2030–2050.

The chemical sector concentrated in and around Sittard-Geleen is significant and well-established and it is the birthplace of Koninklijke DSM[39], known for its innovative products and services in the areas of life sciences and materials. Around 6,000 people work at this innovative company, of which approximately 25% works in research, development and innovation. Therefore, the Netherlands is an important incubator for DSM’s innovative activities, some of which have a global impact. Other companies include SABIC, Sekisui, Celanese, Vynova, OCI Nitrogen, LANXESS, QCP, AnQore, Carbolim and Mitsubishi Engineering Plastics.

Significant innovative activity has arisen around DSM and the University of Maastricht, resulting in the establishment of the Chemelot Industrial Park[40], one of Western Europe's biggest industrial sites. The box below provides more information.

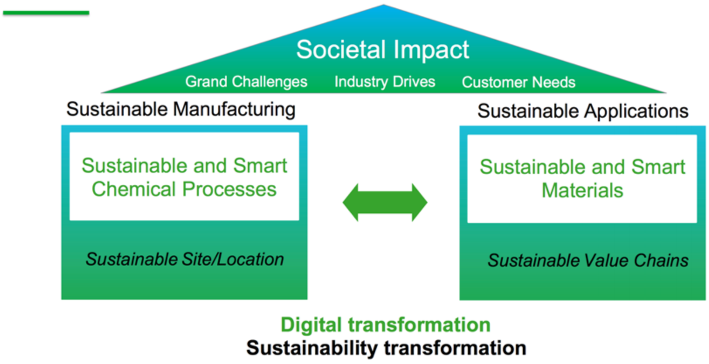
The Chemelot Industrial Park

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 chemical companies into a single, open innovation community of several thousand knowledge workers. The composition of the partners means that the ownership structure of Chemelot is based on the Triple Helix principle. Altogether, Chemelot provides jobs for around 8,000 people of more than 100 nationalities, and hosts more than 60 factories and 150 companies. It offers business opportunities in biomaterials, functional coatings, smart packaging, renewable energy, and automotive supply. Its total area

[37] https://www.cbs.nl/-/media/_excel/2017/40/170512%20export%20provincie%20limburg%20def.xlsx.
[38] https://www.liof.com/en/Key-Industries/Chemicals-and-Materials.
[39] DSM is a major chemical company, still operating in Limburg. In 2002, DSM sold its petrochemical division (naphtha crackers and polyolefin plants) to SABIC of Saudi Arabia. In 2010, the agro and melamine business groups were sold to OCI Nitrogen.
[40] More information available online at: https://www.chemelot.nl/.

comprises some 800 hectares. Chemelot has also a Research and Business Campus where many companies perform research and develop new products and which offers space to approximately thousand students and researchers.

The activities of the campus are focused on high-quality materials, biomedical materials, and bio based materials. The campus provides a creative ground for innovation and for new companies. Every year, the campus scouts out approximately 100 start-ups. The best of them in the chemical and materials sector are offered incentives to establish a permanent presence on the campus. Companies on the campus can access various sources of regional venture funding, including from the regional development agency LIOF and LimburgMakers (see Section 4.3). Sustainability is at the heart of the operation of the campus. The campus aims to achieve societal impact by sustainable manufacturing and sustainable applications (see figure below).



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 moved its entrepreneurship development activities to the campus in 2017, aiming at further strengthening its presence on the campus.

More information available at: https://www.chemelot.nl/homepage

Statistical indicators – Limburg (incl. Sittard-Geleen), The Netherlands

Indicators on the chemical sector	SIC 20	SIC 21	SIC 22	SIC 23	Notes
Number of companies	104	19	132	223	Eurostat, 2015 (sbs_r_nuts06_r2)
Employment + share of the manufacturing total in brackets	5,868 (10.4%)	182 (0.3%)	3,244 (5.8%)	4,166 (7.4%)	Eurostat, 2015 (sbs_r_nuts06_r2)
Growth rate of employment (%)	-3.7%	15.2%	0.8%	-4.0%	Eurostat, 2015 (sbs_r_nuts06_r2)
Output - Turnover	Nearly 22% of the added value that the chemical industry in the Netherlands generated in 2015 came from Limburg. With an added value of €1.6 billion, the chemical sector represented one-fifth of the total industrial added value generated in Limburg in 2014 (with a prospect to grow to €2.4 billion in 2020).				Ad-hoc reports, referenced in text
Turnover (all the Netherlands) (€m)	46,826	5,803	8,998	5,609	Eurostat, 2015 (sbs_na_sca_r2)
Gross value added per employee (all the Netherlands) (thousand €)	191	159	87	81	Eurostat, 2015 (sbs_na_sca_r2)
Export activity	In 2015, chemical industry represented 20% of the total value of exports of the Limburg region.				Ad-hoc reports, referenced in text
Export activity (all the Netherlands) (thousand €)	21,874,968	6,272,927	4,416,912	1,182,369	Eurostat, 2015 (ext_tec07)
Supply chain integration	N/A	N/A	N/A	N/A	

Wages (€m)	399.9	N/A	148.7	191.2	Eurostat, 2015 (sbs_r_nuts06_r2)
Average wage/salary (€)	68,149	N/A	45,838	45,895	Own calculation, based on Eurostat data
Skills levels	There is an ageing workforce in the Dutch chemical sector, which is tackled by public-private skills planning.				http://www.chemlandscape.cefic.org/wp-content/uploads/pdfs/Netherlands-70.pdf
Age profile					
Average size of enterprise	56 employees	10 employees	25 employees	19 employees	Own calculation, based on Eurostat data
Ownership structure	N/A	N/A	N/A	N/A	

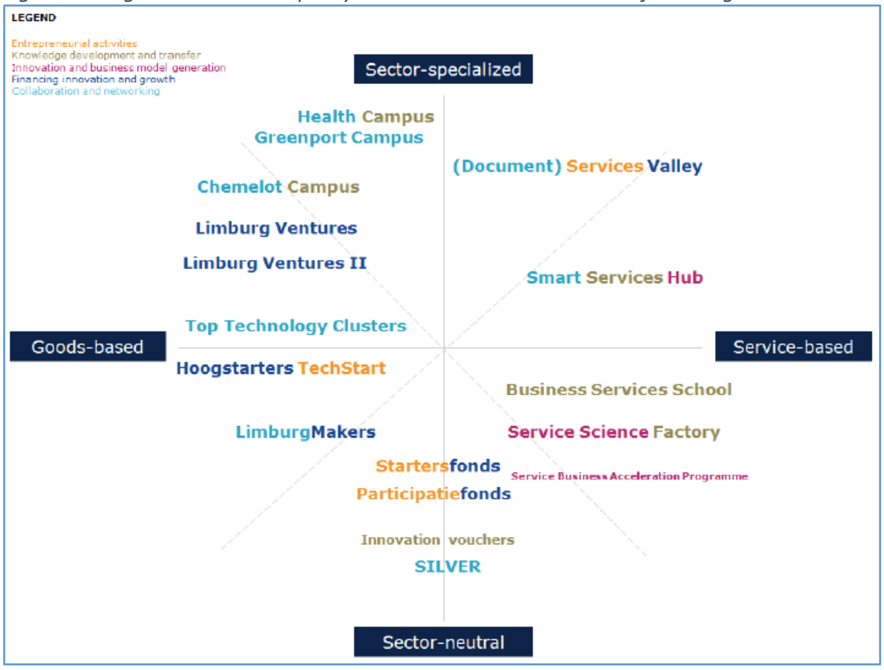
4.2 Policy agenda

Limburg's innovation policy revolves around creating the right framework conditions (by developing knowledge infrastructure), networking (a vital, resilient and innovative network of SMEs) as well as clustering and investing in campuses in those areas where the provincial economy has its strengths, including the chemical sector. The Smart Specialisation strategy for the region of the Southern Netherlands[41] covers also the province of Limburg (in addition to Noord-Brabant and Zeeland). It aims to develop the innovation potential of the region, and to make the region an economic pillar for the Netherlands. Chemistry is one of the five priority areas of smart specialisation. The strategy is a key regional innovation policy document that is linked to the funding opportunities in the Operational programme (OP) Zuid (Southern Netherlands). The Zuid programme's focus is stimulating innovation and the transition to a low-carbon economy, specifically aiming at SMEs and the collaboration between industry, knowledge institutions and the government. It also focuses on crossovers between international top clusters (high tech systems, chemistry, agro-food) and national top clusters (life sciences and health, bio-based economy, logistics and maintenance). Limburg is one of the first European model demonstrator regions[42] which harness the transformative power of service innovation and foster cross-sectoral spill-overs between manufacturing and service sectors.

The development of industrial campuses (including Chemelot) that match with the national top-sector policy is a cornerstone in the economic policy of Limburg. Four campuses have been established so far, combined under the name Brightlands. The campuses are bringing their resources together in public-private partnerships and it is expected that these investments will lead to new start-ups and new knowledge-intensive jobs. The platform LimburgMakers[43] is one of the instruments to support innovation in the region. It provides subsidy for innovative projects in the manufacturing sector up to 50% of the total costs. Other instruments are the MIT Zuid[44] programme and CrossRoads2[45], a project within the European programme Interreg Vlaanderen-Nederland. This project aims at cross-border collaboration between SMEs in Flanders and the Netherlands. Figure 9 provides an overview of the innovation support instruments in the region.

[41] RIS3 Zuid (2013) *Research and Innovation Strategy for Smart Specialisation for Zuid-Nederland, the region compromising Noord-Brabant, Limburg and Zeeland (the South Netherlands).*
[42] The concept of the 'model demonstrator region' or 'large scale demonstrator' is the cornerstone of a new systemic approach launched by the European Commission that aims to foster economic growth by addressing a specific problem or societal challenge through service innovation and under real life conditions.
[43] The official website available at: https://www.liof-limburgmakers.nl/.
[44] More information available at: https://www.stimulus.nl/mit-zuid/.
[45] More information available at: https://www.crossroads2.eu/.

Figure 9 - Regional innovation policy instruments in the Province of Limburg



Source: Technopolis Group and Dialogic (2014) Policy Brief for the Province of Limburg. European Service Innovation Centre

4.3 Innovation ecosystem

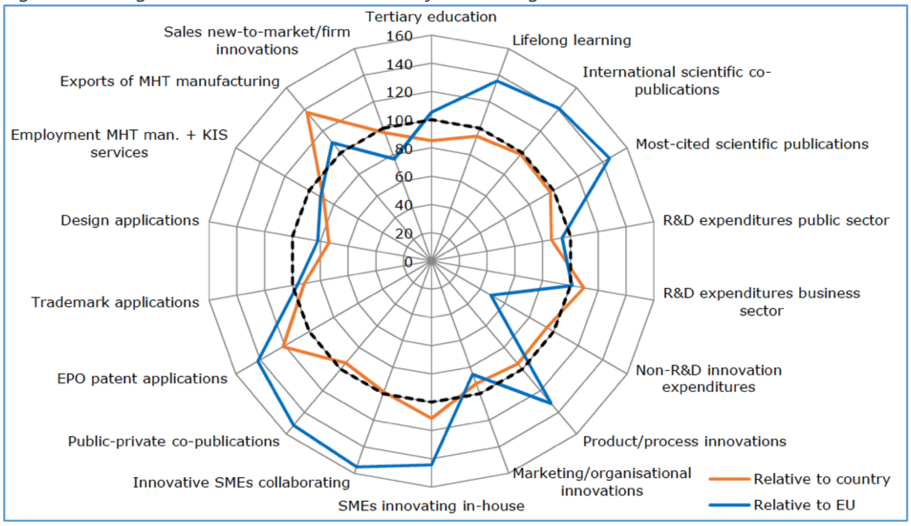
The province of Limburg is an Innovation Leader, and innovation performance has increased significantly over time (Figure 10). It is one of the few regions in the EU with advanced policy thinking in terms of developing its manufacturing industry through the transformative power of service innovation. It has already demonstrated its capacity and capability to transform the region from an old mining area into one that hosts a developed chemical manufacturing industry and it has an ambition to continue with the transformation in new, innovative fields.

The Limburg Development and Investment Company (LIOF)[46] is the regional development and investment company operating in Limburg. LIOF was established in 1975 and is headquartered in Maastricht. Its purpose is to support the development of the province's economy and its business climate. The Dutch Government (the Ministry of Economic Affairs) and the province hold an equal share (both 50%) in LIOF and make important decisions on the basis of equal consultation. LIOF provides venture capital to innovative and potentially viable SMEs, stimulate knowledge-driven and innovative projects created by SMEs and promotes the regional SMEs to foreign investors. LIOF provides finance all sorts of start-up companies. It offers pre-seed finance of €30,000 to €35,000, accounting for a maximum of 80% of the business development ('Techstart' fund). LIOF has a participation fund, called Participatiefonds, supporting the development of small companies and expansion of medium to large companies. Small companies can get a loan of €150,000 to €500,000 and medium to large companies can get a loan of €500,000 to €2,000,000.

