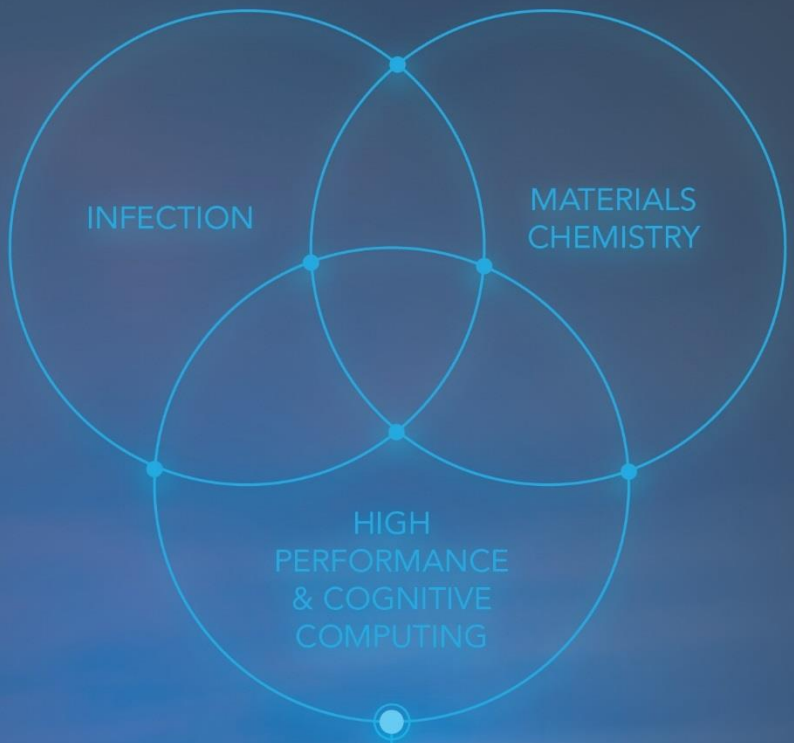
LIVERPOOL CITY REGION +
A SCIENCE & INNOVATION AUDIT
MAIN REPORT

SPONSORED BY THE DEPARTMENT FOR BUSINESS, ENERGY & INDUSTRIAL STRATEGY
SEPTEMBER 2017



Department for Business, Energy & Industrial Strategy

LIVERPOOL CITY REGION COMBINED AUTHORITY

Liverpool City Region Local Enterprise Partnership

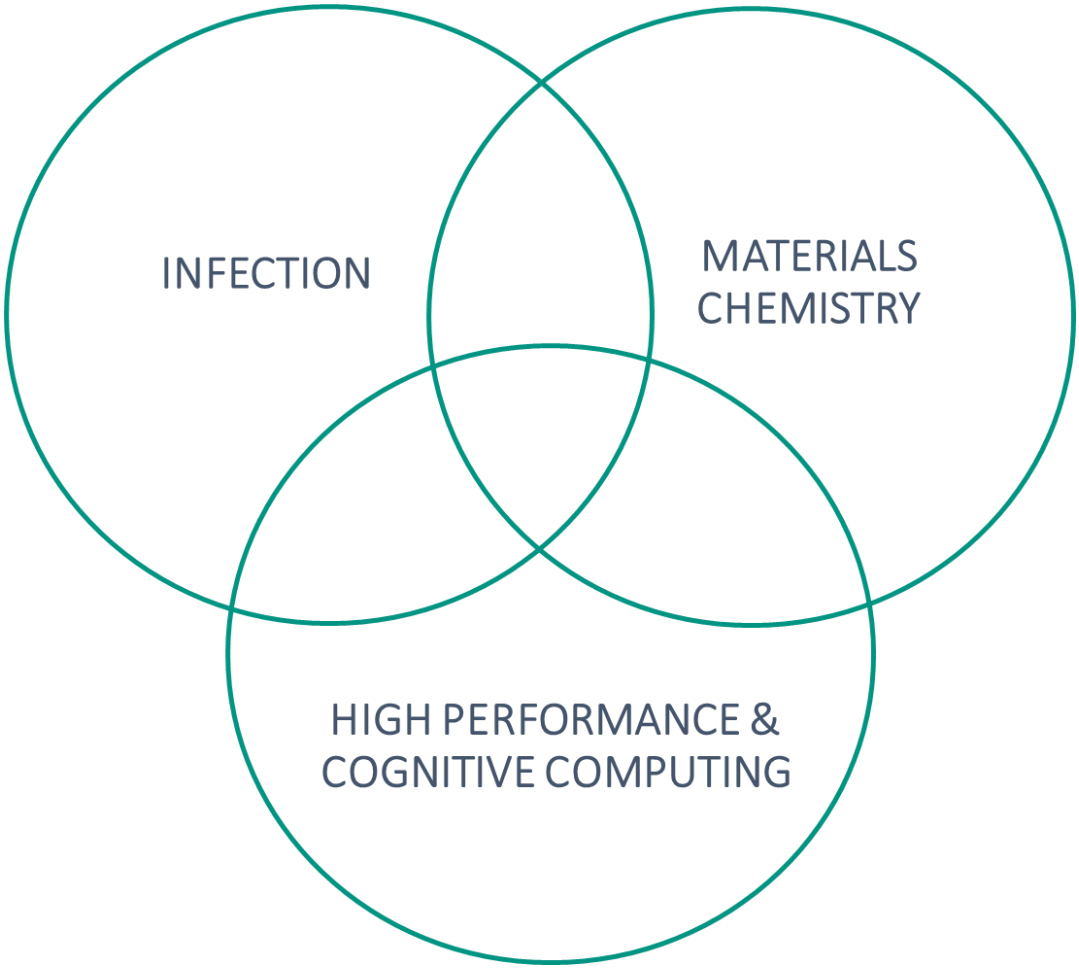
LSTM LIVERPOOL SCHOOL OF TROPICAL MEDICINE

Science & Technology Facilities Council

Unilever

UNIVERSITY OF LIVERPOOL

Liverpool City Council



OUR FINALISED SCIENCE & INNOVATION AMBITIONS:

Infection To consolidate the LCR's position as an international centre of excellence in tackling infectious diseases, and create a cluster of anchor and high growth companies to take advantage of global market opportunities in infection.

Materials Chemistry To apply the LCR's world class materials chemistry capabilities and commercialisation model to provide transformational opportunities for mature UK sectors, create new high-growth industries, and become a recognised global leader.

HP&CC To harness the LCR's world-leading High Performance and Cognitive Computing[1] capabilities to accelerate cross-sector growth and productivity, public sector transformation, and develop a world-class data-centric and disruptive digital technologies cluster.

Innovation Excellence For the LCR to be a national exemplar of place-based and innovation-driven economic growth that supports the UK Industrial Strategy.

[1] NB. We have chosen to use this term rather than "Artificial Intelligence", while acknowledging that the two are closely related.

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Foreword from the Mayor of Liverpool City Region

As the newly elected Mayor of the Liverpool City Region, I am delighted that we are submitting this "LCR+" Science & Innovation Audit (SIA) report, an important initiative that was specifically referenced in our Devolution Agreement with government.

This is an exciting time for the City Region, and maximising our exceptional scientific, industrial and innovation assets is critical to effecting the transformational and inclusive economic growth that is at the heart of my vision for the future. So much so in fact, that I have taken on personal responsibility for leading the Innovation Portfolio on behalf of the Combined Authority.

I would like to record my thanks to the core partners involved for their hard work, vision and rigour in producing this detailed evidence-based analysis, and equally to the numerous other businesses and key stakeholders, both within the City Region and across the North and beyond, for their input and involvement.

The initiatives set out here touch every part of the Liverpool City Region, demonstrating how broadly-based our science and innovation economy and assets are. By the same token, we are clear that the world-leading initiatives profiled in this audit can only be fully realised by collaborating with the "best of the best" elsewhere.

Working closely with government, UKRI, the LCR Innovation Board, industry and other strategic partners, I am very pleased - together with Asif Hamid as the Local Enterprise Partnership Chair and designated LCR Business Portfolio Lead - to commend these LCR+ SIA proposals and confirm my personal commitment to delivering them in practice.

Steve Rotheram, Mayor of Liverpool City Region

Asif Hamid, Chair of Liverpool City Region LEP

Introduction from the LCR+ SIA consortium

We are at a pivotal moment in the Liverpool City Region's history. We must respond to the major economic, technological, environmental and political changes that are underway so that our economy and its people prosper in the future. The grand challenges we face include shifting trade patterns, in part generated by Brexit, increased automation as the Fourth Industrial Revolution (4IR), driven by data and computing power, becomes pervasive, and new demographic and health concerns, including anti-microbial resistance. These challenges bring with them opportunities and threats, which we must understand and navigate if we are to achieve our ambitions for our City Region.

In May 2017, our residents elected their first-ever City Region Mayor who will take control of newly devolved budgets – ranging across Transport, Skills, Infrastructure, Planning, Housing, and Business Support, including support for Innovation – as part of our historic Devolution Agreement.

Devolution provides us with an unprecedented opportunity to take charge of our economic future. To build on recent success and to address the challenges before us, we will work with national and international partners to develop and implement policies and programmes that promote economic growth, which is both sustainable and inclusive.

The Government's Industrial Strategy Green Paper, launched in February 2017, identifies 10 pillars that underpin industrial success. Partners used these pillars, together with the indicative Industrial Strategy Challenge Fund themes, to shape development of this Science and Innovation Audit. We are ideally placed to work with Government to strengthen and build on these industrial priorities, based on our track record of:

- Promoting sustainable and inclusive economic growth;
- Developing world-class infrastructure and world-leading research institutions and businesses, and
- Leading the Devolution agenda.

The City Region's capabilities across a range of industry sectors, its economic resilience, and its distinctive assets are key to our efforts to drive economic growth for our and the wider UK's benefit. Interlinking these assets and collaborating ever more closely is multiplying and accelerating the Liverpool City Region's resurgence.

And the strength of that resurgence is already significant. Our City Region economy is worth almost £30bn in GVA terms, equivalent to the entire outputs of the national economies of Lithuania or Slovenia. We have the second highest incidence of high-growth firms in the England. Our City Region is internationally renowned with an outstanding physical environment, and a waterfront recognised by UNESCO as a World Heritage Site. And wrapping around all this, we have significant and deep-rooted industrial strengths, which underpin fully the four prime capabilities defined by the Northern Powerhouse Independent Economic Review of 2016.

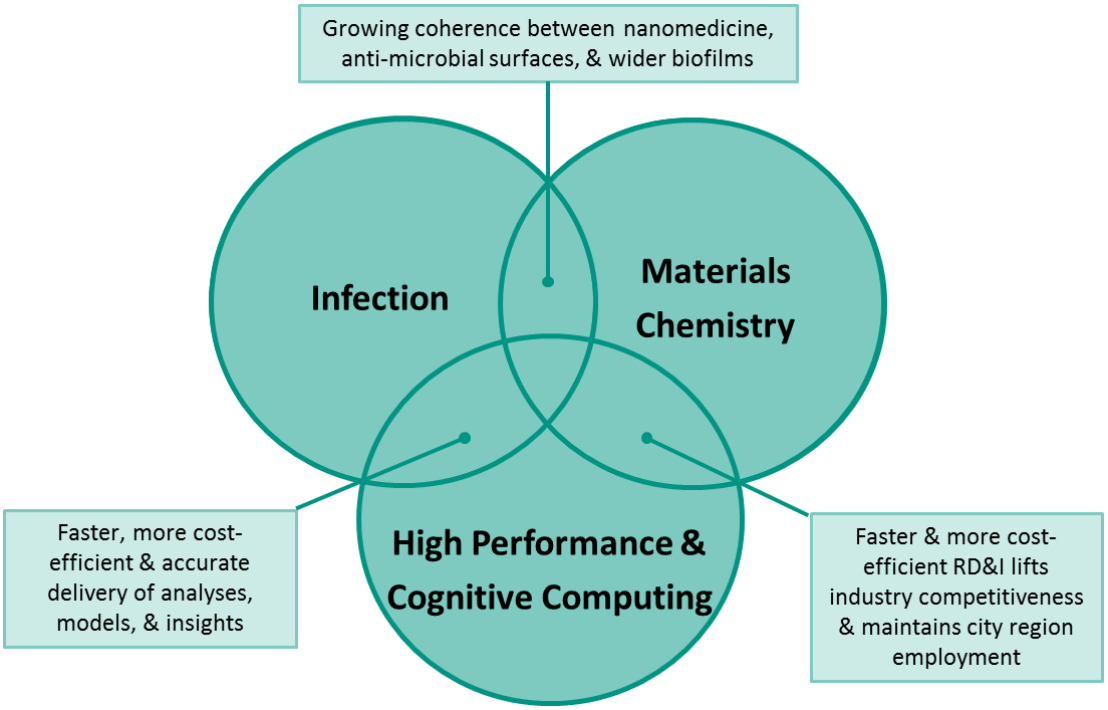
Our single Growth Strategy, *Building Our Future*, published in 2016, sets out how we will capitalise on our strengths to unlock further economic growth and create tens of thousands of new jobs and businesses. We aim to achieve:

- 100,000 additional jobs by 2040;
- A net increase of 20,000 businesses over the next 25 years;
- An additional 50,000 people coming to live in the City Region by 2040, and
- Increasing the City Region's economy to around £50bn by 2040.

We are a happening, moving, and exciting place. Our SIA is a vital part of the work we are progressing to add further to our ambition for transforming the Liverpool City Region. With a clear and robust basis in evidence, overlaid with participative and creative thinking from 150+ organisations, it sets out the three 'themes' where our wider City Region, both in its own strength and by working with others, has proven excellence in science and innovation, which can be further exploited. These areas are:

- Infection;
- Materials Chemistry, and
- High Performance Computing & Cognitive Computing.

At a Glance – our LCR+ Science and Innovation Audit 2017



Source: SDG Economic Development

We have no doubt that the relationships and ideas that this SIA has helped to catalyse will contribute directly to consolidating and heightening our international standing in the three focal areas considered within this SIA, and drive us on to achieve new global benchmarks. They will add further to a vibrant and dynamic innovation ecosystem which continuously builds and strengthens links within the City Region, the Northern Powerhouse, and the wider UK. Having had a relatively small share of investment in science and innovation, LCR has a pipeline of significant and exciting ideas which are ripe for investment from public and private sectors.

We hope that you will work with us to help deliver our SIA projects and ambitions, as well as develop new, related collaborations. This is because they matter and can make a difference, not just for our place – the Liverpool City Region – but also for the wider North and indeed the rest of the UK.

On behalf of the Liverpool City Region+ Consortium

- Joe Anderson, Mayor of Liverpool, Liverpool City Council;
- Professor Janet Beer, Vice Chancellor, University of Liverpool;
- Dr. Jon Hague, Vice President Operations & Open Innovation, Unilever; Chair of the Liverpool City Region Innovation Board;
- Professor Janet Hemingway, Director, Liverpool School of Tropical Medicine, and
- Professor Susan Smith, Head of Daresbury Laboratory, Science & Technology Facilities Council.

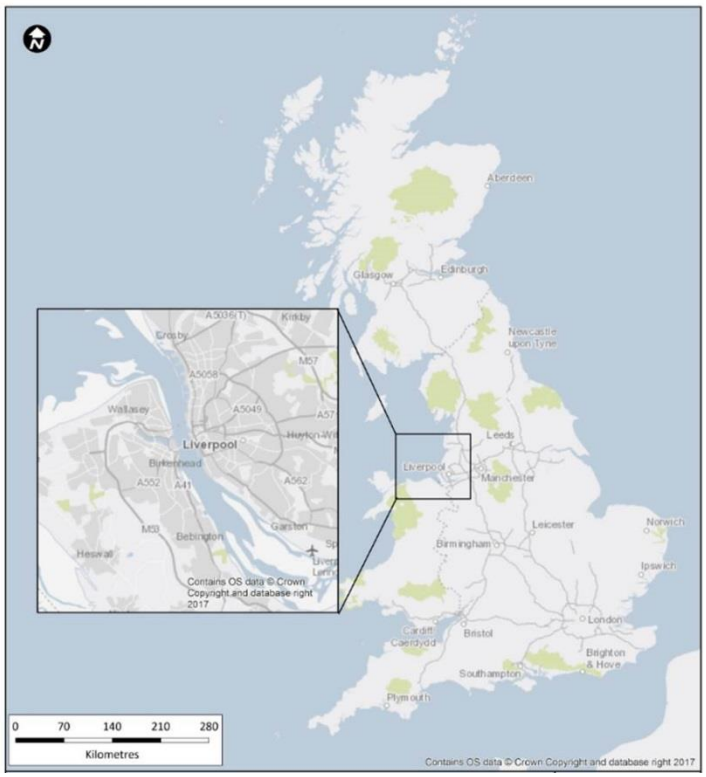
1 Introducing the Liverpool City Region+

Headline Messages

- Liverpool City Region (LCR) has a global profile, unique heritage and capacity/capability for innovation
- LCR has distinctive world class "smart specialisation" assets and a strong innovation ecosystem
- LCR has scale, critical mass, and covers a functional economic geography
- The City Region is resilient and recovering well from economic restructuring
- There is a single, agreed plan to tackle remaining challenges and exploit future opportunities
- Our focus is on commercialisation; industry involvement is fundamental to all we do
- Our growth sectors and capabilities match those of the wider Northern Powerhouse
- Devolution has further strengthened our integrated local governance, partnership and resources
- LCR is ideally suited to delivering a place-based approach to the UK Industrial Strategy

Our Place

1.1 The coterminous area covered by the Liverpool City Region (LCR) Combined Authority and the Local Enterprise Partnership (LEP) comprises the six local authority districts of Liverpool, Halton, Knowsley, Sefton, St. Helens and Wirral. As a City Region, we are at the forefront of devolution thinking and action, while our LEP is applying Smart Specialisation principles to drive place-based innovation and commercialisation for productivity-based growth by focusing on existing strengths in the context of the drivers of economic and technological change.[2]



1.2 As an economy, we have the scale, assets, governance arrangements, capabilities, and the appetite to play a lead role in

[2] The evidence of our approach is outlined in paragraph 1.22.

delivering the government's Industrial Strategy, nuanced and specified for our place. We have a population of 1.53m people (ONS, *MYE 2016*) - one of the smallest LEP areas by geography, but ranked 14 of 39 on population virtue of our higher population density (NOMIS, *LEP area profiles*) – with an economy generating £29.4 billion Gross Value Added in 2015 (ONS, *GVA 2016*) and providing employment for 612,000 workers (ONS, *BRES – Total Employment*).

1.3 Our spatial footprint represents a functional economic geography with an integrated labour market - 86% of LCR's workforce live within the City Region itself[3]. But we are also a connected place; a significant proportion of LCR residents commute to work in the wider economic hinterland, including parts of West Lancashire, Warrington, Cheshire, Greater Manchester and North East Wales.

1.4 The City Region also has important trade links with Ireland, North America, and a host of other international trading partners. Liverpool's trading significance is likely to increase in the light of Brexit, the widening of the Panama Canal and the greater shipping capacity this offers, and the completion of the Liverpool 2 Deep-Water Terminal, which can now handle 95% of the world's container ships. Liverpool's port handles around 8% of the UK container market UK and this is expected to increase to between 15% and 20%, once the new facility reaches capacity[4]. The Port is already the country's biggest transatlantic port (45% market share) [5].

1.5 The Liverpool brand has a high international profile thanks to our unique history and culture, shaped by our maritime and trading heritage. In the nineteenth and early twentieth centuries, Liverpool was one of the world's leading ports and mercantile centres, enabling the Industrial Revolution here and in the wider North West.

1.6 This history gives the City Region a uniquely outward-facing culture, which underpins our open working approach generally, and to research and innovation in particular. While anchored in, and focused on, the LCR, the development of this SIA and associated initiatives depends on effective and ongoing collaborations with a rich mix of businesses and academic, research, trade and industry bodies, within the LCR and across the North of England, wider UK, and internationally – hence the "LCR+" designation for our SIA (Appendix 1 sets out partners and stakeholders and their roles in the SIA).

1.7 Our SIA focuses on three themes – Infection, Materials Chemistry, and High Performance and Cognitive Computing (HP&CC) – where, as we demonstrate below, we have demonstrable potential to be world-leading and have a significant economic impact. All three are based on actual and latent assets, world-class research, and industry capability. Working with other LEPs, universities, and industry groupings in the North East, Tees Valley and Hull/Humber, we are also an active partner in the Offshore & Subsea Technologies SIA, and the Bio-Economy of the North of England SIA.

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[3] Parkinson, Evans, Meegan &, Karecha, 2016, *The State of Liverpool City Region Report: Making the most of Devolution.* University of Liverpool and Liverpool John Moores University. *www.liverpoollep.org/wp-content/uploads/2016/01/SOLCR.pdf-Jan-15.pdf*

[4] Peel Ports https://www.peelports.com/news/2016/official-opening-of-peel-ports-400-million-liverpool-container-terminal

[5] *ibid*

1.8 Our LEP was also a founder member of the Northern LEP Innovation Leads' Working Group that is now formally collaborating with Innovate UK to produce an innovation strategy for the North of England.

Socio Economic Profile

1.9 In 2016, the University of Liverpool (UoL) and Liverpool John Moores University (LJMU) co-authored '*The State of Liverpool City Region Report: Making the most of Devolution'*[6], an independent and comparative analysis of the City Region's socio economic position. This identified the main socio-economic challenges and opportunities we face, and informed directly the City Region's Growth Strategy and the implementation of our Devolution Agreement.[7]

1.10 The report concluded that 'There is cause for optimism – if realism . . . During the last decade, Liverpool City Region has become a good news story - one of genuine progress from difficult beginnings and of increased ambition and achievements . . . But the challenges should not be underestimated'.

So, what are the main challenges . . .?

1.11 The State of the Liverpool City Region Report (SOLCRR) assessed LCR's performance against London and eleven 'second tier' UK City Regions to identify the key challenges we face. These include:

- ***Population*** – long-term economic restructuring over four decades resulted in population decline toward the end of the twentieth century. Since 2001, with economic recovery LCR's population has increased by around 2.1%, less than population growth in the UK as a whole but a reversal of the long-term decline in the LCR (SOLCRR);
- ***Wealth and Income gaps*** – high levels of economic inactivity contribute to a low level of GVA per head (LCR=£18,472, UK =£25,351 GVA) ONS, GVA 2016). Our GVA per head is second lowest of the 12 comparator areas. The LCR's 7.2% growth in GVA per head (2010-2015) lags significantly behind the national rate of 14.7% (ONS, GVA 2016). Gross Domestic Household Income in LCR is £15,415, the eighth lowest of London and the second-tier cities (UK=£17,965) (ONS, GDHI 2016);
- ***Not enough businesses***– in comparison with the other areas, we have a relatively low business density, with low business start-up and survival rates (ONS, Business Demography); this limits our ability to increase productivity and generate employment, closing the business density gap is a priority for partners in the City Region;
- ***Not enough jobs*** – we have the joint lowest jobs density among the 12 comparator City Regions (LCR =0.69, UK=0.81 jobs per Working Age Adult). LCR also has the lowest employment rate among the 12 cities (currently, LCR=67.7%, UK=73.9%). Levels of self-

[6] Parkinson, Evans, Meegan &, Karecha, 2016, *The State of Liverpool City Region Report: Making the most of Devolution.* University of Liverpool and Liverpool John Moores University. www.liverpoollep.org/wp-content/uploads/2016/01/SOLCR.pdf-Jan-15.pdf

[7] Appendix 2 provides a table of socio-economic statistics comparing the City Region against its peers.

employment (LCR=11.0%, UK=13.9%) are also relatively low, reflecting our heritage of large paternalistic employers (SOLCRR);

- ***Not enough private sector jobs*** – we are overly-dependent on public sector jobs - employment in the public sector is high (22.4%) compared with the GB rate (18.6%); helpfully, though, public sector employment reliance is reducing (ONS, BRES);
- ***Skills gaps*** – Table 1-1 shows that LCR has comparatively low educational attainment and skilled workers rates. Among the 12 comparator City Regions, LCR has the second lowest proportion of residents with degree level skills and LCR has the third highest proportion of residents with no qualifications (SOLCRR);
- ***High levels of poverty and multiple deprivation*** – LCR is the most deprived LEP area and contains many of England's most disadvantaged neighbourhoods (IMD 2015). Knowsley is England's second most deprived local authority district, Liverpool fourth;
- ***High rates of worklessness and poor health*** – we have the highest proportion of workless households (24.2%) amongst the comparator areas. LCR also has a very high proportion of economically inactive residents that are suffering from a long-term illness and the rate is 1.4 times the UK average (SOLCRR);
- The City Region's Growth Strategy, *Building Our Future*[8], highlights concerns about the quality of the jobs on offer in the City Region, with an increasing proportion of vacancies being for part-time and flexible roles. This SIA will help to tackle the problem as it targets high-value, permanent jobs over short-term ones, and the trap of low-value employment.