The Geleen cluster benefits from a long standing and close relationship with the University of Maastricht, which is also linked to the United Nations University – Maastricht Economic and Social Research Institute on Innovation and Technology (UNU-MERIT): together they are a well-known centre of excellence on innovation policy. The smaller scale of the Geleen/Limburg cluster compared to others, and the greater weighting towards higher-value specialty products, encourages close cluster collaboration.

[46] More information available at: https://www.liof.com.

Figure 10 - Regional Innovation Scoreboard for Limburg



Source: EU Regional Innovation Scoreboard 2017

4.4 Additional commentary

4.4.1 Low Carbon solutions

The Operational Programme Zuid promotes innovation and the transition to a low carbon economy. With this programme, and in combination with additional public and private co-financing, the region aims to strengthen its potential for research and innovation while at the same time supporting the shift to a resource-efficient, low-carbon economy. Limburg therefore aims to contribute to the overarching EU2020 strategy for smart, sustainable and inclusive growth and to the Dutch targets set in this regard.

4.4.2 Circular Economy

In November 2017, the European Investment Bank (EIB) and the Province of Limburg signed a loan agreement to support investments in regional sustainability projects. The €30 million loan is guaranteed under the European Fund for Strategic Investments (EFSI), part of the Investment Plan for Europe of the European Commission[47]. The Limburgs Energie Fonds (LEF), a fund established by the Province of Limburg, investing in small- to medium-sized projects in and for Limburg in the areas of reduction of carbon emissions, removal of asbestos in buildings and circular economy initiatives, channels the loan.

The sector of High-Tech Smart Materials (HTSM) in Limburg develops and produces high-end products, components, smart materials and services for customers worldwide. Public and private collaboration in research and development of HTSM forms an essential link in the circular economy cycles. In the context of chemistry and bio-based concepts, Limburg aspires on a leading position internationally in more sustainable chemicals and materials.

4.5 References

Brainport 2020 Strategy

Centraal Bureau voor de Statistiek (2016) *Export – Province of Limburg*, available online at: https://www.cbs.nl/-/media/_excel/2017/40/170512%20export%20provincie%20limburg%20def.xlsx

[47] More information available online at: http://www.eib.org/infocentre/press/releases/all/2017/2017-314-european-support-for-sustainable-investments-in-limburg.htm.

Coalition Agreement for the Limburg 2015 – 2019.

Netherlands Foreign Investment Agency (2016) *Chemicals: The Netherlands*.

Official website of Chemelot - https://www.chemelot.nl

RIS3 Zuid (2013) Research and Innovation Strategy for Smart Specialisation for Zuid-Nederland, the region compromising Noord-Brabant, Limburg and Zeeland (the South Netherlands).

S3Chem Interreg Europe (2016) Smart Chemistry Specialisation Strategy: Report on current status of implementation of Regional Innovation Strategies in Limburg.

Technopolis Group and Dialogic (2014) *Policy Brief for the Province of Limburg*. European Service Innovation Centre.

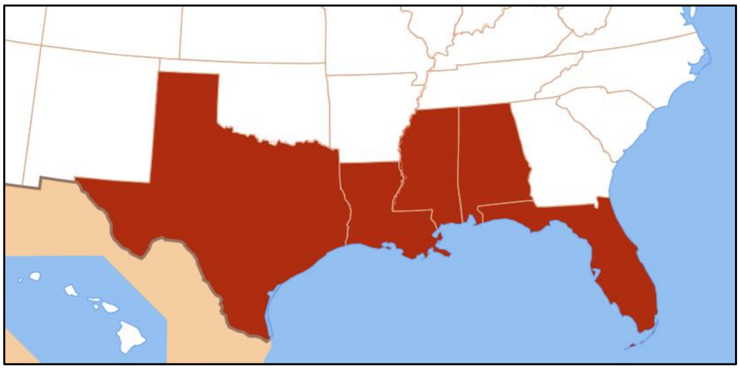
TNO (2017) Synthesis of the CBS-TNO report on Composition analysis of the Limburg economy.

VNCI and Deloitte (2012) The Chemical Industry in the Netherlands: World leading today and in 2030–2050.

5 Gulf Coast (USA)

5.1 Chemical and process sector

Figure 11 The Gulf Coast of America.



Source: Wikipedia.

The Gulf Coast of the USA includes the states of Alabama, Florida, Louisiana, Mississippi and Texas. It is known as the heart of petrochemical manufacturing and chemical production in the US due to its geographical proximity in the gulf being a rich source of natural resources for chemical manufacturing. The intra-costal system along the Gulf Coast is also a major water route to transport chemicals[48]. Texas and Louisiana produce a majority of all primary petrochemicals[49] and Texas alone has the highest value of shipments (in 2015) and chemical exports (in 2016) in the US. One part of Texas' continued success is the hub at Mont Belvieu which has attracted significant fractionation and storage activities[50], an approach planned to enhance the offering of the Appalachian region[51]. Overall, the region produces the most chemicals compared to the other US regions and has seen higher percentage increases in recent years, likely due to recent investments (Figure 12).

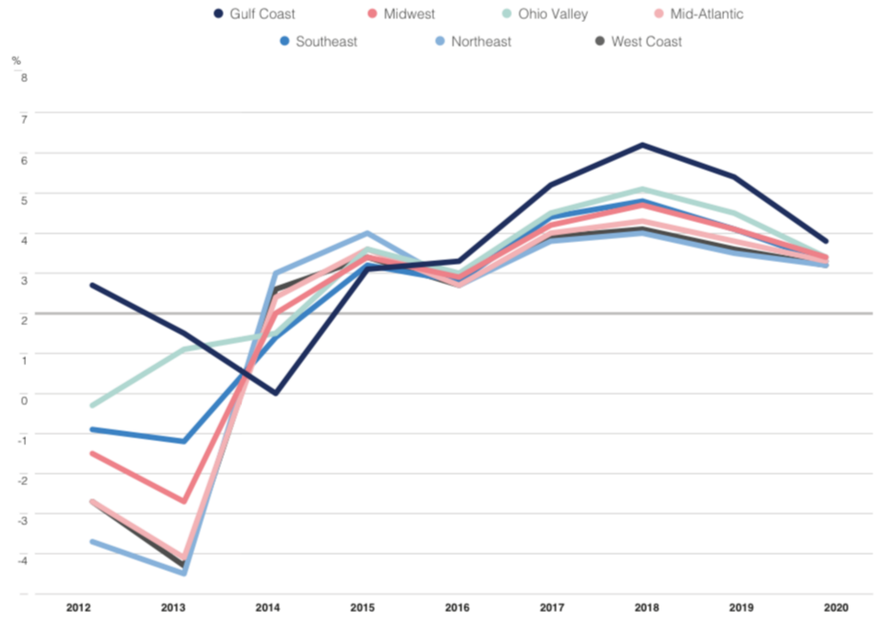
[48] American Chemistry Council (2017) – "Elements of the business of chemistry 2017" https://www.americanchemistry.com/2017-Elements-of-the-Business-of-Chemistry.pdf

[49] Office of Energy Efficiency and Renewable Energy – "Chemicals Industry Profile" https://www.energy.gov/eere/amo/chemicals-industry-profile

[50] Oil and Gas Journal (06/02/2014) – "What's at Mont Belvieu?" https://www.ogj.com/articles/print/volume-112/issue-6/speical-report-worldwide-gas-processing/what-s-at-mont-belvieu.html

[51] Petrochemical Update (16/06/2017) – "U.S. prepared for more than a second wave of chemical investment– ACC" http://analysis.petchem-update.com/engineering-and-construction/us-prepared-more-second-wave-chemical-investment-acc

Figure 12 U.S. Chemical production by region 2012-2020 (% change year-on-year).



Source: American Chemistry Council, December 2015.

The refining and chemical manufacturing industry contribute 5% of GDP in the Gulf Coast whilst only employing less than 1% of the total employed population[52]. Supply chain groups are planning around $155 billion in capital investments, 80% of that spending will take place in the Gulf region[53]. 210 chemical and plastics industry projects have been announced in America's Gulf Coast region since 2010 (valued at $133bn) which could create around 317,000 jobs, according to the American Chemistry Council (ACC)[54]. As of March 2018, 53% percent of this is completed or in-progress. Due to changes in the American tax law ('Tax Cuts and Jobs Act' – January 2018)[55], ExxonMobil announced investments in the chemical manufacturing sector of over $50bn[56] in addition to the $20bn planned from 2013-2022 specifically in the Gulf Coast region[57].

The entire refining and chemical manufacturing industry employed 253,000 people in the Gulf Coast in 2015 (0.7% of all employment)[58]. It is estimated that one of these jobs may support an additional

[52] U.S. Bureau of Economic Analysis.
[53] Petrochemical Update (11/01/2018) - "Supply chain capital spending peaks as companies prepare for export tsunami" http://analysis.petchem-update.com/supply-chain-logistics/supply-chain-capital-spending-peaks-companies-prepare-export-tsunami
[54] American Chemistry Council Statement for the Record Submitted to the Senate Committee on Energy and Natural Resources Business Meeting to Consider Pending Legislation March 8, 2018
[55] American Chemistry Council (18/12/2018) - "ACC Applauds Final Tax Reform Legislation" https://www.americanchemistry.com/Media/PressReleasesTranscripts/ACC-news-releases/ACC-Applauds-Final-Tax-Reform-Legislation.html
[56] ExxonMobil Darren Woods (01/29/2018) – "Tax and regulatory reform's economic boon" https://energyfactor.exxonmobil.com/perspectives/economic-boon/
[57] ExxonMobil (06/03/2017) – "ExxonMobil Plans Investments of $20 Billion to Expand Manufacturing in U.S. Gulf Region" http://news.exxonmobil.com/press-release/exxonmobil-plans-investments-20-billion-expand-manufacturing-us-gulf-region
[58] U.S. Bureau of Labor Statistics (2015) - "2015 annual Quarterly Census of Employment and Wages data"

four jobs in the wider economy[59]. In 2015, Texas employed over 100,000 petrochemical workers[60] with an average annual salary of $82,000[61].

In the wider USA, employment across SIC 20, 21, 22 and 23 was 2,299,000 in 2017[62] and the average wage was $65,080 (1.2% rise from 2016)[63]. There are concerns about the aging workforce for which the median age average is 44.6 across SIC 20-23. This has galvanised chemical manufacturing employers to plan for the recruitment of skilled younger individuals. The regional state governments have invested heavily into education enhancement programmes more generally that could directly or indirectly help those companies employ highly skilled workers for the future[64]. The major universities in the area contribute heavily to the R&D of the sector and run popular courses in their chemical engineering departments. These institutions also help the industry reach out to students through internship programmes.