Table 1-1: Employment and Skills data for the Liverpool City Region

- The City Region's average job density ratio[9] is 0.7, well below the GB average of 0.83 (ONS, Jobs density 2015, via NOMIS)
- 32% of the City Region's workforce is qualified to NVQ4+, six percentage points below the UK average of 38% (ONS, annual population survey data, Jan-Dec 2016)
- 51% of the area's workforce is qualified to NVQ3+, six percentage points below the GB average of 57% (ONS, annual population survey, Jan-Dec 2016)
- Just over 12% of the City Region's workforce has no qualifications, almost four percentage points higher than the GB average (ONS, annual population survey, Jan-Dec 2016).

. . . and the main opportunities?

1.12 Set against these socio-economic challenges, we have reasons for real and substantive optimism. The State of the Liverpool City Region Report identifies three broad aspects of competitive strengths for our place: a productive workforce, a diverse economy, and a range of economic sector strengths. These strengths will be reinforced by work to join-up the City Region's research assets with its business base, work that this SIA has catalysed.

[8] Liverpool City Region Local Economic Partnership and Combined Authority 2016, *Building Our Future*; Liverpool City Region Growth Strategy, https://www.liverpoollep.org/growth-strategy/

[9] The ratio of jobs available divided by resident population aged 16-64.

A Productive Workforce

1.13 The Northern Powerhouse Independent Economic Review (2016)[10] reported that GVA per job in the LCR was higher than in all other City Regions in the North of England, despite the fact that LCR worker productivity had dipped after 2010 and failed to return to its previous levels. Productivity in the City Region, as measured by GVA per job filled, was £43,250 in 2015 (equivalent to £27.60 an hour). This is below the average for England of £50,715 (equivalent to £31.40 per hour), but above the averages achieved by most other sub regions in the North of England.

1.14 The City Region's relatively strong rate of worker productivity is due to the presence of higher-value sectors, especially Pharmaceuticals, Chemicals, Coke and Petroleum, Wood and Paper, IT Services, Printing and Recording, Automotive, and Water and Air Transport, as well as high-value Professional Services.

1.15 This SIA develops proposals, set out in Chapter 7 and Appendix 9 that will help maintain the City Region's competitiveness in its key sectors, while also helping to develop new and disruptive technologies that will build the economic sectors of the future.

A Diverse Economy

1.16 The evidence shows that that City Regions which are most successful in responding to economic change are least dependent on single sectors. Reflecting this, the State of the City Region Report uses the Krugman Similarity Index to measure relative economic specialisation. The analysis shows that LCR's economy is reasonably diverse in terms of its sector spread and crucially, it is not over-reliant on any single particular sector.

Business Growth and High Growth Firms

1.17 In recent years, LCR has performed well in terms of business growth, and in relation to high growth firms. Table 1-2 shows that the City Region outperforms the English LEP average in terms of (a) the percentage of businesses which grew from an annual turnover of £1-2m in 2012 to at least £3m by 2015, (b) the incidence of high growth firms over the period 2012-2015, and (c) net job creation.

Table 1-2: Business Growth Data for the Liverpool City Region

Indicator	Liverpool City Region	LEP Average
% of £1-2m T/O businesses in 2012 growing to a minimum of £3m by 2015	6.5%	5.8%
% of 2012 start-ups surviving to 2015	52.0%	55.3%
% of surviving 2012 start-ups growing from <500k to > £1m T/O by 2015	1.7%	1.6%
High-growth firm incidence rate as % of firms with 10 or more employees (2012-15)	8.5%	7.2%
Net Job Creation Ratio (2014-15)	3.5%	2.6%
Start-ups per 10,000 population in 2015	35	43

Source: Enterprise Research Centre Growth dashboard data, https://www.enterpriseresearch.ac.uk/wp-content/uploads/2016/02/ERC-HGF-LEP-Insight-Feb-2016.pdf

[10] Transport for the North, 2016, Northern Powerhouse Independent Economic Review, http://www.transportforthenorth.com/?s=Northern+Powerhouse+Independent+Economic+Review

Growth Sectors and Northern Powerhouse

1.18 *Building Our Future* provides a clear vision for how the City Region will deliver sustained, ambitious growth. The Strategy is based on developing the three pillars of Productivity, People and Place, specifically within the seven Key Growth Sectors listed at Table 1-3. It is the City Region's inherent strengths in these sectors and the unique mix of assets that, if fully exploited, will create jobs, improve productivity and stimulate growth.

1.19 The LCR accounts for around 10% of the North's population and GVA and is well placed to help deliver the Northern Powerhouse opportunity. The seven LCR growth sectors align closely with the Prime and Enabling Capabilities identified within the Independent Economic Review of the Northern Powerhouse, as shown in Table 1-3. Our three themes relate directly to Northern Powerhouse themes: Infection forms part of Health Innovation, Materials Chemistry forms part of Advanced Manufacturing & Materials, and HP&CC is a key part of the Northern Powerhouse's Digital capability.

Table 1-3: Liverpool City Region's seven growth sectors, and alignment with the Northern Powerhouse capabilities

LCR Growth Sector	GVA bn (2012)	Total Employment 2015	Alignment with Northern Powerhouse Capabilities	
			Prime	Enabling
Advanced Manufacturing	£3.3	47,000	Advanced Manufacturing & Materials	
Digital & Creative	£1.0	14,000	Digital	
Financial & Professional Services	£2.2	45,000		Financial & Professional Services
Health & Life Sciences	£4.1	134,000	Health Innovation	
Low Carbon Energy	£1.9	35,000	Energy	
Maritime & Logistics	£0.8	19,000		Logistics
Visitor Economy	£1.3	63,000		

Source: Liverpool City Region Forecasts, Oxford Economics 2016

And prospects for further growth?

1.20 LCR LEP commissioned Oxford Economics to produce growth forecasts for use in the development of 2016's LCR Growth Strategy. The forecasts from the 'LCR Aspirational Scenario' are as follows:

- LCR GVA growth to 2040 of 85.9% or 2.4% per annum, this compares with UK GVA growth over the same period of 76.1% or 2.2% per annum.
- LCR Total Employment (Jobs) growth to 2040 of 17.3% or 0.6% per annum, this compares with UK Total Employment growth over the same period of 13.5% or 0.6% per annum.

Science and Innovation Assets and Capabilities

1.21 The City Region has a critical mass of distinctive scientific and industrial assets within its rapidly evolving innovation ecosystem (see Map 1-1). These are set out in the LCR Innovation Plan – first published in 2014 and one of the first to be produced by any LEP in the country – which reflects the explicit emphasis we place on applying smart specialisation principles to levering economic growth.

1.22 The associated focus is on niches within 4 'sectors' that match across to those in the Northern Powerhouse Economic Review, and with particular accent on inter-sector 'cross-fertilising':

- **Advanced Manufacturing & Big Science**, based on distinct clusters in automotive, rail, chemicals/fast-moving consumer goods (FMCG). Key companies located in the LCR include: Alstom, BASF, Croda, Getrag Ford, Ineos Chlor, Innovyn, Jaguar Land Rover, Johnson Controls, LPW Technology, NSG/Pilkington, Sigmatex, Unilever.
- **"Blue/Green"** - globally significant low carbon energy growth sector, linked to the first and largest deployment in the world of next generation 8MW wind turbines. Key companies located in the LCR include: ABB, Acal Energy, ACL, Bibby, Cammell Laird, Clarke Energy, CMA CGM, DONG Energy, Iberdrola, Maersk UK, Peel, Stobart.
- **Digital & Creative**, based on data intensive sciences, sensors/Internet of Things and the creative sector, linked to the STFC Hartree Centre. Key companies located in the LCR include: AIMES, Atos, Baltic Creative, FACT, IBM, NVidia, Mellanox, O2, Red Ninja, Shop Direct.
- **Health and Life Sciences,** based on nationally significant capabilities in infection, precision e-health, and paediatrics. Key companies located in the LCR include: Actavis Biologics, Baxter Healthcare, Bristol Myers Squibb, Eli Lilly, Evgen Pharma, Mast Group, Medimmune/AstraZeneca, Nutricia, Seqirus, Videregen, Vitaflo/Nestlé Health Science.

1.23 There is also a sub-place-based focus on our two internationally significant concentrations of research and innovation assets and capabilities:

- The **Knowledge Quarter Liverpool**[11] board comprises UoL, LJMU, LSTM, The Royal Liverpool and Broadgreen University Hospitals NHS Trust, Liverpool City Council, Liverpool Vision and The Hope Street Community Interest Company. KQ Liverpool is already home to some of the world's most influential players in science, health, technology, culture and education, who are collaborating to reposition Liverpool at the forefront of global innovation, grow the economy and create new employment.
- **Sci-Tech Daresbury Enterprise Zone**, one of the UK's leading science and innovation campuses, anchored by STFC's Daresbury Laboratory, home to 100+ high-tech companies from start-ups to multinationals, and with major research capabilities[12].

[11] http://www.kqliverpool.co.uk/

[12] Sci-Tech Daresbury has recently secured the award for the UKSPA Member seen to be "setting the pace" – see http://www.ukspa.org.uk/awards-dinner#sthash.yJwnkRTD.dpuf

1.24 LCR has an enviable track record of attracting external investment and funding, founded on established and effective governance and management arrangements. The nature of £2+ billion of recent/ongoing catalytic innovation investments gives an insight into the pace and scale of developments building on the LCR's existing assets/capabilities (Table 1-4).

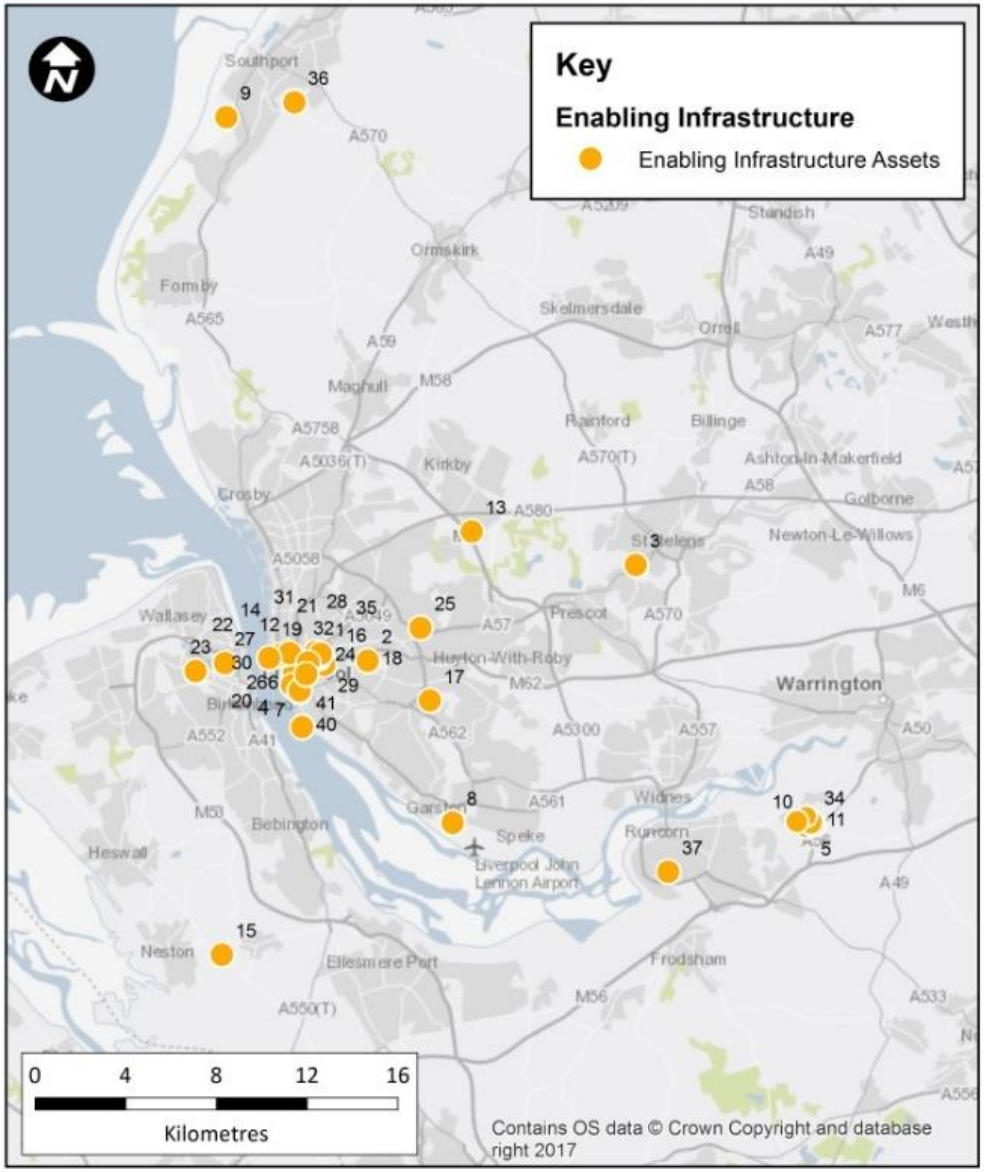
Table 1-4 Recent investments in Liverpool City Region

- 2015 £115.5m Government investment in the Hartree Centre matched by £200m from IBM and an ongoing £35m expansion of space and facilities at Sci-Tech Daresbury
- £279m completion of the new Alder Hey Children's Hospital
- Unilever's new £24m Advanced Manufacturing Centre (opening 2017)
- £64m UoL-Unilever Materials Innovation Factory*[13] (opening 2017)
- £15m joint LJMU-UoL "Sensor City"* University Enterprise Zone project (opening 2017)
- The £8m ERDF co-funded LCR 4.0 project, a UK-leading 4IR initiative using IoT (Internet of Things) and sensor technologies to transform the productivity of the LCR manufacturing sector
- New £25m Life Sciences Accelerator*
- New £20m Liverpool BioInnovation Hub*
- New £335m Royal Liverpool Hospital* (opening 2018)
- New £124m Clatterbridge Cancer Centre* in the Knowledge Quarter (opening 2018)
- Paddington Village*, a £1bn flagship expansion site that will house 1.8m square feet of science, technology, education and health space.

1.25 Strategic development and delivery of the innovation agenda is championed by the dedicated, high level cross-sector LCR Innovation Board established in 2013, whose purpose is to drive the commercialisation of knowledge and ideas, increase productivity, maximise investment, enhance skills, attract talent, and accelerate growth across all sectors of the City Region's economy.

13 * denotes that this is located with Knowledge Quarter Liverpool

Map 1-1: The spatial distribution of Science and Innovation assets in the Liverpool City Region (non-exhaustive list)



Key Assets

1. Accelerator and CEIDR (Centre of Excellence in Infectious Diseases Research)
2. AIMES Data Centre
3. Alexandra Business Park
4. Atlantic Container Line UK Ltd.
5. Atos
6. Baltic Creative
7. Elevator Studios (Baltic Triangle)
8. Estuary Commerce Park
9. Hibernia Transatlantic Cable/ FibreOptics
10. IBM Research
11. Innovation Agency (Academic Health Science Network for the North West Coast)
12. Knowledge Quarter Liverpool (Liverpool Science Park)
13. Knowsley Business Park
14. Launch 22
15. Leahurst Veterinary Centre
16. Liverpool Clinical Laboratories
17. Liverpool Hope University
18. Liverpool Innovation Park
19. Liverpool John Moores University
20. Liverpool Life Sciences University Technical College
21. Liverpool School of Tropical Medicine
22. Liverpool Science Park (Base of Liverpool Health Partners)
23. Marine, Energy, & Automotive Park
24. Materials Innovation Factory (MIF)
25. Medicines for Children Research Network
26. Mersey Waters Enterprise Zone (Liverpool Waters)
27. Mersey Waters Enterprise Zone (Wirral Waters)
28. MerseyBIO Incubator
29. MicroBioRefinery (UofL)
30. MRC (Medical Research Council) Centre for Drug Safety Science (UofL)
31. National Oceanography Centre
32. North West Cancer Research
33. Royal Liverpool & Broadgreen University Hospital NHS Trust
34. Sci-Tech Daresbury Enterprize Zone, STFC & The Hartree Centre
35. Sensor City
36. Southport Business Park
37. The Heath Business & Technical Park
38. The Studio School, Liverpool
39. UK Microsoft Associate College (The City of Liverpool College)
40. University of Liverpool
41. University of Liverpool Department of Computer Science

Liverpool City Region - Science and Innovation Audit 2017

Asset Register: Enabling Infrastructure

sdg economic development

Created by:	Last Updated:	Scale:
CLacy	30/05/2017	300,000

\\sdgworld.net\Data\Manchester\Users\CLacy\Private\LCR SIA Asset Map\Enabling Infrastructure.mxd

2 Strengths in Science and Innovation

Headline Messages

- We have an established history of building and exploiting complementary strengths in industry and academia – over 20 years' experience in strategic partnerships
- These strengths reflect the region's long history of vibrant industrial and research communities linked to a port of global significance
- The resulting expertise in infectious diseases and in materials chemistry is world-class
- Our innovation ecosystem is built on a shared vision for co-funded and co-located research and open innovation facilities where industry and academia work together to commercialise research and innovation
- Our innovation ecosystem is now being enhanced by access to the Hartree Centre's high-performance computing and cognitive computing capability
- Building the potential to provide transformational opportunities for mature sectors and create new high-growth industries
- A significant attractor of valuable inward investment into LCR R&D in our strategic SIA themes (23% of funding sourced from overseas)

The LCR's Close Coupling of Excellence in Science and in Innovation

2.1 The LCR's excellence in science and research is closely coupled with its excellence in business and industrial innovation. Relative to the rest of the UK, we have a high concentration of employment and local business units in the following sectors:

- Three times the national average employment, and twice the national average in local businesses, in the manufacture of basic pharmaceutical products and preparations;
- Well over twice the national average employment, and twice the national average in local businesses in the manufacture of chemicals and related products.

2.2 These industrial strengths are translated into valuable contributions to UK exports. The North-West region accounts for over 10% of total UK exports in crude materials and non-edible products except fuels (18.5%), chemicals and related products (15.1%), and food and live animals (10.7%).[14] As with all advanced economies, industry in the North-West is part of the Global Value Chains (GVCs) that span the world economy – importing goods and services, adding value through areas of competitive advantage and then exporting. This region is a key player in this system of GVCs linked to the chemicals and related industries, a role based on the North-West's world-class innovation capability.

[14] HMRC Regional Trade Statistics (RTS) extracted from www.uktradeinfo.com

2.3 This concentration of industrial activity in technologically sophisticated industries correlates with the SIA's excellence in science and research. This correlation reflects a long-term strategic effort by both industry and academia to cultivate reciprocal relationships that enable cutting-edge science to be closely coupled to cutting-edge industrial innovation, exemplified by the Materials Innovation Factory, or, as in the case of tropical medicine, the ability to create major global health advances for which Liverpool is the epicentre.

The LCR innovation ecosystem is founded on a close coupling of excellence in science, industrial innovation & practical public good applications and is expressed in a strong partnership ethos

2.4 Thus, in terms of research performance the LCR performs very strongly in clinical medicine and excels in infectious diseases whilst also being the strongest chemistry department in the UK, with particular excellence in materials chemistry. This message is well-demonstrated in the 2014 Research Excellence Framework (REF) (see Appendix 5 for more detail). This highlighted, the LCR's research excellence in Chemistry, General Engineering, Electrical & Electronic Engineering, Metallurgy and Materials, all of which had over 90% of their research outputs classed as world-leading or internationally excellent. Whilst Clinical Medicine as a whole had 71% of its output classed in this top tier there is specific world-class research in Infectious Diseases in the LCR (see discussion below and Appendix 5 for more detail).

2.5 A more granular profile of the SIA's research excellence is provided by data on the latest citation rates (details of which can be found in Appendix 5). LCR research in infectious diseases is cited more than 2.3 times the global average and materials chemistry research is cited nearly 2.5 times the global average. High-performance and cognitive computing research in the SIA is cited at over twice the global average rate. Whilst citation data de-coupled from the in-depth peer review of the REF are subject to bias and limitations these are clear strengths that support the hypotheses framing this SIA offer.

2.6 Technopolis analysis of data on patent application activity for Infection and HP&CC[15] found that, the UK ranks 7th globally, in terms of patent activity for the topic of infectious diseases, for both patent applications by location of applicant, and by location of inventor and that LCR accounted for 31% of UK patent applications between 2004 and 2011. The analysis also found that on a broad definition of HP&CC, including both software and hardware, the UK ranks 9th in terms of patent applications by location of applicant, and 7th by location of inventor, and that LCR accounted for 26.5% of UK patent applications between 2004 and 2011.

2.7 As regards the R&D expenditure in the North West, gross expenditure in all sectors in 2014 was £2,557m, which is 8.3% of UK total R&D. The proportional breakdown by R&D performing sector is in line with UK norms except for the case of government sector R&D, which is estimated at 1.55% of total R&D expenditure. This is below both the Wave 2 SIA

[15] Due to the complexity of the keyword searches analysis of patent application data for Materials Chemistry was not feasible.

average (6.28%) and the UK as a whole (at 7.26%).[16] This indicates that the North West is currently under-represented in its emphasis on government sector R&D.

2.8 These long-standing and globally distinctive advantages are now being enhanced by access to high-performance computing via Science and Technology Facilities Council (STFC) Hartree. This introduces a cutting-edge capability to innovate faster, cheaper and at a scale and scope that has not been possible in the past. As we move towards the third decade of the Twenty-First Century, innovation in both industry, and the public good objectives of improved global health, will rest upon the ability to deploy advanced computation and automation in the discovery, testing, application and market introduction of new products and processes. This dimension is not aspirational in the LCR. Computationally enabled discovery, testing and applications are already well-established features of LCR capability in the infection and materials chemistry themes.

2.9 Materials chemistry is key to many sectors from automotive and aerospace through to fast moving consumer goods (and health). Consequently, breakthrough advances in materials chemistry can rejuvenate mature industries and catalyse the formation and growth of entire new industries. This potential is amplified by the 'Industry 4.0' capability that is an established feature of the Liverpool Model – given the genuinely collaborative project, LCR 4.0, which is UK-leading in the development of the fourth industrial revolution.

The 'Liverpool Model'

2.10 The LCR has a long-standing and clearly articulated strategic approach to fostering innovation. This approach is shaped by the combined industrial and academic history of the LCR, and is currently reflected in the *Liverpool City Region Innovation Plan: 2014-2020*[17], that sets out our smart specialisation strengths and priorities, the delivery of which is overseen by the dedicated LCR Innovation Board.

2.11 Whilst the principles of any innovation ecosystem are generic, their particular expression in LCR, known as the 'Liverpool model', is unique. Its close coupling of science and innovation excellence has been created via long-term strategic collaboration between industry and academia. This collaboration is based upon an 'open innovation' model that recognises the value of creating shared cutting-edge automated high-throughput facilities that can be accessed by a wide range of academic researchers and companies and with a major emphasis on knowledge-sharing supported by state-of-the art computational capability. Access to specialised equipment, technical skills, robust streamlined industry-grade methodologies and proprietary data and academic thought leadership are all key to this Liverpool Model – which is described in more detail in Chapter 6.

2.12 The Liverpool innovation ecosystem model also prioritises the concentrated co-location of complementary organisations, a process that is notable in the Liverpool Knowledge Quarter and Sci-Tech Daresbury. This density facilitates the exchange of tacit knowledge and know-how – key aspects of any effective innovation precinct.

[16] See Appendix 5 for more detail.
[17] https://www.liverpoollep.org/wp-content/uploads/2015/06/wpid-lcr-innovation-plan-draft2014.pdf

The Liverpool innovation ecosystem model is an exemplar of how to build strategic collaboration by closely braiding together research excellence and practical relevance – creating both industrial and public good benefits

2.13 More broadly, there is now growing attention being paid to Global Innovation Networks (GINs).[18] These are cross-border collaborative arrangements involving universities, research institutes, high-technology firms and (increasingly) philanthropic organisations. The OECD has started to focus on GINs as a complement to mapping the Global Value Chains (GVCs) that focus only on business and trade – and that constitute the bulk of the world economy. GINs have a distinctly different role and configuration to GVCs, including a strong global public good dimension (e.g. health research and innovation assisting people in less developed countries).