Statistical indicators – Gulf Coast (USA)

Indicators on the chemical sector	SIC 20 - Manufacture of chemicals and chemical products	SIC 21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	SIC 22 - Manufacture of rubber and plastic products	SIC 23 - Manufacture of other non-metallic mineral products	Notes
Number of companies	N/A	N/A	N/A	N/A	
National - Employment + share of the manufacturing total in brackets	805,000 (5.22%)	518,000 (3.36%)	529,000 (3.43%)	447,000 (2.90%)	Bureau of Labor Statistics – Total USA Employed persons by detailed industry and age 2017
Growth rate of employment (%)	N/A	N/A	N/A	N/A	
Output - Turnover	N/A				
Export activity	N/A	N/A	N/A	N/A	
Supply chain integration	N/A	N/A	N/A	N/A	
Wages (€m)	N/A	N/A	N/A	N/A	
Average wage/salary (€)	USD82,000 (€71,000)	N/A	N/A	N/A	Business in Texas (June 2015) (Texas only)
Skills levels	N/A	N/A	N/A	N/A	

[59] Scott, Loren (2014) - “The Energy Sector: Still a Giant Economic Engine for the Louisiana Economy”
[60] Business in Texas (June 2015) – “Petroleum refining & chemical products” https://businessintexas.com/sites/default/files/07/24/17/petroleum.pdf
[61] Business in Texas (June 2015) – “Petroleum refining & chemical products - overview” https://businessintexas.com/industries/petroleum-refining-chemical-products
[62] Bureau of Labor Statistics – Total USA Employed persons by detailed industry and age 2017
[63] May 2017 National Industry-Specific Occupational Employment and Wage Estimates - NAICS 3250A1 - Chemical Manufacturing (3251, 3252, 3253, and 3259 only) https://www.bls.gov/oes/current/naics3_325000.htm
[64] American Chemistry Council (2016) – “United states chemicals 2016” https://www.gbreports.com/wp-content/uploads/2016/02/US_Chemicals2016_IE_web.pdf

National Age profile	45.2	44	43.9	45.3	Median age. Bureau of Labor Statistics - Employed persons by detailed industry and age 2017
Average size of enterprise	N/A	N/A	N/A	N/A	
Ownership structure	N/A	N/A	N/A	N/A	

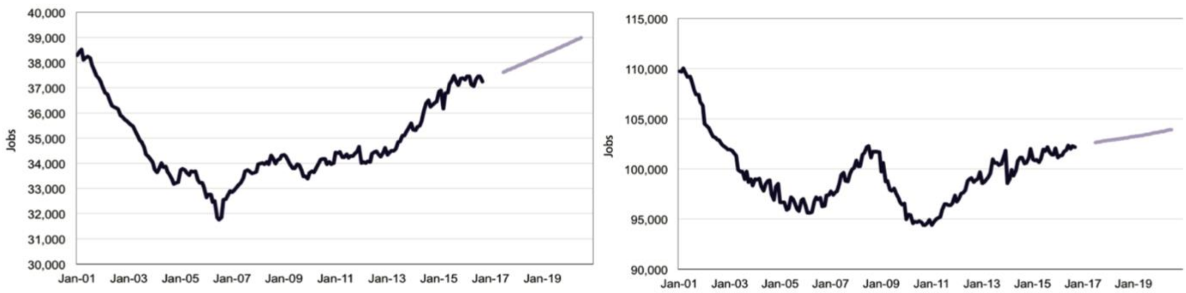
The Gulf Coast's manufacturing sector employment is growing rapidly, particularly in Texas and Florida and Figure 13 shows that Louisiana and Texas refining and chemical manufacturing employment since the shale gas boom in 2005/06 has increased significantly but has not reached the high levels of the very early 2000s. Projections by the LSU Centre for Energy Studies (purple in the graphs) predict increases in the sector for both states.

Table 1 Employment in the Gulf Coast manufacturing sector and employment growth

State	2017	2018	Growth %
Alabama	262,900	268,100	1.9%
Florida	363,700	375,800	3.2%
Louisiana	134,600	137,300	1.9%
Mississippi	143,900	144,700	0.5%
Texas	848,300	877,700	3.3%
Gulf total	1,753,400	1,803,600	Average: 2.16%

Source: U.S. Bureau of Labor Statistics, 2018 annual Quarterly Census of Employment and Wages data.

Figure 13 Louisiana (left) and Texas (right) Refining and Chemical Manufacturing Sector Employment Forecasts. Source: LSU centre for energy studies.



Source: Data from - U.S. Bureau of Labor Statistics, 2015 annual Quarterly Census of Employment and Wages data.

There are concerns over the transportation of chemical exports to and from the Gulf Coast region. A combination of port and rail congestion has led to manufacturers planning new supply chains to bypass the area, despite improvements being made to ports in the Gulf, particularly Houston. This will likely become progressively more detrimental given the large proportion of new projects and investment being injected into the region both now and in the future. In addition, chemical production was greatly reduced or completely shut down by the negative impact of Hurricane Harvey. The areas directly affected by Harvey account for around one-fifth of total chemical industry shipments in the United States[65].

In the wider US context, a study exploring workforce challenges in the North American chemical industry reported a concern about the age profile of workers in the industry, specifically the challenge of replacing retiring employees with suitably talented younger workers[66]. Other issues CEOs cited included skill sourcing (attracting appropriately skilled employees), changing demographics (retiring workers and retaining millennials) and leveraging digital technology (AI, collaboration tools, data analytics). The US has recorded the second highest sales of chemicals in the world since 2011, behind China, and is the EU's biggest trading partner, contributing 21.9% of the EU's total chemicals trade in 2016[67,68]. The US contributed almost 20% of world chemical exports in 2016 and is the world's biggest producer of bioethanol (54% of world production in 2013). Increased exports resulted in a $32 billion trade surplus in chemicals in 2017 and total chemical exports rose 4.9% to $127 billion, while imports rose 2.8% to $96 billion. Two-way trade between the U.S. and its foreign partners reached $223 billion at the end of 2017, a 4.0% expansion over 2016[69]. The shale gas boom in the United States has greatly reduced energy and feedstock costs for production in comparison to Europe which has contributed significantly to this boom in activity. The US contributes 20% of global R&D investment in the chemical industry and spends around €7.9bn annually on R&D, behind China and the EU.

5.2 Regulation and policy agenda

Relatively light regulatory conditions have provided a good environment for the chemical sector, particularly for activities such as fracking which allow for the collection of natural gas (crucial for chemical manufacturing)[70]. However, environmental regulations pose a large problem for the sector. Despite earlier rejections in the senate, several states are considering and implementing carbon cap and trade programmes to reduce emissions, encouraged by the Environment protection Agency (EPA). The extra cost of dealing with the regulation in a rapidly growing region such as the Gulf Coast would offset its shale gas cost saving gains. Regulation on the chemical industry is also seen as very outdated and inconsistent across states, many companies are calling on the government to implement regulation similar to REACH in Europe to fix this issue and bringing all regulation and company procedures in line to improve efficiency[71].

The biggest policy decisions that impact upon the Gulf Coast's chemical sector are those on import/export tariffs. The position of private companies and the American Chemistry Council (ACC) is that eliminating tariff and non-tariff barriers on intra-company trade, as well as overall trade would be of great benefit to the sector. These refer to both the section 232 and 301 actions on steel and aluminium which has exasperated the Chinese government who have, in turn, imposed tariffs on

---

[65] American chemistry Council (31/08/2017) – "Statement By ACC President and CEO Cal Dooley in Response to Hurricane Harvey" https://www.americanchemistry.com/Media/PressReleasesTranscripts/ACC-news-releases/Statement-By-ACC-President-and-CEO-Cal-Dooley-in-Response-to-Hurricane-Harvey.html
[66] Accenture and the American Chemistry Council (2016) – "The North American Chemical Industry: Building a Workforce for Tomorrow"
[67] Cefic Chemdata International (2011) - Facts & figures 2011 of the European chemical industry
[68] Cefic Chemdata International (2017) - Facts & figures 2017 of the European chemical industry
[69] Petrochemica Update (16/11/2017) – "US Gulf develops automated systems to improve container availability" http://analysis.petchem-update.com/supply-chain-logistics/supply-chain-capital-spending-peaks-companies-prepare-export-tsunami
[70] David Spence (2010) – "Fracking Regulations: Is Federal Hydraulic Fracturing Regulation Around the Corner?" https://www.mccombs.utexas.edu/~/media/Files/MSB/Centers/EMIC/EMIC%20Misc/Fracking-Regulations-Is-Federal-Hydraulic-Fracturing-Regulation-Around-Corner.PDF
[71] Health and Safety Executive – "Registration, Evaluation, Authorisation & restriction of Chemicals (REACH)" http://www.hse.gov.uk/reach/

Chemical exports[72]. The ACC also produced a report that encourages the government to modernise the NAFTA to boost U.S. chemical exports to Canada and Mexico by 34 percent by 2025. Withdrawal from the agreement would force Canada and Mexico to import from the US's main competitor: China[73].

The US Gulf Coast reflects a fragmentation of responsibility across several States, though at federal level the recent Tax Cuts and Jobs Act introduced on November 2nd 2017[74]. It includes a number of provisions long-sought by the chemical industry, such as slashing the corporate tax rate from the current 35% to 21% and taxing U.S.-based multinationals only on their domestic income. The bill has already led to optimistic announcements by major companies[75], with ExxonMobil pointing to "recent changes to the U.S. corporate tax rate coupled with smarter regulation" as factors contributing to a decision to invest $50 billion over five years. The company plans to increase oil production in the Permian Basin in West Texas and New Mexico, which will be in addition to its existing $20 billion Growing the Gulf effort, which aims to start or increase 11 chemical, refining, lubricant and liquefied natural gas projects in Texas and Louisiana. Others have attributed record net income to the reduced income tax from the act[76]. Tax changes include a preferential rate for repatriated earnings reinvested in plants and equipment than for those taken in cash or equivalent.

5.3 Innovation ecosystem

The landscape of innovation policy is very wide as the region is made up of several states with different innovation agendas; Florida is chiefly concerned with Marine ecosystem solutions and Texas is more focused on the energy technology and higher education sectors. Taking Houston (Texas) as one example, The Greater Houston Partnership's 'Houston Exponential' initiative[77] 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. This scheme was set up because Houston's start-up activity was under-indexed in high-growth, high-impact start-up innovation, particularly in tech. The key recommendations made by the Innovation Technology Task Force focused on the government creating a better innovation ecosystem by creating an innovation district and better encouraging corporate relationships with the start-up community[78].

The Gulf Coast Community Foundation is a community supported charity using grants to invest in the areas of health and human services, civic and economic development, education, arts and culture, and the environment. Their aim is to support local innovation to attract talent and big business to the

---

[72] American Chemistry Council (12/04/2018) "ACC President and CEO Testifies on Damaging Impact Tariffs Would Have on Booming U.S. Chemicals Industry" - https://www.americanchemistry.com/Media/PressReleasesTranscripts/ACC-news-releases/ACC-President-and-CEO-Testifies-on-Damaging-Impact-Tariffs-Would-Have-on-Booming-US-Chemicals-Industry.html

[73] American Chemistry Council (28/02/2018) "ACC Report: NAFTA Critical to Growth and Job Creation by U.S. Chemical Manufacturers" - https://www.americanchemistry.com/Media/PressReleasesTranscripts/ACC-news-releases/ACC-Report-NAFTA-Critical-to-Growth-and-Job-Creation-by-US-Chemical-Manufacturers.html

[74] 115th United States Congress – "An Act to provide for reconciliation pursuant to titles II and V of the concurrent resolution on the budget for fiscal year 2018" - https://waysandmeansforms.house.gov/uploadedfiles/bill_text.pdf

[75] See for example https://blog.americanchemistry.com/2018/01/tax-law-is-boosting-chemical-industry-investment-in-the-u-s/

[76] Newsok (3rd May 2018) "Westlake Chemical Corporation Announces Record First Quarter 2018 Results" https://newsok.com/article/feed/2138010/westlake-chemical-corporation-announces-record-first-quarter-2018-results

[77] The Greater Houston Partnership – "Houston Exponential" https://www.houston.org/innovation/

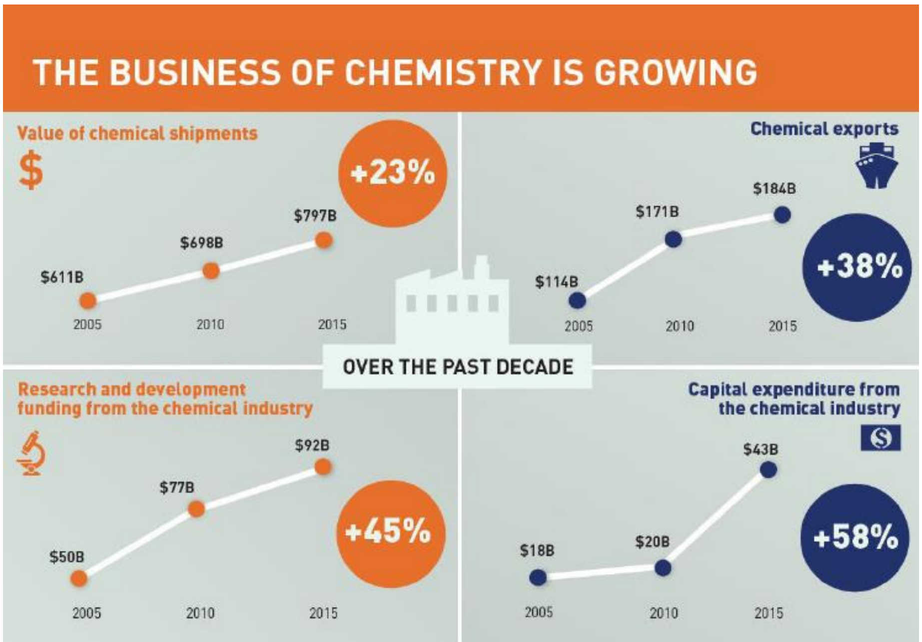
[78] Houston Technology & Innovation Task Force (June 2017) - "Startup Genome Global Startup Ecosystem Report 2017" http://www.houston.org/pdf/comm/Startup-Genome-Report-2017.pdf

region using their BIG-Bright Ideas initiative that connects new and growing businesses with the right resources and partners[79]. The Foundation also provides a $500,000 incentive-grant called the "innovation challenge" scheme which encourages innovators to develop business solutions to positively and sustainably impact the Gulf Coast region's Blue Economy[80].

5.4 Additional commentary

The shale gas boom

The availability of inexpensive natural gas in the Gulf coast region has been the key to the its success as the gas is used as a feedstock in the production of various chemical commodities[81]. This in turn has brought significant investment to the region in what is called the "shale gas boom" due to the plentiful feedstock. Dow is has committed to expanding its operations on the Gulf, spending $6bn on facilities including a new "cracker" used to produce ethylene as a result of the boom. It has also led to a growth in employment: Since 2010, the number of chemical industry jobs has grown from 786,500 to 805,600, with an accompanying increase in average hourly wages from $21.07 to $22.75.



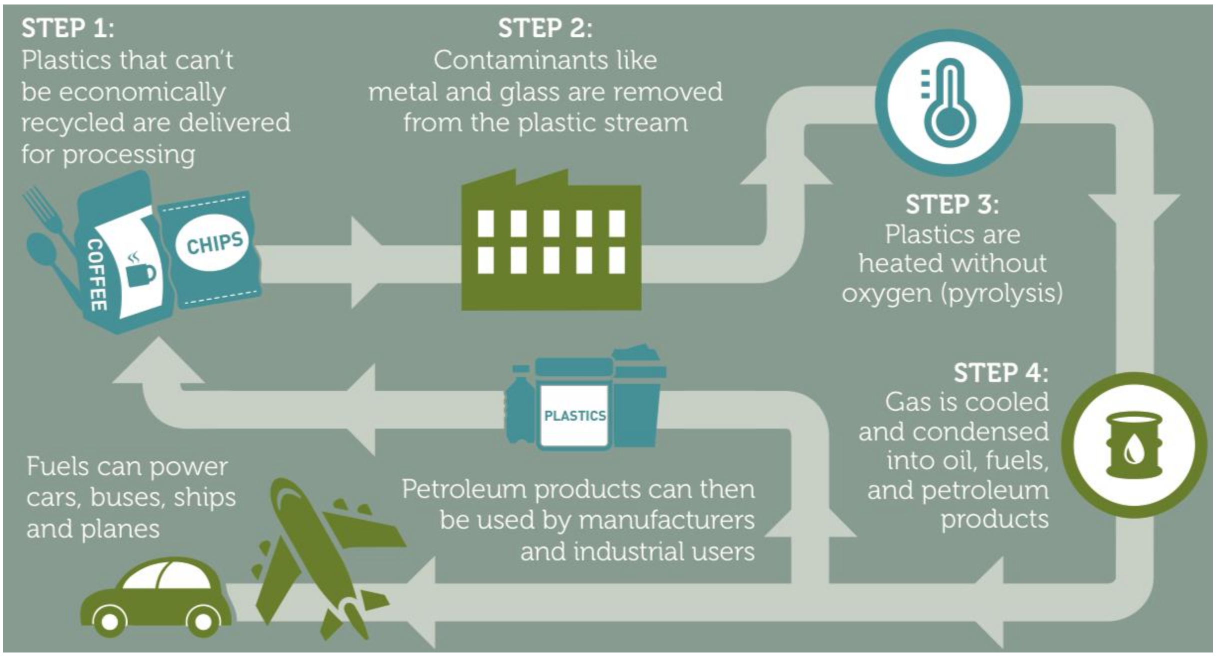
Source: American Chemistry Council, 2014. Growth of the U.S. chemical industry since the shale gas boom.

Of even greater importance to the rebirth of the US chemical industry is the fact that proven reserves of shale gas have also risen. The issue the area had previously was not that reserves were not available but that the technology for extracting them was not available, natural gas crackers are now technologically and economically viable methods for extracting the natural gas. In its 2015 "Fueling Export Growth" report, Nexant found that U.S. chemistry exports linked to shale gas could double from $60 billion in 2014 to $123 billion by 2030. The trade balance in plastic resins, in particular, is expected to accelerate.

[79] BIG Bright Ideas on the Gulf Coast - http://gulfcoastceoforum.com/BIG/62622714
[80] MOTE (06/08/2015) - https://mote.org/news/article/gulf-coast-innovation-challenge-mote-projects-make-finals
[81] Center for Energy Studies and the Economics & Policy Research Group (Spring 2017) – "Gulf Coast Energy Outlook" https://www.lsu.edu/ces/publications/2017/GCEO2017.pdf

Plastics-to-Fuel and Petrochemistry (PTFP) facilities produce fuels and chemistry products from post-use plastics that are not traditionally recycled in commercial markets; the process is known as "pyrolysis". The Plastics-to-Fuel and Petrochemistry Alliance[82] advocate for these facilities across the country, using the arguments that they would create jobs and improve the environmental conditions of oceans and the air. They produce factsheets for legislators and companies interested in establishing these facilities, they are also collecting a membership to raise awareness of these technologies. This is an example of a circular economy that has made some legislative headway in the Gulf state of Florida, passing a bill that allows for pyrolysis[83].

Figure 14: The process of using plastics to make fuel.



Source: American Chemistry Council: The Plastics-to-Fuel and Petrochemistry Alliance[84].

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[85]. As Port Houston is the most active port on the Gulf Coast for the Chemical sector's supply chain (Texas' shipments amount to over $129bn), this may have a significant impact on the efficiency and transparency of exports and imports for the sector and make the area even more attractive for investors. The higher demand for Gulf Ports is an issue for the supply chain, Port Texas has invested over $1bn in growth over the last 5 years in preparation for this. More widely, container availability issues cost the industry supply chain a significant amount in wasted time manually checking containers in ports. New systems have recently come online to automate this

[82] Plastics-to-Fuel and Petrochemistry Alliance - https://plastics.americanchemistry.com/Plastics-to-Fuel-Technologies-Alliance.html
[83] Florida House of representatives (27/06/2017) "CS/HB 335 - Resource Recovery and Management" - http://myfloridahouse.gov/Sections/Bills/billsdetail.aspx?BillId=56996&SessionId=83
[84] https://plastics.americanchemistry.com/Product-Groups-and-Stats/Plastics-to-Fuel/Infographic-What-Are-Plastics-to-Fuel-Technologies-and-How-Should-They-Be-Regulated.pdf
[85] Petrochemical Update (08/03/2018) – "Port Houston joins blockchain pilot program to digitize the supply chain" http://analysis.petchem-update.com/supply-chain-logistics/port-houston-joins-blockchain-pilot-program-digitize-supply-chain

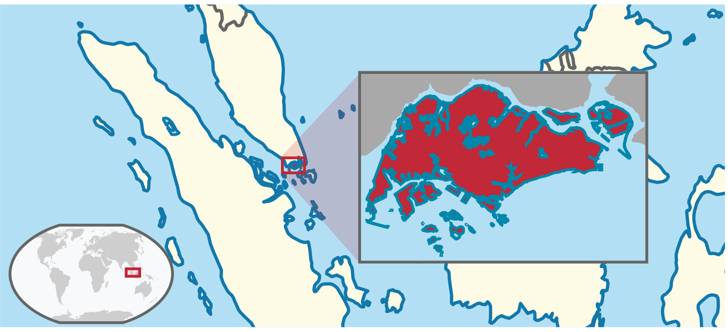
process which has in turn provided economic benefits to the trucking industry which makes more money when trucks are on the road[86].

[86] Petrochemical Update (16/11/2018) – "US Gulf develops automated systems to improve container availability" http://analysis.petchem-update.com/supply-chain-logistics/us-gulf-develops-automated-systems-improve-container-availability

6 Singapore

6.1 Chemical and process sector

Figure 15 Geographical location of Singapore.



Source: Wikipedia

Singapore is an island city state best known for being a financial services centre and is less known as a chemical hub despite having some of the largest chemical plants in the world and a growing chemical sector. In 2017, Singapore was the world's fifth-largest refinery export hub and ranked within the top 10 globally by chemical exports volume. There are currently over 1,000 specialty companies in Singapore, including: 3M, Evonik Degussa, Huntsman and Siltronic.

The Energy and chemicals sector comprised 34.1% of Singapore's S$303.8bn manufacturing output in 2014[87]. Exports in 2016 were USD$34bn, up from USD$25bn in 2006. Imports in 2016 were $18bn, up from $12.5bn in 2006[88]. There were 25,000 employees in the chemical manufacturing sector in 2015[89] and 59,300 (1.6% of total employment) employed in the petroleum, chemical and pharmaceutical product manufacturing sector in 2017[90]. In 2016, the top partner countries to which Singapore exported chemicals included Belgium, China, United States, Indonesia and Malaysia[91].

Off the South West coast of Singapore is Jurong Island, an artificial island among the world's top 10 petrochemical hubs (Figure 16). It features an integrated downstream value chain: refineries to cracking to petrochemical companies to speciality chemicals companies. Located on the Island, the Institute of Chemical and Engineering Sciences (ICES) undertakes world class research programmes in developing new processes and applications for the chemical industry. The island was developed with the support of a highly interventionist government that has successfully brought many of the world's major petrochemicals and other chemical and process companies to the country. Importantly, this presence includes regional headquarters and high-value scientific and technical functions as well as manufacturing and distribution. The Chemical Process Technology Centre was set up on Jurong Island in 2004 to support the training of new entrants to the chemical industry and to enhance the capabilities of existing professionals.

[87] Singapore Energy and Industrial Council (2015) – "Energy & Chemical Industry" http://www.scic.sg/index.php/chemical-industry

[88] World Integrated Trade Solution – Singapore country profile "Singapore Export in thousand US$ for Chemicals World between 2006 and 2016" https://wits.worldbank.org/CountryProfile/en/Country/SGP/StartYear/2006/EndYear/2016/TradeFlow/Export/Indicator/XPRT-TRD-VL/Partner/WLD/Product/28-38_Chemicals

[89] Ministry of Trade and Industry (2015) – "Economic Survey of Singapore 2015"

[90] Manpower research and Statistics Department (2017) "Administrative records and labour force survey"

[91] World Integrated Trade Solution 'Singapore Chemicals Exports By Country 2016' https://wits.worldbank.org/CountryProfile/en/Country/SGP/Year/LTST/TradeFlow/Export/Partner/by-country/Product/28-38_Chemicals

Figure 16 Map of Singapore with Jurong Island highlighted in red.

Source: Wikipedia Commons.

In 2016, there were 744 companies operating across SIC 20-23 in Singapore employing almost 40,000 workers (10.3% of manufacturing total). These figures are highest in SIC 20 and 22, although employment for those SIC codes has recently been falling by around 5.7%. Output and wages are highest in SIC 20 yet SIC 21 exports the most and has the highest number of workers per enterprise (although the total number of enterprises is lowest). The smallest area by far is SIC 23.

Statistical indicators – Singapore

Indicators on the chemical sector	SIC 20 - Manufacture of chemicals and chemical products	SIC 21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	SIC 22 - Manufacture of rubber and plastic products	SIC 23 - Manufacture of other non-metallic mineral products	Notes
Number of companies	282	53	279	130	Census of manufacturing activities 2016
Employment + share of the manufacturing total in brackets	18,101 (4.7%)	6,943 (1.8%)	9,859 (2.6%)	4,754 (1.2%)	Census of manufacturing activities 2016
Growth rate of employment (%)	-5.8%	N/A	-5.6%	N/A	Administrative Records and Labour Force Survey, Manpower Research Statistics Department, MOM (2017-2018)
Output - Turnover	£ 21,741,634,000	£ 9,361,525,000	£ 944,618,000	£ 967,849,000	Census of manufacturing activities 2016. National: S$81bn (energy and chemical industry) (€51.6bn) - Economic development board Singapore
Export activity	£ 13,115,663,000	£ 15,404,535,000	£ 8,563,612,000	£ 39,778,000	Census of manufacturing activities 2016.
Supply chain integration	N/A	N/A	N/A	N/A	

Wages (€m)	£ 1,026,174,000	£ 395,134,000	£ 235,620,000	£ 96,263,000	Census of manufacturing activities 2016
Average wage/salary (€)	£ 56,691.56	£ 56,911.13	£ 23,898.98	£ 20,248.84	Census of manufacturing activities 2016
Skills levels	Highest skilled workers across the manufacturing sector				American Institute of Chemical Engineers (AIChE)
Age profile	N/A	N/A	N/A	N/A	
Average size of enterprise	64	131	35	37	Calculated from first two rows of table
Ownership structure	N/A	N/A	N/A	N/A	

6.2 Regulation and policy agenda

The Energy & Chemicals Industry Transformation Map ("ITM") launched in 2017 with the aim to make Singapore a globally competitive and leading energy and chemicals hub. Through the ITM efforts, the industry is expected to achieve a manufacturing value added of S$12.7 billion and to introduce 1,400 new jobs by 2025[Error! Bookmark not defined.]. SkillsFuture Singapore (SSG), Workforce Singapore and the EDB d eveloped a skills framework and launched it alongside the ITM. This consists of four SkillsFuture Earn and Learn Programmes for specific jobs in the sector (e.g. process technicians and laboratory analysts) from which 91 graduates have entered 31 companies in the sector.