2.14 GIN participation is particularly important because the UK now only accounts for 2.7% of global R&D expenditure (2.49% of global business sector R&D, 4.6% of global higher education R&D, 1.64% of government R&D and 2.8% of other sources (including the growing philanthropic contribution).[19] Consequently, excellence in research attracts significant inward overseas investment in UK performed R&D. The UK is a net beneficiary of these transnational flows of R&D funding, with one of the largest proportional contributions of overseas funded R&D for a large advanced industrial economy. In 2014, 17% of UK R&D was funded from overseas, this contribution has been growing at an annual average rate of 3.3% since 1990.[20] The LCR's performance in attracting inward investment in R&D is very strong indeed. Over 24% of funding for materials chemistry is sourced internationally, and over 29% for infectious diseases. Overseas funding for computing, at 16% is broadly in line with the UK average for all R&D. Taking all three themes together, over 23% of total research funding is sourced from overseas, a proportion that is increasing dramatically from non-EU sources (notably US philanthropic funding for the Infection theme). The LCR's strategic innovation themes are Brexit-tolerant.

2.15 Participation in elite GINs therefore acts as a powerful focus for inward international investment in research, substantial funding that can then be translated into local GVA and jobs via a number of well-established routes. The more developed the LCR component of supply chains linked to the research and innovation in infectious diseases and materials chemistry the stronger the local leverage of this inward investment. The proposals for additional funding in this SIA report are designed to further enhance this inward flow of investment in R&D, with consequent impacts on the regional economy.

The LCR's excellence in infectious diseases and in materials chemistry gives it international prominence in emerging Global Innovation Networks and evolving Global Value Chains – the Liverpool Model is a globally connected asset for the UK

[18] OECD. 2017. The links between global value chains and global innovation networks: An exploration. *OECD Science, Technology and Industry Policy Papers.* No. 37, OECD Publishing, Paris.
[19] OECD (2017) Main Science and Technology Indicators (data are for 2014).
[20] ONS R&D data.

Priorities for strengthening our innovation ecosystem

2.16 Whilst some SIAs seek to build more effective industry-academic partnerships to stimulate innovation *we already have this partnership approach up and running*. Consequently, our challenge is not to build our innovation ecosystem – it is to make it even better. This means extending and enhancing the performance of our established open innovation partnership approach to research and innovation in ways that address our priorities to grow and attract more innovative small businesses. At present, our innovation ecosystem links key large and medium sized companies with our universities and research organisations. Both the industry and academic partners in the SIA recognise that the future growth in GVA and employment requires more innovation-based businesses to be launched and to thrive – creating new jobs and new wealth. This will help to build the local high-technology supply chains that are important to the multi-national corporations and existing smaller companies in our SIA.

2.17 This increase in company start-ups will also help our universities and research organisations to generate increased economic, social and environmental impacts in the North West. As the scale of business start-up activity increases, the accumulating experience of how to navigate the opportunities and risks faced in starting and growing businesses expands. This, in turn, generates 'knowledge spillovers', pervasive flows of know-how between people that can benefit all companies in a geographic area, e.g. the Knowledge Quarter and Daresbury site. The result is that it becomes easier for universities to exchange and exploit knowledge the larger the scale of new business activity – the more it happens the more likely it is to be successful, helping to retain graduates in the city and its surroundings.

2.18 As the LCR is currently under represented in small and medium sized businesses this aspect is important to us. Our approach is to leverage our excellence in research, translation and innovation in infectious diseases and materials chemistry, supported by high performance computing, to contribute to this expansion of new business-driven GVA and employment growth in the North West of England. As the LCR open innovation facilities about to come on stream are already over-subscribed, further expanding this ecosystem capacity will provide a major growth point.

2.19 The net result of our strategy and these complementary regional innovation assets is the move towards an integrated synergy-based regional innovation system. This system can deliver computationally-enabled new materials innovations with the potential to transform and rejuvenate a wide range of industries in the UK, and can also help to attract substantial inward investment targeting global disease reduction outcomes. The sheer scale of this inward investment provides opportunities to leverage this research funding via start-ups and local supply chain development in companies supporting infectious diseases research processes (Instrumentation, Materials and Chemicals etc.) The resulting levels of trust and reciprocity are, now, a key intangible asset for the City Region. The combination of shared physical assets (expressed clearly in the Materials Innovation Factory, discussed in Chapter 6) and the intangible asset of effective industry-academic collaboration creates a powerful competitive edge for this regional innovation system. It also provides a role model worthy of emulation across the UK – and world-wide.

3 Focusing on our SIA – Themes and Process

3.1 As part of our Expression of Interest for undertaking a Science and Innovation Audit in 2016, informed by the above evidence, partners in the LCR proposed three hypotheses – one for each of three areas of scientific excellence – to be tested as part of the formal SIA process. The areas of excellence were introduced in Chapter 3; the hypotheses and associated ambitions, articulated at the start of the process, are summarised in Table 3-1 below.

Table 3-1: Our Starting Points - SIA Hypotheses and Ambitions

Hypotheses	Ambitions
• Linking and enhancing the LCR's world-leading knowledge, research and facilities in infection can, with wider collaboration, catalyse an internationally significant cluster of companies that will generate economic productivity and growth for the LCR, Northern Powerhouse and the UK.	• Support the development of a cluster of high-growth companies to take advantage of global market opportunities in Infection.
• Linking and enhancing the world class Materials Chemistry assets and capabilities in the LCR, and wider North of England, can deliver a step change in regional and national productivity growth, through competitive advantage in digital materials design.	• Transform productivity in Chemicals & Process Industries, and create a world-leading Fast Moving Consumer Goods (FMCG) cluster and IP pipeline.
• The nationally significant High Performance Computing (HPC) and cognitive computing e-infrastructure capabilities at STFC's Hartree Centre and elsewhere in LCR can scale and accelerate productivity, skills and growth across a range of industrial sectors including Materials Chemistry and infection.	• Ensure world-leading High Performance Computing & Cognitive Computing to accelerate cross-sector growth, and support the development of a world-class business cluster in disruptive technologies around Sci-Tech Daresbury.

Source: LCR+ SIA Expression of Interest to BEIS, December 2016

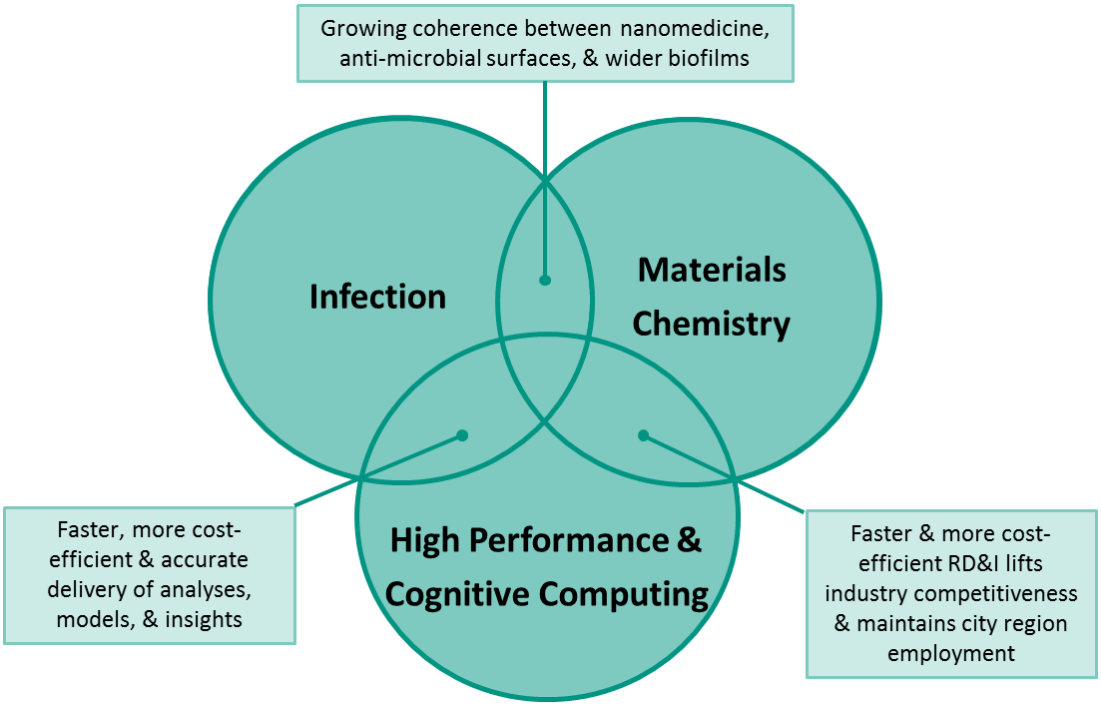
3.2 Having been selected to progress an SIA as part of the national Round 2 process, our SIA process has tested these hypotheses through:

- Reviews of data and evidence on the relevant science and innovation assets and capabilities within the LCR – including collaborations within the City Region, the North of England, the UK, the EU and the rest of the world;
- Reviews of potential research issues, sources of funding and investment, technological change and market potential; and

- One-to-one stakeholder consultations and conference activity to explore current and potential research, innovation and translation activities, including cross-theme collaborations.[21]

3.3 Our work has been informed by an over-arching framework of analysis (Figure 3-1).

Figure 3-1 Liverpool City Region Science & Innovation Audit at a glance



3.4 In the following Chapters, we present the evidence in support of each of our three SIA Themes. Using a disciplined and robust approach, in Chapter 3 we provided a systematic analysis of the excellence of our science and innovation activities in our key research and development bodies. We follow this up in Chapters 5, 6 and 7 with detailed depictions of each of our Theme areas – Infection, Materials Chemistry, and High Performance and Cognitive Computing. Each of these 'SIA in Theme Detail' chapters cover the following aspects:

- National and international trends and global market opportunities;
- Local science and innovation assets;
- Local science and innovation talent;
- National and international engagement;
- Developments in the wider funding landscape; and
- Key Conclusions.

3.5 It should be noted that the findings of the SIA have led to revisions to our hypotheses and ambitions. These 'before and after' perspectives are discussed in Chapter 7.

[21] Appendix 3 provides a list of conference attendees and a note of the key points discussed at the conference.

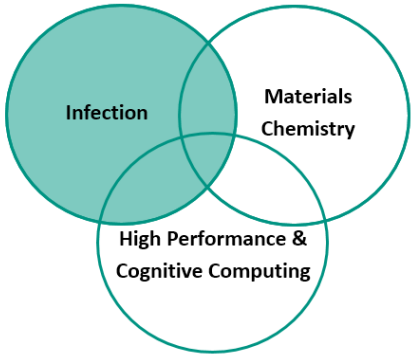
4 In Detail: SIA Theme 1 – Infection

Headline Messages

- Infection is a global problem, which accounts for seven of the top 20 causes of mortality
- The City Region has world-class facilities, expertise and track record in developing public-private partnerships, both domestically and internationally, in tackling Infection
- Partners in the City Region have developed the 'Liverpool Advantage', an approach that supports research, innovation and product development for infection diagnosis, treatment and control
- As well as generating greater local economic benefit by attracting firms in the global supply chain to the City Region, partners will enhance the global public good achieved by research led from the City Region, as proximity and improved collaboration should reduce the time it takes to move from initial findings to market
- The University of Liverpool and Liverpool School of Tropical Medicine have formalised joint working by launching their 'Centre of Excellence in Infectious Disease Research' (CEIDR)
- The SIA process helped partners to identify areas where collaboration between the three SIA themes could add value to ongoing work and help to build a City Region offer based on a unique combination of world-leading research and innovation strengths
- Interactions are being developed between CEIDR and the other two SIA Themes to facilitate development of products to prevent, treat or diagnose infectious diseases will need
- CEIDR will work with businesses to harness partners' expertise, track-record in forming public-private partnerships, and pipeline approach to translate new products
- CEIDR will enhance the worldwide reputation of Liverpool and the LCR, through its work to tackle global diseases.

Introduction

4.1 Infection is a global challenge which still accounts for seven of the top 20 causes of mortality. Within the Infection category there are well established conditions, such as lower respiratory tract infections, HIV and TB, alongside newer or emergent diseases such as SARS, Zika and Ebola. Across the full spectrum of Infection, humankind is in an arms race with the infectious agents, which are becoming resistant to infections faster than industry can replenish the pipeline. This poses one of the greatest threats to health services nationally and internationally.



4.2 It is recognised that revitalisation of the pipeline requires close co-ordination of funding and expertise across multiple stakeholders. The 2015 figures show that industry contributed only 15% of the USD$3.5 billion spent on early-stage product development for infectious

diseases.[22] This co-ordinated model provides an ideal platform for LCR to capitalise on its translational academic base in this area, given it already attracts 0.5% of this global spend.