Aligning to the ITM, the Government has taken steps to ensure better cross-border cooperation to enhance and secure better trading opportunities. As part of the ASEAN Regulatory Cooperation Project (from the International Council of Chemical Associations), the American Chemistry Council (ACC), Japanese Chemical Industry Association (JCIA) and Singapore Chemical Industry Council (SCIC) will lead efforts to advance chemical regulatory cooperation in the ASEAN region. The objective of this project is to promote industry coordination in the ASEAN region and advocate to minimise behind-the-border regulatory barriers that impede trade and more resource intensive than required[92].

Regulation surrounding risk assessment in the chemical industry in Singapore has changed drastically due to the introduction of the 'Safety Case Regime'. The Safety Case Regime allows flexibility for companies to tailor their risk mitigating measures, allowing for a holistic risk assessment strategy as opposed to 'one-size-fits-all' regulations[93]. This allows for more flexibility for companies but does increase their burden in proving their compliance to the regulator.

The Chemical sector and national government has been cognisant of ensuring supply chain security following events in other countries such as in Denmark where the 'Petya' incident hit the Danish shipping line leading to then shutting down all IT and communications infrastructure as a security measure which meant massive disruption. Singapore Chemical Industry Council has put in place an overarching programme linking their security programmes with other national programmes within and outside the country[94]. Their intention is to use their ISO 28000 supply chain security standard as the base it is a flexible framework that can easily be integrated with other security initiatives as shown below.

[92] ASEAN Regulatory Cooperation Project (2016) - http://www.scic.sg/asean/
[93] Ministry of Manpower (September 2017) "Safety Case Regime for MHIs" http://www.mom.gov.sg/workplace-safety-and-health/major-hazard-installations/safety-case-regime
[94] The Singapore Chemical Industry Council (Jan-Mar 2018) "Supply Chain Security" (page 16) http://www.scic.sg/images/newsletter/1st%20issue%20of%20the%20SCIC%20quarterly%20newsletter%202018.pdf

Figure 17 Representation of the proposed overarching security programme ISO 28000 aligning with examples of other supply chain security programmes.

6.3 Innovation ecosystem

From 2002 to 2012, business expenditure on R&D in the chemicals and materials sector in Singapore more than quadrupled to USD$660 million[95]. The sector has attracted outside investment from Evonik, a speciality chemicals company based in Germany, is building its first research hub in Singapore, with operations expected to commence in 2018[96].

The Ministry for Trade and Industry has committed to support the growth of Singapore's specialty chemicals offering by strengthening Singapore's innovation ecosystem using applied research and novel platform technologies. The aim of this is to enable companies to shorten innovation cycles. The government also stated that they "will work with leading players to develop domain knowledge in their labs in Singapore as well as support companies who adopt 'open innovation' as a means to co-innovate and co-develop system solutions with their partners" [97]

Specifically, for the chemical industry, 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 4 projects which are closely linked to the chemical industry[98].

6.4 Additional commentary

6.4.1 Feedstocks

Singapore has no natural feedstocks; crude oil, natural gas or mineral deposits, but by the late 1970s Singapore became one of the largest refining centres in the world and produced a large output of refined products with which to use as feedstock to develop their now established petrochemicals and specialty chemicals industry[99]. The disconcertingly low price of crude oil around 2015 was a significant

[95] The Straits Times (28th July 2017) "The man behind S'pore's chemical engineering drive" https://www.straitstimes.com/singapore/the-man-behind-spores-chemical-engineering-drive
[96] The Straits Times (7th December 2017) "Speciality chemicals firm Evonik sets up first Asia research hub in Singapore" https://www.straitstimes.com/business/economy/speciality-chemicals-firm-evonik-sets-up-first-asia-research-hub-in-singapore
[97] Speech by Mr Lim Hng Kiang, Minister for Trade & Industry, at Chemex 2017 (21st October 2017) https://www.mti.gov.sg/MTIInsights/SiteAssets/Pages/ITM/Images/Energy%20and%20Chemicals%20ITM%20-%20Minister%20Speech.pdf
[98] The Singapore Chemical Industry Council (Chemicals Digest - July-Sep 2017 issue) "Democratising access to High Performance Computing (HPC) with Singapore's first petascale computer" https://www.nscc.sg/wp-content/uploads/2017/11/NSCC-featured-in-ChemDigest-July-Sep-2017-Issue.pdf
[99] Carpenter, Keith; Kiong Ng, Wai. (April 2013) "Singapore's Chemicals Industry: Engineering an Island" http://fscarbonmanagement.org/sites/default/files/cep/20130456.pdf

problem for the industry. Singapore's total merchandise trade dipped 9.5% to $884.1 billion in 2015, largely due to the contraction of oil trade by 36%[100]. The Marine and Port Authority of Singapore's (MPA) Liquified Natural Gas (LNG) bunkering pilot programme provides a safe, efficient, sustainable and transparent technical framework for conducting LNG bunkering operations in Singapore to increase efficiency in the supply chain[101].

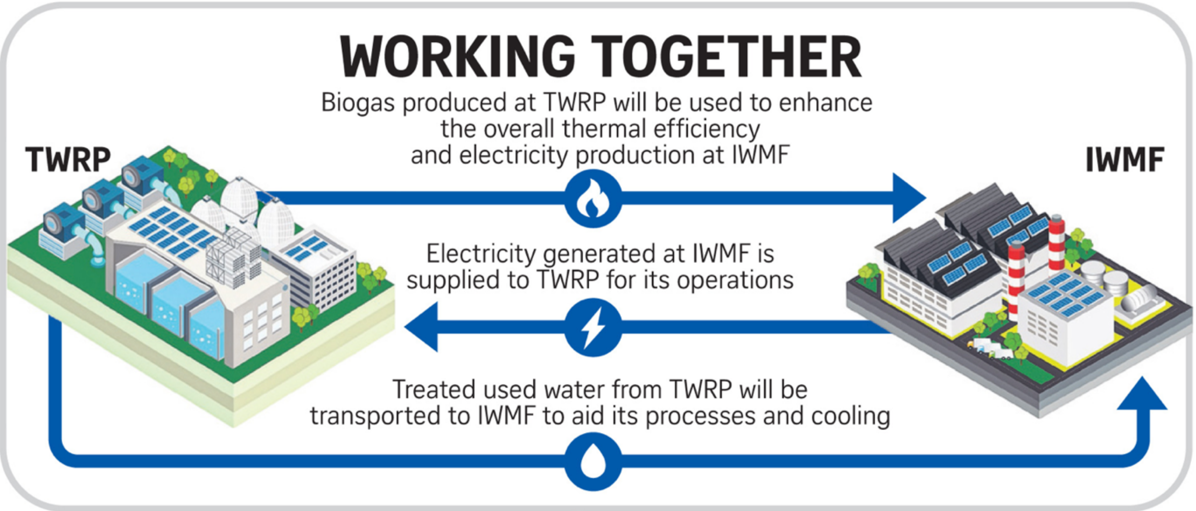
6.4.2 Low Carbon solutions

Contributing to a drive towards low-carbon solutions, it was announced in early 2017 that the government planned to implement a carbon tax of between S$10 and S$20 per tonne of greenhouse gas emissions from 2019 as part of the measures that will enable Singapore to meet its commitments under the Paris Agreement of the UN Framework Convention on Climate Change (UNFCCC). In the area of energy efficiency, a recent Memorandum of Understanding with the Energy Institute was signed to help the industry improve energy efficiency via capacity and capability building[102]. Singapore chemical and industry council have their responsible care Awards for manufacturers to encourage sustainable practices.

6.4.3 Circular Economy and Digitisation

Singapore's 1st Effluent Water Treatment Recovery Plant was commissioned in July 2016 targeting industrial wastewater recycle from a refinery. Since then, the co-construction of a water reclamation plant and waste management facility aims to further make use of industrial waste[103]. The two facilities will complement each other when completed in 2027 and become completely energy self-sufficient, as shown below.

Figure 18: How the two energy reclamation facilities will operate.



Source: PUB and NEA, The Straits Times Graphics.

[100] The Singapore Chemical Industry Council (2016) "Singapore chemicals 2016" https://www.gbreports.com/wp-content/uploads/2016/06/CW-Singapore-2016-Pre-Release-v10-medres-single.pdf

[101] The Straits Times (3rd May 2017) "Singapore aims to be LNG bunker-ready by 2020" https://www.straitstimes.com/business/companies-markets/spore-aims-to-be-lng-bunker-ready-by-2020

[102] The Singapore Chemical Industry Council (December 2017) – "Chem Digest" http://www.scic.sg/images/newsletter/2017-ChemDigest-Q4.pdf

[103] The Straits Times (12th July 2016) "2 'green' plants to improve waste treatment efficiency" https://www.straitstimes.com/singapore/environment/2-green-plants-to-improve-waste-treatment-efficiency

Industrial Digitisation in Singapore – Industry 4.0

Digitisation of chemicals manufacturing will be the cornerstone of the Industry Transformation Map (ITM) for the energy and chemicals sector in Singapore, alongside other government initiatives such as 'Smart Nation', 'e-government action plan' and 'Infocomm Media 2025'[104]. The government has also set aside S$80 million to help SMEs build digital capabilities[105]. Automated measurement using advanced sensor technology, sophisticated data analytics and visualization 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, since personnel will less frequently have to enter hazardous areas, e.g. to make measurements, while plant condition can be monitored continuously, and potential failures predicted in time for intervention. However, rigorous cybersecurity will be essential for protection of plant and infrastructure. These developments and will demand new and improved skills from senior professionals to plant operators. The Economic Development Board have supported consultants Accenture in mapping digital skills[106] needed, including data and trend analysis; automation management; cybersecurity; big data management; modelling and simulation; and user interface design.

Case study – Evonik Industries

Evonik Industries expanded its specialty chemicals manufacturing plants in Singapore on Jurong Island in 2015. A plant operator in the petrochemical industry deals with an average of 1,500 alarms per day - more alarms than they effectively can process. Evonik installed Siemens' Simatic PCS 7 Alarm Management Solution, one of the company's flexible, integrated automation and drive solutions for the chemical industry, which helped Evonik reduce the alarm load in the control room by more than 50% through filtering, aggregating and prioritizing alarms[107]. Siemens also supplied Evonik's Methionine plant with a fully integrated energy management solution. The plant manufactures an amino acid for healthy and sustainable animal nutrition, requiring a reliable power supply to meet the demands of the complex production processes. The power supply, designed for industry, buildings and infrastructures is a fully integrated energy management solution, providing a 'one-stop-shop' solution for the plant's entire electricity supply across the entire value chain. With a reliable power supply, other than keeping the production up and running, the company precisely meets the demands of complex chemical production processes.

The improved automation and digitalization at the plant enabled Evonik to reduce energy consumption and waste by 10%-20%.

Evonik Industries Singapore. Source: Siemens Pte Ltd

[104] Economic Development Board (7th August 2017) "Government leads digital disruption in Singapore" https://www.edb.gov.sg/en/news-and-resources/insights/innovation/government-leads-digital-disruption-in-singapore.html

[105] Business Times (21st February 2017) "Over S$80m set aside to help SMEs go digital" https://www.businesstimes.com.sg/government-economy/singapore-budget-2017/over-s80m-set-aside-to-help-smes-go-digital

[106] https://www.straitstimes.com/singapore/skills-map-for-energy-and-chemicals-workers

[107] Siemens, Chemical Industry in Southeast Asia, Siemens Fact Sheet, 25 August 2016

7 South Korea

Figure 19 Map of South Korea with regions highlighted.

Source: Wikipedia.

South Korea is the world's 5th largest chemical production country. South Korean Chemical exports in 2016 were USD$34bn, up from USD$18bn in 2006. Chemical imports in 2016 were USD$35bn, up from US$23.5bn in 2006[108]. On the backdrop of the 'Miracle on the Han River', the country's chemical industry has followed a similar path of economic growth and expansion since its development in the 60s and 70s, going from a net importer to net exporter over a 50-year period (Table 2).

108 World Integrated Trade Solution – Republic of Korea country profile "Rep. of Korea Export/Import in thousand US$ for Chemicals World between 2006 and 2016" https://wits.worldbank.org/CountryProfile/en/Country/KOR/StartYear/2006/EndYear/2016/TradeFlow/Import/Indicator/MPRT-TRD-VL/Partner/WLD/Product/28-38_Chemicals

Table 2 History of the South Korean chemical industry, 1966–2010.

	Government Sector Led			Private Sector Led	
	1966–1978 Development	**1979–1988 Growth**	**1989–1997 Take-off**	**1998–2003 Restructuring**	**2004–2010 Second Take-off**
Major Players and Key Industry Characteristics	Government-led nurturing of industries, launch of Ulsan Complex	Petrochemical industry foundation laid, launch of Yeosu Complex	Large-scale expansion, launch of Daesan Complex	Restructuring of industries Proactive mergers and acquisitions	Expansion of economic scale and foreign investment
Ethylene Capacity	115 kton/yr 1 company	5,055 kton/yr 2 companies	4,330 kton/yr 8 companies	5,760 kton/yr 7 companies	7,770 kton/yr 6 companies
Trade Balance	Net import	Net import to balanced	Net import to net export	Net export	Net export
Major Growth-Leading Industries	Light industry	Light industry transitioned to heavy industry and chemical industry	Heavy industry and chemical industry Markets in Asian developing countries	Parts and materials industries Markets in China	Biotech, Nanotech, Information tech-nology, and Environ-mental technology; Markets in BRIC countries
Global Environment	Companies in developed countries led industry, globalization Stable earnings; demand growth in Western Europe, North America, and Japan	Oil majors expanded beyond oil; developed petrochemicals industry after oil crisis Majors diversified business due to falling profits	The end of the Cold War; economic globalization Economic depression in Europe and Japan; growth of Asian economic power	Accellerated mergers and acquisitions: BP+Amoco (1998); Exxon+Mobil (1999); Chevron+Philips (2000); Dow+UCC (2001); SABIC+DSM (2002)	High competitiveness of Middle East petrochemicals Projects in China for self-sufficiency High cost pressure; record oil prices

Source: Korea Petrochemical Industry Association.

Foreign Investment has been a large part of this growth, particularly in the specialty chemicals area; as Invest Korea states: "These foreign companies have enriched the Korean chemical industry by approximately US$7.5 billion in FDI between 2003 and 2013, making it the Korean economy's second highest recipient of foreign investment. And since the future of Korean´s chemical industry depends highly on new, environment-friendly composite materials of higher functionality, extensive and efficient R&D investments are essential for Korea to continue down its path towards becoming a regional specialty chemical hub" [109].

In 2016, the estimated total value of Korea's specialty chemicals market was USD 52.5 billion, representing a 3 percent increase over 2015. It focuses on the development of finished multi-application products, such as dyes, paints, and surfactants. However, South Korea does not have the fundamental core technologies and investment to develop sophisticated specialty chemicals. As a result, the market demands for these chemicals relies on imports[110]. These imports are essential for the production of some of the country's top export chemicals, including ships, plastics and petrochemicals.

Ulsan (the de facto industrial capital, located on the southeast tip of the peninsula) accounts for around 35 percent of total production. Ulsan is home to Asia's largest chemical industrial complex (2.4 billion m^2). Ulsan accounts for around 35 percent of Korea's total production, and 203 companies in Ulsan recorded KRW 135 trillion in production, the biggest scale among the city's three major industries, and USD$45.3 billion in export in 2013, accounting for 40 percent of the nation's chemical industry[111]. Busan is part of the Southeast Economic Zone of South Korea, along with Ulsan and South Gyeongsang. Busan is known for its ship building and marine industries with the country's largest port (5th busiest in the world[112]) and second largest population (Seoul having the largest).

---

109 Spot-Chemi Blog (1st October 2015) "South Korea's Chemical Industry; Past and Future – Part 2. The Future" https://blog.spotchemi.com/south-koreas-chemical-industry-past-and-future-part-2-the-future/

110 Export.Gov "Korea - Specialty Chemicals" https://www.export.gov/article?id=Korea-Specialty-Chemicals

111 Invest Korea "Petrochemical Industry" http://www.investkorea.org/ulsan_en/industry/industry03.do

112 Yonhap News Agency (24th November 2016) "Cargo processed at Busan port dips 6.5 pct in Oct" http://english.yonhapnews.co.kr/news/2016/11/24/0200000000AEN20161124005100320.html

A summary of South Korea's major companies by value chain is below.

Figure 20 Korean petrochemical industry's companies by value chain.

Types	Names of companies
Basic fractions and intermediary materials (9)	(NCC companies) LG chem, Lotte chem, YNCC, Korea petrochem Ind. (NCC+BTX companies) SKGC, Hanwha total (BTX companies) GS caltex, S-Oil, Hyundai cosmo
synthetic resin (16)	LG chem, SKGC, Lotte chem, Hanwha total, etc.
Synthetic fiber (9)	Korea petrochem Ind., Tongsuh petrochem, Lotte chem, Samnam petrochem, etc.
Synthetic rubber (4)	Kumho petrochemical, Kumho polychem, SKGC, LG chem
Etc. (6ea)	Lotte BP chem, OCI, Yongsan chem, Isu chem, etc.

Source: KPIA, "Current status of petrochemical industry and prospects", inside materials, 6 Mar. 2015.

The chemical manufacturing sector employs almost 2m people across the four sub-sectors, representing 16.57% of all employment in the manufacturing sector (Table 3). The rubber and plastic sub-sector employs the most out of the four while Pharmaceuticals employs the least.

Statistical indicators – South Korea

Indicators on the chemical sector	SIC 20 - Manufacture of chemicals and chemical products	SIC 21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations	SIC 22 - Manufacture of rubber and plastic products	SIC 23 - Manufacture of other non-metallic mineral products	Notes
Number of companies	N/A	N/A	N/A	N/A	
Employment + share of the manufacturing total in brackets	529,419 (4.51%)	141,306 (1.2%)	905,797 (7.72%)	367,391 (3.13%)	Ministry of Employment and Labour 2017 data (manual analysis)
Growth rate of employment (%)	N/A	N/A	N/A	N/A	
Output - Turnover	USD 177 billion in 2013.				Japan Industry News
Export activity	Exports in 2016 were USD$34bn, up from USD$18bn in 2006.	N/A	N/A	N/A	World Integrated Trade Solution
Supply chain integration	N/A	N/A	N/A	N/A	
Wages (€m)	N/A	N/A	N/A	N/A	
Average wage/salary (€)	N/A	N/A	N/A	N/A	
Skills levels	N/A	N/A	N/A	N/A	
Age profile	N/A	N/A	N/A	N/A	
Average size of enterprise	N/A	N/A	N/A	N/A	
Ownership structure	N/A	N/A	N/A	N/A	

7.1 Policy Agenda

Korea's regulatory environment and increased bureaucracy presents challenges to foreign companies in terms of significant administrative and technical burdens that are translated into an overall increased cost of doing business. Since 1991, all chemicals have been categorised and regulated by the Toxic Chemicals Control Act (TCCA). As public and government concern over chemical processes and hazardous products has risen, newer legislation introduced in January 2015, split the regulations into a new version of TCCA (called the Chemical Control Act or CCA) and K-REACH. The Chemical Inspection and Regulation Service defines that difference as, "K-REACH focuses on registration and evaluation of substance while CCA focuses on the control of hazardous substance and response to chemical accidents." Like REACH in Europe, it has yet to be concluded if the advantages of this bureaucracy will outweigh the burden[109]. The other most frequently raised regulatory issues have been a lack of transparency, inconsistency, as well as concerns over the protection of confidential business information[110].

The "Government R&D Innovation Plan 2015" aims to strengthen government-backed research institutes by applying the Fraunhofer Model, the international gold standard in industry-academia partnership[113]. This was proposed to address the low rate of successful commercialization of R&D outputs.

7.2 Innovation

In the last 10 years Korea's chemical sector has received GBP 6bn in foreign direct investment (FDI), making it the second highest recipient of FDI amongst all OECD countries. In 2016, for example, Japanese chemical manufacturer Kuraray and Kuwait's chief petrochemical company PIC both invested in the market. Furthermore BASF, one of the world's largest chemical companies, moved its electronic materials headquarters from Germany to Seoul in 2013 and established a R&D centre the following year. Also in 2014, world-leading chemicals company Dow Chemical Company built a plant in Cheonan, Korea, to mass produce quantum dot materials, and international chemical group Solvay also opened a research centre in collaboration with Korea's Ewha Women's University[114].

The innovation landscape in South Korea has also grown significantly in the last decade; the Government has increased its R&D by an annual average of 12% over the past ten years, reaching 6th in the world in investment and 1st in investment as a percentage of GDP. The Government has supported 1713 start-ups and SMEs in all sectors since January 2017, up from 45 as of 2015. They invested total USD$445.4 million as of January 2017, up from $11.6 million as of 2015[115]. The majority of incubator / accelerator programs and other start-up support initiatives are underpinned by the government. These are often instituted in collaboration with Chaebols (e.g. Samsung) or universities[116]. On the regional level, Ulsan aims to become Asia's top advanced chemical industry city by 2030 through building national research centres and R&D facilities and developing new industries in biochemistry, fine chemistry, and nanochemistry[111].

Busan foreign direct investment proposition (i.e. attracting the HQ/R&Di functions of BASF and Dow Chemical).

[113] Korean Ministry of Science and ICT (2015) "Government R&D Innovation Plan" http://english.msit.go.kr/cms/english/pl/policies2/__icsFiles/afieldfile/2015/11/11/Government%20RnD%20Innovation%20Plan.pdf

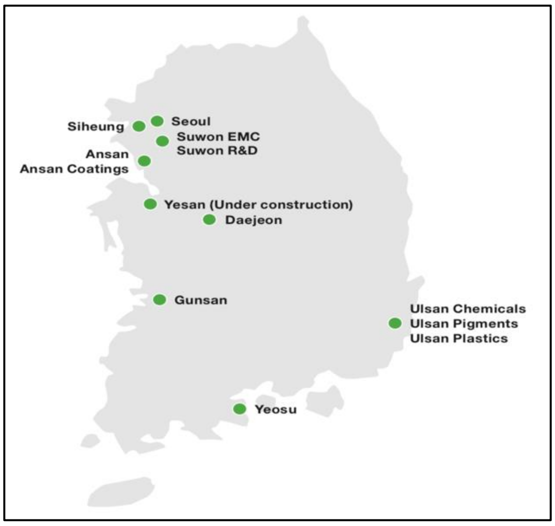
[114] British Chamber of Commerce in Korea (15th December 2016) "New Opportunities in Korea's Chemical Industry" http://bcck.or.kr/chemical-industry-korea/

[115] Sang-yirl, Nam. (12th June 2017) "Overview of Korean Start-up Ecosystem" https://www.itu.int/en/ITU-D/Innovation/Documents/Documents_Events_Presentations/2017_WSIS/MON_WSIS17/08%20KISDI.pdf

[116] Global Innovation Project (29th October 2016) "The South Korean Startup Ecosystem - An Overview" http://www.global-innovation-project.com/posts/the-south-korean-startup-ecosystem-an-overview/

The Korea Trade-Investment Promotion Agency (Kotra), founded in 1962, is spearheading efforts globally to not only promote exports but also attract investment by foreign businesses. In 2014, South Korea reported about $19 billion in foreign direct investment, up 30% on the year and the highest on record. Industry observers believe Kotra was involved in about 80% of those deals[117]. The EU increased its biotech and pharmaceutical investment by 707%, chemical investment by 103% and machinery and equipment investment by 21% in South Korea to enter the Asian, and specifically Chinese, market. More widely, the Korean government has offered tax breaks and other incentives to attract big companies to Korea, specifically targeting Merck and Soray[118].

Dow Chemical have their HQ in Seoul an R&D centre commissioned in 2012, as well as 5 other sites across the country operated by other areas of Dow[119]. More significantly, and with world-scale production sites in Yeosu, Ulsan, Gunsan, Ansan and Yesan, BASF maintains a global research and development center in Suwon and four technical development centers in Dongtan, Ansan, and Siheung to provide broad chemical solutions for Korea's key industries including automotive, construction, consumer products, paint, coatings, electronics and electric[120]. BASF have a regional HQ for electronic materials in Seoul and its new research and development (R&D) centre in Suwon, Korea is playing an ever more important regional role in BASF's Asia Pacific business. 2014 saw the establishment of BASF's global sales HQ for organic electronics in Korea and a new site for engineering plastics compounding in Yesan[121].



Source: BASF in Korea report 2014.