4.3 Together, the Liverpool School of Tropical Medicine (LSTM) and the UoL constitute the UK's largest concentration of expertise in translational-focused research, development and innovation in infectious diseases. The two institutions are separate, but their scientists have collaborated for around a century. The recently launched Centre of Excellence in Infectious Disease Research (CEIDR) exemplifies this joint working.

4.4 Research excellence comes from attraction and retention of talent and collaborations with other research institutions, businesses and funders. These efforts are designed to feed directly into patient benefit.

4.5 The industrial/academic interface, includes Chemistry, Pharmacology (including the MRC Centre for Drug Safety Science), Parasitology, Medical Microbiology, Vector Biology and Veterinary Sciences

4.6 Public-private partnerships in product development (PDPs) feature broadly in this R&D space. There are currently 16 large PDPs supporting innovation to reduce the burden of infectious diseases. Only two sit in the UK, and both are anchored in our City Region.

4.7 Concerted action is required to build a world-leading business and innovation cluster in Infection which will increase the City Region's ability to generate employment and GVA.

National & International Trends & Global Market opportunities

Background

Infectious Diseases

4.8 Infectious diseases are spread by direct or indirect contact (including insect vectors) and may contribute to both mortality and chronic health burden. These are commonly measured in disability adjusted life years (DALYs). The DALYs attributable directly to infectious disease in 2015 were estimated at over 340 million. Table 4-1 gives the 2015 estimates of DALYs from several common infectious diseases.

Table 4-1: Estimates of Annual Deaths by Infectious Diseases

Disease	Deaths	DALYs
Tetanus	56,700	3,510,000
Measles	73,400	6,956,000
HIV/AIDS	2,305,200	133,378,000
Hepatitis B	65,400	1,097,000
Malaria	730,500	55,769,000
Diarrhoea	1,312,100	71,589,000
Tuberculosis	1,112,600	40,302,000
Lower respiratory Infections	2,700,000	103,048,000

Source: The Global Burden of Disease Study 2015. The Lancet Vol 388, 1447 – 1850 2016

[22] G-Finder 2016, Neglected disease research and development. http://www.indiaenvironmentportal.org.in/files/file/GFINDER%20full%20report.pdf

Partners' role in international markets

4.9 The classical model for drug and vaccine development – with discovery, development and delivery being undertaken in-house by a single major pharmaceutical company – faces financial challenges. Products operate in a price sensitive market, where even in high income countries the market has been commoditised. Hence, the low-price threshold for antibiotics has effectively stopped the industrial discovery and development pipeline for over a decade. Interventions for diseases in low income countries, such as HIV, can be subject to downward pressure on margins that make these markets unattractive to industry. This has led to the development of a new partnership-based approach to product development, discussed below.

4.10 For markets with this disease profile, partners in the City Region have learned, industry often develops products under Corporate Social Responsibility programmes, generating public good, rather than profits derived from intellectual property. Unlike standard in-house industrial product development pathways, market dynamics have resulted in two major shifts. First, research and innovation are heavily dependent on public sector expertise; second, the risk associated with development of new interventions is mitigated by financial and scientific support from Product Development Partnerships (see Table 4-2).

4.11 Once a product is developed, industrial partners agree to produce at very low profit margins appropriate for the high burden countries and research partners do not look to generate income from royalties, except where the product, e.g., an anti-malarial vaccine or drug, is used in high income countries.

Table 4-2: Product Development Partnerships – an organisational approach to product development

- A Product Development Partnership (PDP) is a not-for-profit organisational structure that enables the public, private, academic, and philanthropic sectors to pool funding for the development of drugs, vaccines, and other health tools as public goods.
- PDPs target products which are needed for the public good, but where the market incentives are insufficient to support industry undertaking this work in isolation. Antibiotics are a case in point – they do not target a neglected disease in low and middle income countries – but the pipeline stopped because the antibiotic market became commoditised and the profit margins were too low to support R & D.
- Liverpool City Region hosts two PDPs – the Innovative Vector Control Consortium (IVCC) and Anti-Wolbachia Consortium (AWOL) – and partners in the City Region supported the development of MMV, which now sits in Switzerland, but with which partners in the City Region still engage.

4.12 The Infection Theme offers a global profile for the City Region in the promotion of world health through PDPs.

Markets associated with Infectious Diseases

4.13 The global Infection market falls into three broad categories: diagnostics, therapeutics and prevention, which operate differently in different regional markets. Each category tends to be dominated by a relatively small number of large, multi-national companies. Most of these

companies are not located in the City Region, but many work in partnership with LSTM and UoL.[23] Thus, the City Region has an opportunity to use its scientific excellence to attract inward investment from major companies.

Diagnostics

4.14 As interventions become more expensive, having accurate diagnostics at the point of care becomes increasingly important. The global market includes hospitals, clinics, blood banks, reference laboratories and increasingly the self-test consumer market. The drivers of global demand are high occurrence rates of various infectious diseases, such as STIs, HIV, Human Papilloma Virus, Hepatitis, and bacterial infections. North America currently accounts for the largest share of the global market for diagnostics, followed by Europe. The need for cost-effective diagnostics is, however, more global, with demand growing in the Asia Pacific, Latin America and Middle East, and an expanding donor-driven market in Africa.

4.15 Major companies operating in this global market, and which partners will seek to work with and where appropriate attract to the City Region, include: Abbott Laboratories; Affymetrix Inc.; Becton, Dickinson and Company; bioMérieux; Cepheid Inc.; Hologic Inc.; Life Technologies; Myriad Genetics Inc.; Qiagen N.V., Sysmex (lasers) and others working on non-molecular diagnostics.

Therapeutics

4.16 Once an infection is diagnosed, patients require treatment or therapeutics. North America accounts for the largest share of global market for infectious diseases therapeutics by value. The next largest markets are Asia and Europe. China and India are expected to be the fastest growing infectious diseases therapeutics markets.

4.17 Major companies operating in this global market, and which partners will seek to work with and where appropriate attract to the City Region, include: Merck & Co.; Pfizer; Johnson & Johnson; F. Hoffmann-La Roche; GlaxoSmithKline Pharmaceutical, Inc.; Auritec Pharmaceuticals; Novartis; Achillion Pharmaceuticals; Isis Pharmaceuticals; Astra Zeneca, BASF, Bayer, and Gilead Sciences.

Prevention

4.18 Prevention activity takes many forms – including vaccination, public health insect control, and improved hygiene – and therefore generates many different markets. Often preventative measures cannot be optimally deployed without detailed understanding of epidemiology and huge data sets need to be employed to model different approaches to the deployment of interventions. The City Region's High Performance Computing capability means that it is well placed to identify and exploit the opportunities in this market.

4.19 One of the most significant challenges to be faced in relation to prevention is anti-microbial resistance (AMR)[24] and antimicrobial coatings on the surfaces of medical devices are likely to

[23] Appendix 9 which sets out proposals for the future, provides a list a key business partners for UoL and LSTM.

[24] Jim O'Neill et al, Tackling Drug-resistant infections globally Final Report and Recommendations, May 2016 and Annual Report of the Chief Medical Officer, Volume Two, Infections and the rise of antimicrobial resistance, 2011

see significant market growth faced accordingly. The LCR has expertise to feed into this area – outlined in our proposals in Appendix 9.

4.20 Research by Global Market Insights into the antimicrobial coatings market (2016)[25] reported that the market was set to treble over the next 20 years to approximately USD$7bn:

- The medical devices market, to reduce hospital acquired infection;
- The construction sector, to comply with building regulations to reduce infection risk; and
- The food and beverage sector, in response to regulatory requirements and in the search to extend the shelf-life of its products

4.21 The market is dominated by a few large companies (four firms accounted for around 30% of the global antimicrobial coatings market in 2015)[26], but small-scale regional suppliers and manufacturers have increased competition in the market. Major companies operating this global market, and which partners will seek to work with and where appropriate attract to the City Region, include: BASF, AkzoNobel, DSM, DuPont, and Dow Microbial Control; Sherwin-Williams; Diamond Vogel Paints; Arch Lonza; Nippon Paint; RPM Ltd; AK Coatings; Sono-Tek Corporation; and Troy Corporation.

Local Science & Innovation Assets

4.22 A map setting out the spatial distribution of a selection of these assets, together with wider enabling assets in the City Region's innovation ecosystem is given at Figure 4-1.

Science assets

4.23 LSTM is focused on the following research themes:

- Resistance research and management;
- Malaria and other insect borne diseases;
- Lung health and tuberculosis;
- Maternal, new-born and child health; and
- Neglected tropical diseases.

4.24 This is complemented by the UoL:

- Understanding how pathogens cause disease;
- Pioneering diagnostics, treatments and vaccines;
- Enhancing food safety and security;
- Tracking emerging and zoonotic (animal to human) infections;
- Developing and optimising antimicrobial agents;

[25] https://www.gminsights.com/industry-analysis/antimicrobial-coatings-market-report
[26] ibid

- Understanding the historical/social contexts & consequences of infectious disease;
- Accelerate solutions to combat biofilms in industrial and clinical setting (or similar).

The importance of the City Region's wider science and innovation asset base

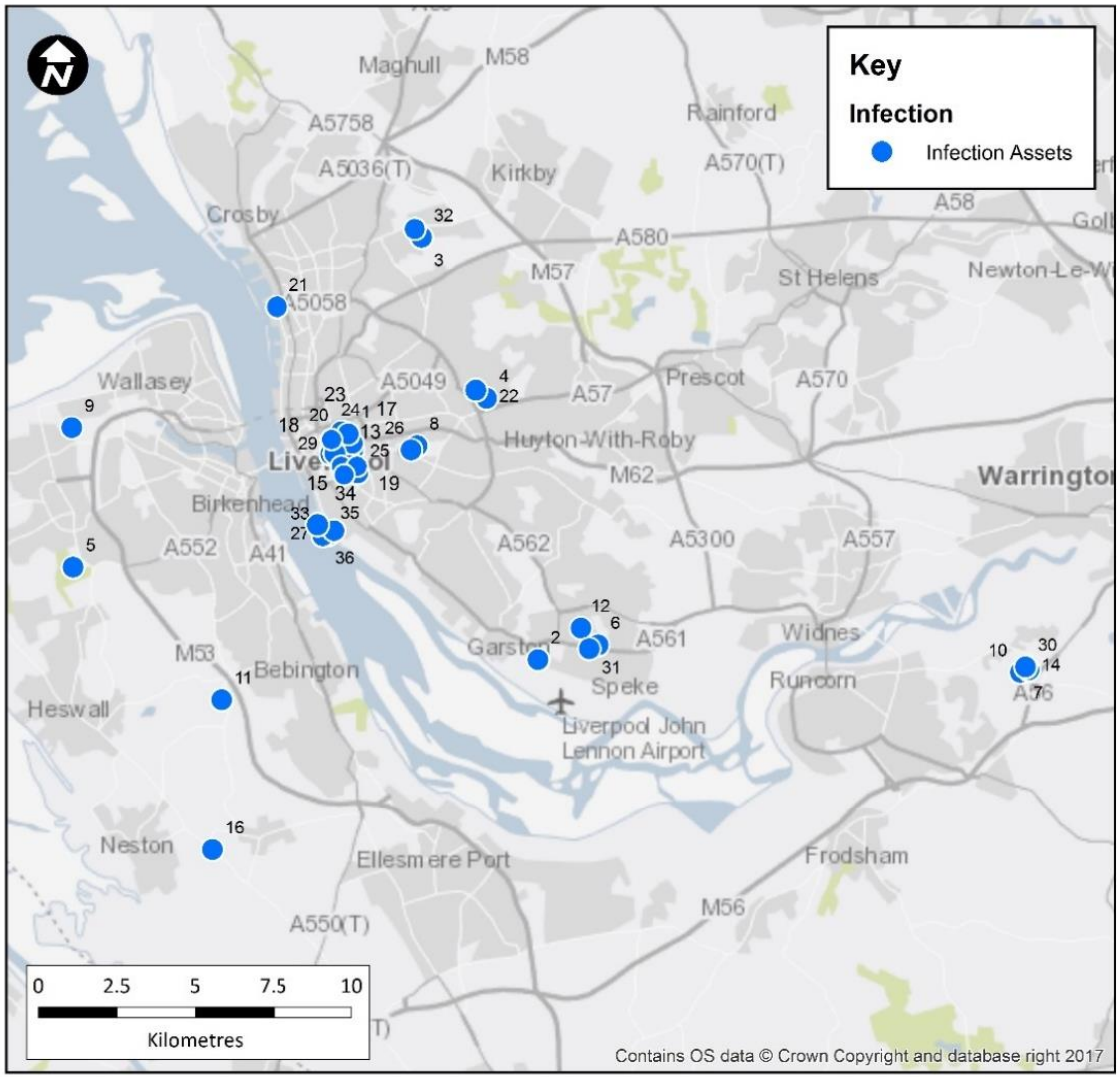
UK aid and Britain's world-leading institutions like the Liverpool School of Tropical Medicine are playing a major role in protecting the world's poorest people from Neglected Tropical Diseases and enabling them to live healthier, more prosperous lives – Bill Gates[27]