[117] Nikkei Asian Review (19th March 2015) "South Korea's promotion arm ramps up efforts to lure businesses" https://asia.nikkei.com/Business/South-Korea-s-promotion-arm-ramps-up-efforts-to-lure-businesses

[118] Yonhap News Agency (29th September 2016) "S. Korea vows to offer incentives to attract foreign investment" http://english.yonhapnews.co.kr/news/2016/09/29/0200000000AEN20160929005400320.html

[119] Dow – Locations in Asia-Pacific - Korea https://www.dow.com/en-us/about-dow/locations?region={6228b4b7-9cbb-4c7c-b64e-f4317f16bad7}

[120] BASF (2016) "BASF in Korea - Report 2016" https://www.basf.com/documents/corp/en/about-us/publications/reports/2017/BASF-in-Korea-Report_2016.pdf

[121] BASF (2014) "BASF in Korea - Report 2014" https://www.basf.com/documents/corp/en/about-us/publications/reports/2015/BASF_Report_Korea_2014.pdf

7.3 Additional Commentary

7.3.1 Feedstocks

Finding biomass is the biggest challenge that Korea faces in the development of a biochemistry industry. Not only biomass but also basic materials such as Poly Lactic Acid (PLA) are heavily dependent on import[109]. According to Reuters, South Korea's combined imports of naphtha and LPG increased 14.3 percent to 88.73 million barrels in the third quarter of 2016 to support their demand for feedstock[122]. 94% of Korea's petrochemical industry depends on naphtha. However, there are examples of companies in South Korea reducing their dependence on imported feedstock. Hyundai Chemical is using Honeywell UOP technology to produce its own feedstock material (xylenes), reducing their plant's dependence on imports[123].

7.3.2 Circular Economy and Digitisation

The UN Framework Convention on Climate Change (UNFCCC) has registered a sulphur hexafluoride recovery and reclamation Clean Development Mechanism (CDM) project in South Korea[124]. This project allows Sulphur Hexafluoride (a useful gas for many manufacturing processes) to be converted into a new virgin product, reducing emissions significantly.

A 2016 report ranked Korea's manufacturing technology innovation third out of the G20 countries, behind the United States and Germany[125]. A 2016 UBS study ranked Korea just 25th out of 139 countries "most capable of adapting to Industry 4.0"[126]. That matters because SMEs dominate South Korea's economy with over three million in total and 99% of manufacturers being SMEs, meaning that encouraging SME uptake of digital manufacturing practices will be crucial. As of November 2016, Korea had implemented 2,600 model "smart, digitalized factories" as part of the Korea Smart Factory Initiative and aims for 10 key sectors to have at least 4,500 smart factories operating by 2025[127]. Supporting the chemical industry, Inmarsat signed a memorandum of understanding with Samsung Heavy Industries in South Korea to provide bandwidth for smart shipping applications resulting in new ships being installed with Inmarsat-approved terminal hardware[128].

7.3.3 Low Carbon solutions

The Government launched a nationwide project in 2010 to address worldwide initiatives in green chemistry and clean energy, establishing an investment plan called "Material and Component Technology 2012". The aim of the project is "to develop 100 core technologies for new materials and

---

122 Reuters (29th November 2016) "South Korea's third-quarter crude oil imports, domestic consumption up, exports down" https://www.reuters.com/article/us-southkorea-oil/south-koreas-third-quarter-crude-oil-imports-domestic-consumption-up-exports-down-idUSKBN13O04H

123 Honeywell (19th January 2016) "Hyundai Chemical Expands South Korean Petrochemical Complex Using Modular Equipment And Technology From Honeywell UOP" https://www.honeywell.com/newsroom/pressreleases/2016/01/hyundai-chemical-expands-south-korean-petrochemical-complex-using-modular-equipment-and-technology-from-honeywell-uop

124 Business Europe (11th April 2017) "Solvay's Sulfur hexafluoride (SF6) reuse program" http://www.circulary.eu/project/solvay-sf6/

125 Felchlin, "Industry 4.0 Korea: Numerous Projects in Korea."

126 UBS (January 2016) "Extreme Automation and Connectivity: The Global, Regional, and Investment Implications of the Fourth Industrial Revolution," https://www.ubs.com/global/en/about_ubs/follow_ubs/highlights/davos-2016/_jcr_content/par/columncontrol/col1/actionbutton.1562449048.file/bGluay9wYXRoPS9jb250ZW50L2RhbS91YnMvZ2xvYmFsL2Fib3V0X3Vicy9mb2xsb3ctdWJzL3dlZi13aGl0ZS1wYXBlci0yMDE 2LnBkZg==/wef-white-paper-2016.pdf.

127 U.S. ITA," Korea - Manufacturing Technology - Smart Factory."

128 Tanker Shipping & Trade (4th October 2017) "Digitalisation enhances Shell's ship operations" http://www.tankershipping.com/news/view,digitalisation-enhances-shells-ship-operations_49393.htm

components in areas such as light-emitting diodes (LEDs), solar power, green cars, and new or renewable energy"[129].

Petrochemistry has traditionally dominated Korea's chemical industry with as much as 70% of total chemical revenues generated from the sector. However, in recent years, in an attempt to diversify revenue sources to mitigate the risk of over-dependency, the Korean government has been financially supporting research and development in the fine, green and sustainable chemical sectors. For example, Ulsan has received government support to drive growth in specialty and healthcare-related chemicals as well as in biochemistry itself[114].

[129] Moon, Il; Cho, Jae Hyun. (December 2011) "The Chemical Industry of South Korea: Progress and Challenges" https://www.aiche.org/sites/default/files/cep/20111240.pdf

8 Points for Synthesis

In this section, we present some emerging findings from the analysis across the six regions. We follow a similar structure, i.e. first we look at the structure of the chemical and process sector, then at the policy agenda and innovation ecosystem and finally at the similarities in terms of how the regions embrace low-carbon economy and circular economy.

8.1 Emerging findings on the structure of the chemical and process sector

We have come across significant issues with the availability of statistical data disaggregated to the regional level. We have attempted to collect all the available data in a standardised way and we present this in a tabular form in the appendix.

The points below illustrate some of the patterns that can be observed across the regions:

- The sub-sector SIC 20 is the most significant sub-sector in terms of the total turnover and the volume of export (especially in Europe), compared to SIC 21, SIC 22 and SIC 23.
- Across the focus regions, the companies operating in the sub-sectors SIC 20 and SIC 21 tend to remunerate at a higher average level than the companies in the two remaining sub-sectors (the average wage/salaries are similar for SIC 20 and SIC 21, these are both larger than the other sub-sectors which are both £37k per year. Annual wages across the 4/6 reporting data under SIC 20 (European regions and Gulf coast) are between £61k-£71k. Total wages are highest under SIC 20 (almost triple SIC 21) although gross value added per employee is the same for both SIC 20 and SIC 21).
- Companies operating in the sub-sectors SIC 20 and SIC 21 also tend to be on average significantly larger (in terms of numbers of employees) than those in the sub-sectors SIC 22 and SIC 23. This applies across the European regions for which the data is available.

In Table 3, we looked more closely at the ten world largest chemical companies and whether they are present at one (or more) sites in the focus regions. We also included the UK. Nine out of the ten world largest chemical companies have a site in at least one of the focus regions, with the majority being present in multiple focus regions). In most cases, this includes production sites as well. Eight companies have some presence in the UK, however, this is not always in Northern England, but also in the South-East, the Midlands etc. None of the ten largest companies has its HQ in the UK, and only three companies, including the world's largest BASF, has their HQ in the focus regions. This points to a certain level of global interdependence across the regions.

Table 3 List of ten world largest chemical producers and their sites in the relevant regions

Company	HQ in the relevant regions	Chemical sales in 2014 ($m)	Other (production) sites in the relevant regions
BASF	Rheinhessen-Pfalz, DE	78,698	Gulf Coast, US Bradford, UK Flanders, BE Zuid-Holland, NL Limburg, NL Singapore South Korea
Dow Chemical Company	-	58,167	Gulf Coast, US Flanders, BE

Company	HQ in the relevant regions	Chemical sales in 2014 ($m)	Other (production) sites in the relevant regions
			Zuid-Holland, NL Multiple locations in the UK Singapore South Korea
Sinopec	-	57,953	N/A
SABIC	-	43,341	Gulf Coast, US Singapore South Korea Teesside, UK Limburg, NL Zuid-Holland, NL Flanders, BE
ExxonMobil	Gulf Coast, US	38,178	Singapore South Korea Fawley, UK Zuid-Holland, NL Flanders, BE
Formosa Plastics	-	37,059	Texas, US
LyondellBasell	Gulf Coast, US	34,839	Rheinhessen-Pfalz, DE Zuid-Holland, NL Multiple locations in the UK Singapore South Korea
DuPont	-	29,945	Flanders, BE Zuid-Holland, NL Multiple locations in the UK Gulf Coast, US South Korea Singapore
Ineos	-	29,652	Multiple locations in the UK Flanders, BE Limburg, NL Singapore South Korea Texas, Alabama, Louisiana, US Rheinhessen-Pfalz, DE
Bayer	-	28,120	Flanders, BE South Korea

Company	HQ in the relevant regions	Chemical sales in 2014 ($m)	Other (production) sites in the relevant regions
			Reading, UK

Source: https://cen.acs.org/content/dam/cen/93/30/09330-globaltop50.pdf, own research

It is perhaps worth adding at this point a note of caution about SIC data. Chemistry, and chemistry-based businesses, underpin many other sectors that would not be regarded as ‘chemical/process’ and there is a real risk of underestimating the importance of the sector. Many firms, especially the larger, serve industries covered by multiple SIC codes and cannot adequately be classified under one, while the codes may be poorly suited to novel industry segments. This is of course an issue across various economic sectors, not only the chemical sector. SIC codes are more suitable for comparing region with region where the relevant industry structure is similar (e.g. predominantly bulk and petrochemicals) than for comparisons where the structure is different (e.g. the more specialty-oriented Geleen area) or where emerging industry segments are involved. As such figures emerging from data classified under a pre-selected set of SIC codes can only be taken as an approximation of the overall significance of chemicals and process as a part of the economy as a whole, or the importance of inter-sectoral dependencies.

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 within it, in the future. Skills shortages have been highlighted in all the continental European clusters, while Singapore has taken extensive steps to improve skills supply and upskill members of the existing workforce.

Several factors contribute to these shortages:

- Existing shortages in many (but not all) engineering and allied disciplines.
- 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 regions where it is mainly located.
- Technological and other changes resulting in new skills demands – an example being the increasing digitisation of the chemical and process industries.

The Northern Powerhouse experiences similar challenges, and these are likely to be further exacerbated by the impact of Brexit.

Finally, in this section, although we have examined the continental European regions individually, it could be argued that the real cluster geography combines Antwerp-Rotterdam and Limburg, and perhaps the Rheinhessen-Pfalz area too (i.e. the ARRRA geography), and that this is the geography to compare with the NPH.

8.2 Policy Agenda

The policy and regulatory environments across the focus regions tell a story of progress in moving towards better integrating the chemical manufacturing industry into economic strategy and the standardisation of regulation both within regions/countries and internationally. The points below summarise the headline findings from the focus regions:

- The European regions explicitly include the chemical sector in their innovation policies and strategies at regional and national levels.
- Singapore takes a different approach by having a specific Energy & Chemicals Industry Transformation Map which aims to transform the sector through better cross-border cooperation to

reduce regulatory barriers in the ASEAN region and a significant industry 4.0 effort to digitise the sector. Alongside this, the SkillsFuture Earn and Learn Programmes aim to upskill workers through education programmes – this type of policy was not identified in any other regions.

- South Korea's Government R&D Innovation Plan 2015 applies the Fraunhofer Model to strengthen government-backed research institutes, a model already operating in some of the European regions but novel in South Korea.
- Singapore and South Korea have had historically bureaucratic and complex chemical regulatory conditions which have made it more difficult to do business within and outside the countries. Both have recently introduced new reforms to reduce bureaucracy and to standardise chemical company compliance procedures.
- The Gulf Coast enjoys lighter regulatory conditions but is negatively impacted by environmental legislation which is costly to comply with. The Gulf Coast and South Korea are moving towards the European model of REACH to improve efficiency and standardise compliance processes.

The broadly common approach to policies for the creation and nurturing of an innovation ecosystem across the European regions, including the NPH, reflects the strong emphasis placed on this subject by the European Commission and the extensive array of instruments and initiatives developed by the EU to support innovation and knowledge transfer at regional as well as at European level. Support for innovative SMEs remains a strong theme, albeit perhaps leaving more to be done with firms just over the SME size threshold. Other common features include an emphasis on knowledge transfer from universities and the research base, support for growing as well as for start-up firms, and smart specialisation or its equivalent. At a wider level, relationships forged across Europe as a consequence of participating in EU-funded schemes have proved highly valuable and enabled sharing of good practice across the Union. The NPH has contributed to, and gained from, this European activity and it remains to be seen how far participation will be able to continue after Brexit.