4.25 The City Region has a range of facilities that support its world-leading status for scientific research into infectious disease. These include:

- Royal Liverpool University Hospital Trust – this hosts our specialist infectious diseases ward and has an expanded 26-bed Clinical Research Facility (CRF; which is MHRA-registered for 'first time in humans' work);
- The Internationally renowned UoL multi-disciplinary Open Innovation Hub for Antimicrobial Surfaces, that already has major industry engagement (8 multi-nationals, 40+ SMEs) and a demonstrable commercialisation pathway (4 patents registered);
- Alder Hey Children's Hospital – hosts a registered Clinical Research Facility for paediatrics;
- The Liverpool Bio Innovation Hub – which houses biobanks and tissue collections;
- The Liverpool Life Sciences Accelerator – which provides access to fully staffed Category 3 anti-microbial, parasitology and insectary provision and rapid biological screening and collocates SMEs with LSTM specialist services;
- UoL multi-disciplinary Open Innovation Hub for Antimicrobial Surfaces - This specialises in surface analysis across a range of materials, including ceramics, metals and polymers. The range of instruments available allows surface analysis ranging from high resolution topography to wetting characteristics and spectroscopy.
- The Liverpool Clinical Laboratories brings together the service laboratory sciences of Medical Microbiology, Virology, Immunology and Immunogenetics;
- The Malawi-Liverpool-Wellcome 'Major Programme' in Blantyre, Malawi – where state-of-the-art laboratory facilities serve populations in the central hospital and the community; and
- The registered Clinical Trials Unit, Medicines for Children Clinical Trials Unit, and Clinical Tropical Trials Units, which allow scrutiny, sponsorship and management of clinical trials.

[27] Quoted by Alistair Houghton, Liverpool City Region Business Profile, Tuesday May 16 2017, p.19

Figure 4-1: The spatial distribution of Infection Theme assets in the Liverpool City Region (non-exhaustive list)



Key Assets

1. Accelerator and CEIDR (Centre of Excellence in Infectious Diseases Research)
2. Actavis Biologics
3. Aintree University Hospital NHS Foundation Trust
4. Alder Hey Childrens Hospital NHS Foundation Trust
5. Arrowe Park Hospital
6. Astrazeneca
7. ATOS Technologies
8. Baxter Healthcare Ltd
9. Bristol-Myers Squibb
10. Centre of Competence for Cognitive Computing
11. Clatterbridge Cancer Centre NHS Foundation Trust
12. Eli Lilly/Elanco
13. Evgen Pharma
14. Innovation Agency (Academic Health Science Network for the North West Coast)
15. Knowledge Quarter Liverpool (Liverpool Science Park)
16. Leahurst Veterinary Centre
17. Liverpool Chirochem
18. Liverpool Clinical Laboratories
19. Liverpool Pancreas Biomedical Research Unit (NIHR)
20. Liverpool School of Tropical Medicine
21. Mast Group
22. Medicines for Children Research Network
23. MerseyBIO Incubator
24. North West Cancer Research
25. North West Coast NHS Genomic Medicine Centre (Liverpool 26. Womens Hospital)
26. Nutricia
27. Open Innovation Hub for Antimicrobial Surfaces
28. Royal Liverpool & Broadgreen University Hospital NHS Trust
29. School of Sport & Exercise Sciences (LJMU)
30. Sci-Tech Daresbury Enterprise Zone
31. Seqirus
32. The Walton Centre NHS Foundation Trust
33. University of Liverpool
34. Videregen
35. Vitaflo
36. Wolfson Centre for Personalised Medicine

Liverpool City Region - Science and Innovation Audit 2017

Asset Register: Infection Theme

sdg economic development

Created by:	Last Updated:	Scale:
CLacy	23/05/2017	200,000

\\sdgworld.net\Data\Manchester\Users\CLacy\Private\LCR SIA Asset Map\Infection.mxd

4.26 Infectious disease research is also supported by the UoL's research programme in personalised health. Recent advances in DNA sequencing technologies and molecular biology has improved the assessment of disease risk in healthy individuals, improved diagnosis and stratified patients for genome-guided treatment options. The pharmaceutical sector has been increasing its investment in personalised health and precision medicine to develop more effective, safer treatments and to benefit from increased efficacy of their early clinical trials, leading to better drug development. The underlying principle is the right treatment, to the right patient, at the right time. Personalised health approaches in infection provide the opportunity to provide more individualised treatments tailored to the individual's diseases and develop biomarkers that will allow for more precise dosing of current and new drugs, including individualised dosing of antimicrobials to optimise microbial killing, minimise toxicity and prevent AMR. LCR has been at the forefront of personalised health approaches through its strengths in pharmacogenetics, its biobank and initiatives such as the FUTURE initiative. This is genotyping 3000 healthy as a resource for pharmaceutical and biotech companies leading to more effective, streamlined and cost effective Phase 1 Clinical studies.

4.27 Furthermore, the City Region's offer on Infection is complemented by Alderley Park in Cheshire, which is an international bioscience campus and home to the Catapult Centre in Medicines Technologies. And the LCR is already home to major international businesses working on infectious disease:

- AstraZeneca employs over 360 people at its biologics site in Speke, which has facilities to bulk-manufacture the nasal spray influenza vaccine Fluenz; and
- Seqirus has one of the biggest biotechnology sites in Europe, employing around 600 people at its site in Speke. It opened a new £6m warehousing facility in 2016 and has announced investment in manufacturing facility worth over £15m.

Maintaining scientific excellence and building innovation capability

4.28 There are significant research and market opportunities in the fields of prevention, diagnosis and treatment of infectious diseases. Private sector companies operating in the modern PDP world can overcome risks and uncertainties in relation to forecast returns on investment (see Table 4-3) and enter this market in partnership.

4.29 The 'Liverpool Advantage' is based on partners':

- Expertise to identify and define tractable research problems;
- Ability to win competitive funding, including public sector support, philanthropic funding and venture capital investments;
- World class assets coupled with academic clinicians who provide a direct link to patients, and
- International networks which help navigate local regulatory requirements.

Table 4-3: Malaria Prevention Case Study

- With funding from the Bill and Melinda Gates' Foundation (BMGF), LSTM created the PDP 'Innovative Vector Control Consortium' (IVCC), which catalysed the development of an insecticide formulation which is effective for 12 months: twice as long as the leading market brand and five times as long as the insecticide that was reformulated;
- The insecticide was developed in partnership with Syngenta and has transformed the market. It is now used in 18 countries and is dramatically reducing malaria transmission;
- Syngenta currently has the largest share of the world market;
- IVCC has subsequently unlocked USD$65m from UNITAID to support research into market dynamics to help increase the numbers of products operating to this new benchmark;
- The project achieved a successful concept-to-launch process, set the benchmark for future products, and saved at least 60,000 lives in the first year of use;
- The project was, however, achieved with partners from outside the City Region. Thus, one area for improvement is the attraction/identification of local collaborators to the City Region where this is appropriate, or where multinational industries are involved ensuring that they consider Liverpool as a UK base for some of their R & D activity.

4.30 Through CEIDR the partners are seeking to develop a 'one stop shop' for industry collaboration – drawing on lessons from the City Region's Health Enterprise Hub, which identifies four routes to access the City Region's health innovation ecosystem:

- Discover – for those who wish to develop new ground-breaking treatments and services through collaborative world-class research and clinical trials;
- Accelerate – for those seeking to maximise funding opportunities and links to leading companies to perfect ideas, commercialise solutions and drive adoption;
- Transform – for those seeking access to NHS clinical expertise, insight, advice, and best practice for large scale innovation; and
- Invest – for those wishing to benefit from support with skills, finance, premises and networks, in order to join one of the UK's most dynamic and connected life science economies.

The Health Enterprise Hub provides access to an integrated network of world class specialists, researchers, academics and companies collaborating, innovating and investing in health and life sciences to transform and improve health outcomes.

Local Science & Innovation Talent

4.31 Maintaining world-leading standards and research requires a stock and flow of highly talented researchers and teachers.

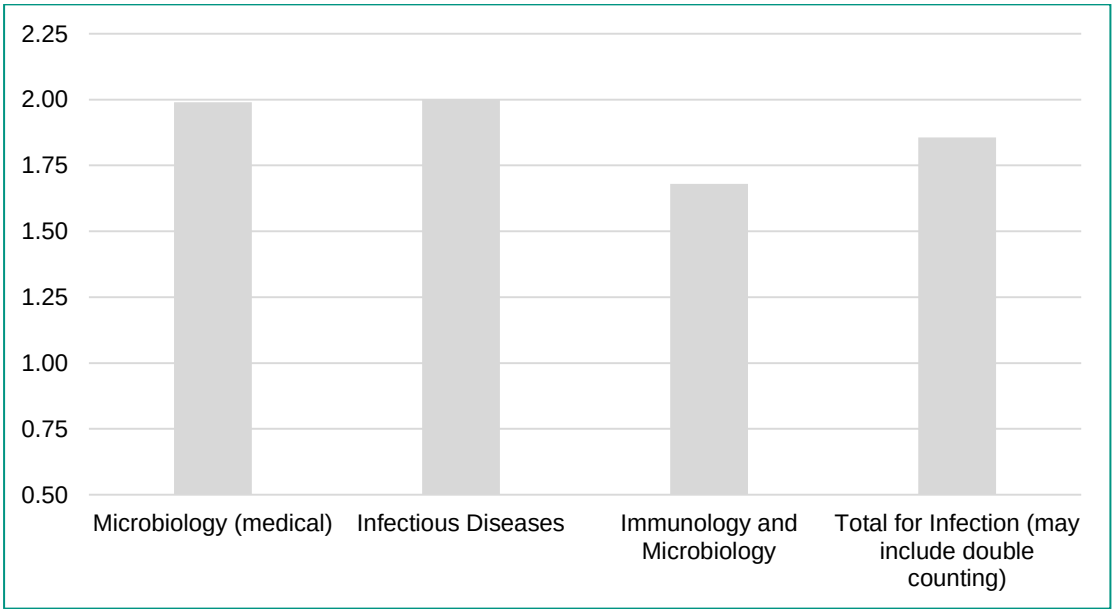
4.32 LSTM employs around 430 staff in the City Region and over 650 worldwide, trains more than 400 postgraduates a year, and has expanded its workforce in Liverpool three-fold between 2002 and 2016. And UoL employs approximately 400 academic and research staff working

on Infection-related research with 20 staff worldwide, trains more than 200 postgraduates in Infection-related research a year, and its research institutes in the Faculty of Health and Life Sciences have all achieved the Athena Swan Silver award, which demonstrates good practice for women working in STEM in higher education and research.

4.33 For the 2014 REF, the UoL and LSTM made a joint submission to UoA-A1 'Clinical Medicine', of which Infection was part. The data covering Clinical Medicine are not sufficiently granular to identify the strength of research in Infection. They show that at the level of Clinical Medicine, 16.4% of outputs were rated 4* and 57.8% were rated 4* for impact. A finer grained picture for Infection research can be developed, however, using SciVAL data, which assess the number of citations against the global average for general headings of Microbiology (medical), Infectious disease and Immunology and Microbiology (Figure 4-2). Researchers at UoL and LSTM are achieving twice as many citations as the global average on Microbiology and Infectious Diseases and 1.68 times the average for citations in Immunology and Microbiology.

4.34 An even finer grained analysis of SciVAL data using keywords (Immunology, Molecular biology, Virology, Microbiology, Parasitology, Vector biology, Infectious diseases) shows researchers in the City Region produced 946 papers between 2011 and 2016, which achieved a Field-weighted Citation Index of 2.35. This demonstrates that at the level of Infection, as opposed to the more general category of Clinical Medicine, Infection research in the City Region is truly world-leading.[28]

Figure 4-2: Field Weighted Citation Index (1=Field Average Citation Rate)



Source: Scopus SciVAL data extracted by the University of Liverpool on behalf of the LCR+ Consortium

4.35 The reputation of the institutions in this area has allowed them to attract highly talented individuals globally, despite an international skills shortage in some areas of Infection.