A further feature of EU policy, in innovation and many other spheres, is a strong emphasis on action at the regional level. Although this has brought many advantages, among changes in UK policy over recent years has been a reduction in regional autonomy and freedom of action, notably with the loss of the former Regional Development Agencies. This disadvantaged the chemicals and process sector, since the three RDAs covering the NPH area all viewed the sector as a priority and provided support for innovation in a variety of ways, while catalysing co-operation among firms and between industry and academia. Although the renewal of interest at national level in industrial strategy and the importance now being attached to 'Place' are developments which will help the sector, the prospect of possible disconnection from EU policy for innovation promotion represents a source of uncertainty and threat for the sector in the UK.

On the industry side, it is often held that the chemical and process sector has long suffered from a lack of 'visibility' in Government compared to the more joined-up aerospace and automotive sectors which are able to present a more united front and speak with a common voice. This is beginning to change with the work of the Chemistry Growth Partnership and others, but the sector has some way to go before it achieves the profile and level of cooperation of, for example, the industry in the Netherlands.

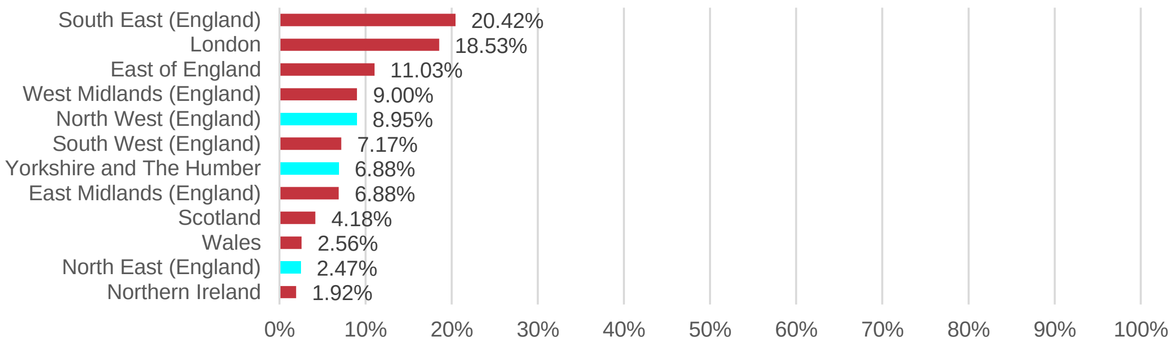
In relation to those areas of the process industry linked to the life sciences, a generic observation is that competitor regions / countries have been better at promoting biotechnology, especially industrial biotechnology (IB), than the UK. The US culture is arguably more startup-friendly, and the German BMBF's (Federal Ministry of Education and Research) activity in IB is extensive, while in the UK, a national strategy for the bioeconomy has yet to be published. A related observation is that in the UK higher education sector, IB is often insufficiently covered in chemical and process engineering courses.

8.3 Innovation Ecosystem

All focus regions showed significant movement towards greater investment and strategic inclusion of the chemicals manufacturing industry. Summary points on the innovation ecosystems across the focus regions are below:

- All three European regions were rated as 'innovation leaders' in the European Innovation Scoreboard. Innovation clusters were identified in Antwerp and Geleen which focused on the chemical sector, including Chemelot which aims to develop new start-ups in the chemical sector to drive innovation.
- Our analysis showed that government supported (partly or fully) incentives for SMEs and start-ups were a particular priority for Antwerp, Geleen, Gulf Coast (Texas) and South Korea. SMEs dominate South Korea's economy with over three million in total and 99% of manufacturers being SMEs, these and start-ups have received a significant amount of government funding.
- Singapore and South Korea have invested significant amounts into R&D, benefiting the chemical industry. Singapore's business expenditure on R&D in the chemicals and materials sector more than quadrupled from 2002-12 due to significant investment from foreign companies.

The Northern Powerhouse's three regions rank 6th (Yorkshire and Humber), 8th (North East) and 10th (North West) highest across the NUTS UK regions, with the West and East classified as Leader- and Yorkshire as Leader on the European Innovation Scoreboard. Out of the 6556 R&D active companies in the UK, 1,200 (18.3%) are registered in the three regions[130].



The North East's relative position to the other NUTS regions is 10th in this measure (**Error! Reference source not found.**). According to FAME, there are 116 R&D active companies in the three regions operating under these four SIC classifications with a combined turnover of £9.437bn.

Table 4 Regional Innovation Scoreboard 2017 - Normalised scores by indicator 2017 ranked.

UK rank	R&D expenditure public sector	R&D expenditure business sector	Non-R&D innovation expenditures
1	Scotland	East of England	South East
2	East of England	South East	North East
3	South East	West Midlands	South West
4	London	East Midlands	West Midlands

[130] Search: "All active companies (not in receivership nor dormant) and companies with unknown situation, with a known value for R&D, Last available year, Last year -1, Last year -2, Last year -3, for at least one of the selected periods".

5	South West	South West	North West
6	Yorkshire and The Humber	North West	Wales
7	Wales	Northern Ireland	Northern Ireland
8	North East	Scotland	Yorkshire and The Humber
9	North West	Wales	East of England
10	Northern Ireland	Yorkshire and The Humber	Scotland
11	East Midlands	North East	East Midlands
12	West Midlands	London	London

Further analysis of the Regional Innovation Scoreboard[131] provides some useful additional insights for the European regions in the comparator group. The indicators[132] used refer to each region as a whole. i.e. pan-sectoral, but for a region with a very strong or dominant role for the chemical and process industries one may make the working assumption that findings for this sector are unlikely to be atypical of the region.

The relevant regions are Rheinhessen-Pfalz; Limburg (including the Geleen cluster); Vlaams-Gewest and Zuid-Holland (together housing the Antwerp-Rotterdam cluster); and the three regions covering the NPH: North West, North East and Yorkshire and the Humber. Analysis of the RIS indicators suggests that for its size, compared to the first four regions listed, the NPH group:

- performs less well in the level of R&D expenditure, especially in business R&D
  - ... but better in non-R&D innovation expenditure
- Has fewer product and process innovators
  - ...but more market and organisational innovators
- Has fewer SMEs innovating in-house
  - ... but more SMEs innovating in collaboration with others
  - ....and perhaps reflecting the last point, generates more public-private co-publication and EPO patent applications
- Generates more sales from new-to-market and new-to-firm innovations.

So the comparison picture is mixed, though given the importance of investment in R&D for the chemical and process sector, the poor level of business R&D (a UK-wide problem of course, not just for the NPH) and lower level of process / product innovators must be of concern.

Moreover, the evidence that the two groups perform well in contrasting areas underlines the scope to learn and share good practice with and among European regions, and for such sharing and exchange to continue notwithstanding Brexit.

Qualitatively, a difference between the UK and other innovation ecosystems is that historically, the UK has placed more weight on universities as driver for innovation compared to other advanced economies, where a stronger role was played by ‘intermediate institutes’ (e.g. Fraunhofer in Germany,

131 http://ec.europa.eu/growth/industry/innovation/facts-figures/regional_en
132 http://ec.europa.eu/growth/industry/innovation/facts-figures/regional_en

TNO in the Netherlands, VITO in Flanders, A*STAR ((including ICES) in Singapore). The UK's approach proved to have some disadvantages, and in the chemical and process sector this was among the factors leading to action to improve linkages and knowledge transfer between the research and knowledge base and industry. Initiatives taken included the creation of Centres of Industrial Collaboration in Yorkshire and the Knowledge Centre for Materials Chemistry - now hosted by CPI, itself a key asset for the NPH and beyond in guiding innovative developments through the well-known 'Valley of Death' and along the technology readiness level scale. More recently the creation of the Catapults represents a shift in UK policy with a recognition that a different sort of entity is needed to complement the lower-TRL R&D and skills provision roles of universities.

A further qualitative advantage for the Geleen and Antwerp-Rotterdam clusters in particular is the Dutch tendency towards collaboration and compacts, influencing the country's approach to innovation: co-operation between business and government is well developed. The small size of Singapore and the strong role of Government encourages a similarly strong level of coordination. The NPH, in comparison, lost some of the connectivity and 'networking' which characterised the industry before a period of fragmentation centred on the break-up of ICI: collaborative links between different business areas were being severed while hard-to-replace skills were gradually being lost with adverse consequences for innovation. In the Tees Valley, this threat led in the very early 2000s to the creation by One NorthEast of the Centre for Process Innovation (CPI), while the continued need to foster interaction and collaboration has been recognised and acted upon by cluster network organisations such as the North East Process Industry Cluster (NEPIC), Chemicals Northwest and YCF-CATCH (a merger of two precursor bodies).

8.4 Circular Economy, Low Carbon and Feedstocks

We found some examples of circular economy and low-carbon innovations across the regions in the form of specific examples from which the Northern Powerhouse might learn from. The narrative on feedstocks was very context specific but was typically tied to the availability and price of natural gas for the regions. Summary points below:

- The European regions explicitly include 'circular economy' 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) and Singapore commissioned an Effluent Water Treatment Recovery Plant to recycle industrial wastewater from refineries. Despite these few examples, there are no significant efforts in any of the regions to establish a serious circular economy in the chemicals sector.
- The European regions have placed the reduction of CO^2 and GHGs in their policies and strategies with various funding incentives to move towards a low carbon economy, although there were no examples from the chemical industry.
- The Singaporean government will establish a carbon tax from 2019 which may mean higher costs for chemical companies. As for digitisation, IBM and Maersk are currently piloting a new blockchain technology in the Port of Houston (to digitize the supply chain process from end-to-end) and South Korea have a smart factories initiative which aims to expand into the chemical sector.
- Mentions of feedstock in the European regions related directly to circular economy with feedstocks produced from recycling other materials.
- In the Gulf Coast, the shale gas boom has meant low-cost natural gas has been used as feedstock, leading to high profitability and less reliance on imports, whereas South Korea has the opposite problem with a massive reliance on feedstock imports. Singapore, like South Korea, has no natural feedstock but has built many refineries to produce it, after struggling to source feedstock in previous

decades. Across all regions, the prices of materials (natural gas, oil) and trade tariffs has had a significant impact on feedstock availability and consequent overall manufacturing costs and profits.

Appendix A Sub-sectorial definitions and SIC Codes

Sub-Sector	Definition	SIC Code
Chemical Manufacturing **(Bulk Chemicals)**	The transformation of organic and inorganic raw materials by a chemical process and the formation of products. This sector has different SIC codes which distinguish the production of basic chemicals from the production of intermediate and end products: [13] Manufacture of industrial gases Manufacture of dyes and pigments Manufacture of other inorganic basic chemicals Manufacture of other organic basic chemicals Manufacture of fertilisers and nitrogen compounds Manufacture of synthetic rubber in primary forms Other chemical products n.e.c Large-scale bulk commodities used in chemical sub-sectors further downstream. [10]	20 20.11 20.12 20.13 20.14 20.15 20.17 20.59
Speciality Chemicals	Differentiated performance products used on the basis of their function. [14] Pesticides and other agrochemical products Paints, varnishes and similar coatings, printing inks and mastics Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations Explosives Glues Essential oils The manufacture of basic pharmaceutical products and pharmaceutical preparations. Including the manufacture of medicinal chemical and botanical products. … As with advanced materials but chemical functionality is the desired outcome rather than mechanical functionality…	20.20 20.3 20.4 20.51 20.52 20.53 21
Polymers and Plastics	Manufacture of resins, plastics materials, non-vulcanisable thermoplastic elastomers, the mixing and blending of resins on a custom basis, as well as the manufacture of non-customised synthetic resins. [13]	20.16

	Processing new or spent (recycled) plastics resins into intermediate or final products using such processes as compression moulding; injection moulding; blow moulding and casting. [13]	22.2
Materials	The process of transferring industrial materials from a raw-material state into finished parts or products? [15] Man-made fibres Manufacture of rubber products Manufacture of other non-metallic mineral products Manufacture of plastic products? (Advanced materials): Research, developments and applications of materials designed to have superior properties (eg. strength, weight, conductivity) or functionality than existing/ traditional materials. [16] Materials whose structure and functionality has been modified to satisfy demanding requirements of specific applications. It also includes the innovative use of basic materials to significantly improve performance of a product or technology. [17]	20.6 22.1 23
Technical Consultancies	Companies who provide expert advice within a particular field by providing technical support, performing trouble-shooting functions and resolving customer issues.	
Wider Supply Chain	The sequence of processes involved in the production and distribution of a commodity or product.	

Appendix 17: Appendix References

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

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

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

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

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

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

[7] 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].

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

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

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

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

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

[13] 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].

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

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

[16] Office for National Statistics, "Business Population Estimates," 2017. [Online]. Available: https://www.gov.uk/government/collections/business-population-estimates. [Accessed 1 August 2018].

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

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

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