[28] Further SciVAL data illustrating performance of other UK institutions is outlined in Appendix 5, Figure A5-5.

4.36 The Liverpool Life Sciences University Technology College (UTC) is the first school in the UK specialising in Science and Health Care for 14 to 19 year olds. It is collocated with the Studio School – which is focused on digital technology, providing a link to the HP & CC theme. It provides outstanding academic and vocational education by working closely with local employers to create the next generation of scientists, healthcare practitioners, engineers and entrepreneurs. The UTC is sponsored by local businesses, including: 2Bio, Thermo Fisher, Unilever, Pro-Lab Diagnostics, Novartis, and Mast Group.

National & International Engagement

4.37 Partners in the City Region have well-established local arrangements to support and develop the City Region's science and innovation ecosystem. Partners are also engaged in significant international and global networks.

4.38 In particular, the LSTM:

- Hosts IVCC, a virtual PDP;
- Operates the Anti-Wolbachia Consortium, a filariasis drug development PDP;
- Accesses funding from externally-hosted PDPs, such as the Medicines for Malaria Venture;
- Has a longstanding partnership with the College of Medicine at the University of Malawi;
- Has unique access to the libraries of major pesticide manufacturers, which enables LSTM to test materials for their suitability to new applications.

4.39 Meanwhile, the UoL:

- Is a major partner (with LSTM) in the Wellcome Trust-Liverpool-Glasgow Centre for Global Health Research and the Malawi-Liverpool-Wellcome Trust Major Overseas Programme;
- Leads the Infection theme of Liverpool Health Partners;[29]
- Hosts two NIHR Health Protection Research Units in emerging and zoonotic infections and in gastrointestinal infections;
- Hosts Small Animal Veterinary Surveillance Network (SAVSNET);
- Operates the Centre for Global Vaccine Research, and
- UOL's Institute of Infection & Global Health works in partnership with the National Institute of Mental health & Neuroscience in Bangalore.

4.40 SciVAL data on publications for infection illustrates the scale of international research collaboration for papers published by City Region researchers:

- 69.12% of publications in Microbiology (medical) had international collaborators;
- 77.56% of publications in Infectious Diseases had international collaborators; and
- 71.79% of publications in Immunology and Microbiology had international collaborators.

[29] http://www.liverpoolhealthpartners.org.uk/partnership/index.php

4.41 The map in Appendix 6 shows the location of research partners.

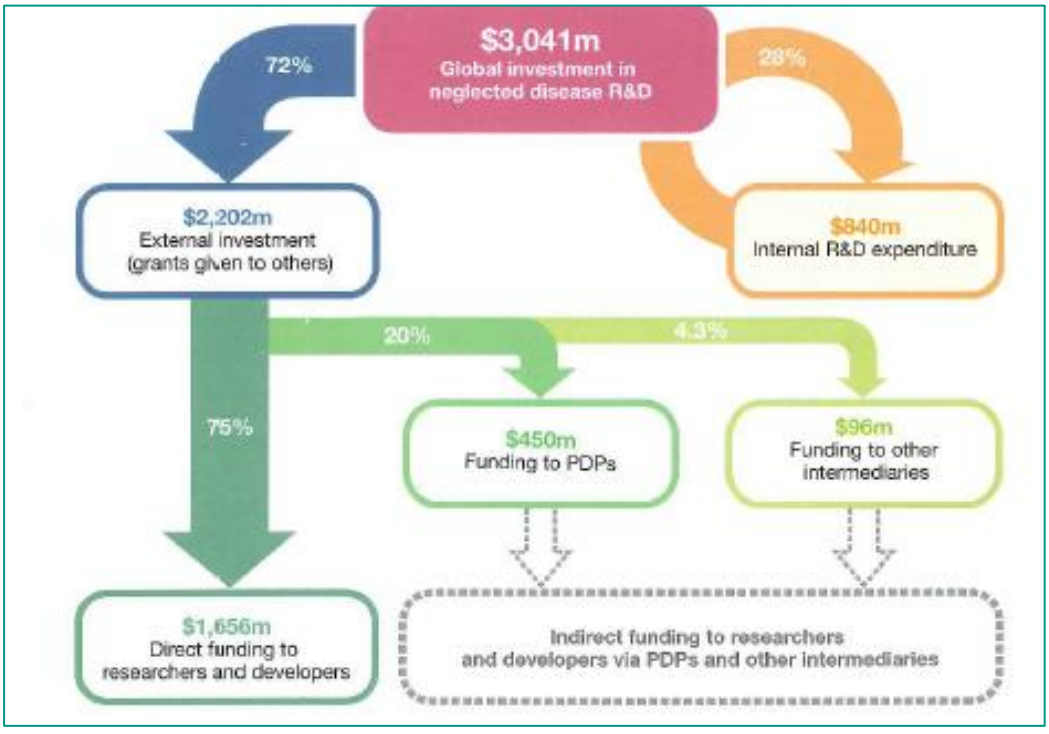
Developments in the Wider Funding Landscape

4.42 Global investment in neglected disease R&D has reached USD£3,041m.[30] Figure 4-3 illustrates funding for infectious diseases early-stage product development R&D globally for 2015.[31] These funding flows have been relatively stable since 2007. Industry matched funding into this landscape in 2015 was 15% of the global investment from other sources, up from 7% in 2007. In 2015, the City Region accessed 0.5% of this global investment – a 188% increase on the previous year, due to a large investment from the Gates Foundation. Partners in the region aim to increase their share of global investment from all sources to >1%.

4.43 Table 4-4 summarises research funding by type of source for Infection over the five years 2012 to 2017 for UoL and LSTM. This shows:

- There is strong support from UK government and tax payer funded national sources;
- UK philanthropic funding is still significant at 15%, and
- Despite the public-good element, business funding is high at 11%, with over half of this coming from UK Business.

Figure 4-3: Global R&D spending on neglected diseases 2015



Source: G-Finder 2016, Neglected disease research and development: A pivotal moment for global health

[30] G-Finder 2016, *Neglected disease research and development: A pivotal moment for global health.* http://www.indiaenvironmentportal.org.in/files/file/GFINDER%20full%20report.pdf

[31] The figures are for R&D spend only and do not include local and regional funding or any capital funding.

Table 4-4: Research funding by type of source for Infection to UoL and LSTM

Organisation Type	Sum of Total Funding (£)	Proportion of Funding
UK Government	172,197,939	40.6%
International Philanthropic	64,888,460	15.3%
UK Philanthropic	67,072,696	15.8%
International Government	52,279,192	12.3%
European Union	20,525,665	4.8%
UK Higher Education	12,539,146	2.6%
European Government	10,050,321	2.4%
UK Business	8,664,107	2.0%
European Business	4,262,759	1.0%
International Sector Body	3,873,912	0.9%
International Business	3,673,419	0.9%
European Sector Body	3,649,513	0.9%
International Higher Education	2,229,519	0.5%
European Higher Education	1,699,590	0.4%
European Philanthropic	560,855	0.1%
Grand Total	**424,517,581**	**100.0%**

Source: University of Liverpool

Conclusions

4.44 Infection is a major global public health concern with significant humanitarian, diplomatic and political, as well as economic implications. The LCR has world-leading assets and expertise in research, innovation and product development for diagnosis, treatment and control of infection. It also has a track record of developing public-private partnerships and accessing significant funding, both domestically and internationally, to tackle infection. The UoL and LSTM have formalised joint working arrangements by launching their CEIDR. CEIDR will work with local, national and international businesses to translate new products for use in global markets. The SIA process helped partners to identify areas where collaboration between the three SIA themes could reinforce the City Region's existing national and international networks, by combining our world-leading research and innovation strengths. Interactions are being developed between CEIDR and the other two SIA Themes to facilitate development of products to prevent, diagnose, and control infectious diseases.

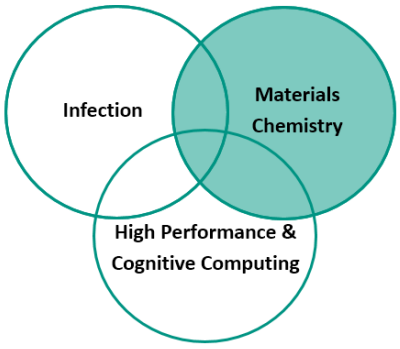
5 In Detail: SIA Theme 2 – Materials Chemistry

Headline Messages

- Materials chemistry lies at the heart of several high value chemical industries and supply chains (e.g. aerospace and automotive)
- The University of Liverpool is world-leading in Materials Chemistry as evidenced by REF2014 and other metrics
- The Materials Innovation Factory (MIF) is built on the twin pillars of computationally-enabled materials design ("the materials design engine") and automated high-throughput applications development and testing (the "materials application engine")
- MIF is a unique LCR+ asset demonstrating the added value of University-industry collaboration, and is a strong and distinct spoke of the Royce institute
- MIF will create academic benefit for the University and the wider global scientific community, and local economic benefit and high value jobs, ensuring competitive advantage for the industrial companies engaged
- The Open Access Innovation model implemented in MIF for Fast Moving Consumer Goods (FMCG) can now be replicated for other materials chemistry-aligned high value chemicals industries (e.g. catalysis, pharma, coatings, energy storage)
- The LCR+ materials chemistry capability therefore builds knowledge leadership directly into UK value chains in a unique way.
- Therefore, LCR+ has the opportunity to be a world-leading 'Industry 4.0' innovation centre for chemical industries through the development of a broader-scoped MIF-type facility

Introduction

5.1 Materials Chemistry involves the use of chemistry for the design and synthesis of materials with interesting or potentially useful physical properties, and the characterization, processing and molecular-level understanding of these substances.



5.2 The synthesis and application of new materials underlies the production of high value chemicals, used in such areas as fast-moving consumer goods (FMCG), catalysis, energy storage, pharmaceuticals and coatings. Hence it is of huge importance to the UK economy, and has a strong bearing on societal issues such as climate change and clean energy.

5.3 The UoL has world-leading excellence in materials chemistry as evidenced by the Research Excellence Framework and other independent metrics, and through sustained and major flagship funding from UKRI, EU, ERC and other agencies. UoL has been chosen as the Materials Chemistry spoke of the Royce Institute; in 2017 the Leverhulme Trust have

invested £10m in the created of the Leverhulme Centre for Functional Materials Design at UoL.

5.4 The Liverpool region has a unique track record in the combination of this UoL-based academic excellence in computationally-enhanced materials chemistry with industrial innovation in automated high throughput materials testing and application. This is exemplified in the Materials Innovation Factory (MIF), a formal UK government funded collaboration which co-locates academically driven computationally enhanced materials design (the materials design engine) at the UoL with accelerated and automated characterisation and testing of new industrial products using these materials (the materials application engine). Unilever are using the MIF model to accelerate the development and testing of new products in the Fast-Moving Consumer Goods (FMCG) sector.

5.5 The "Liverpool Model" for innovation, as exemplified in MIF, is now transferable to a whole range of high value chemical production industries currently based in the LCR and beyond. Thus, LCR+ is poised to become a materials chemistry powerhouse for the UK, generating high value scientific jobs and investment. For instance, the Office for National Statistics estimates that scientific jobs bring a GVA of £40-£60k per worker, which is two to three times the average for the LCR.[32] Our aspiration is that Intellectual Property generated by our Materials Chemistry activity will not be commercialised without our active participation.

National & International Trends & Global Market Opportunities

5.6 The chemicals industry is a key component of the UK economy, making vital contributions to exports, employment and gross value added (GVA). The Chemistry Growth Strategy Group estimates its value to be £200 billion, and highlights the strong potential for a further £100 billion contribution to the UK economy, of which one third will come through product and process innovation.[33] This group stresses the numerous ways in which the products and technologies of the chemical industry are used in medicines and foods, the construction of buildings, transport, leisure, and many other aspects of our daily lives.

5.7 Materials chemistry particularly underpins high value rather than commodity chemical production. High value chemicals then feed directly in a range of economically important industries such as catalysis, pharmaceuticals, energy solutions, coatings and healthcare. Significantly, industries that use chemicals as inputs tend to have higher than average input-output multipliers for induced GVA and employment impacts.

5.8 Many consumer products that are now taken for granted exist only because of fundamental innovations in materials chemistry – for example, lithium ion batteries, which power mobile phones and laptops, would not exist without the basic underpinning materials chemistry research that developed these materials.

5.9 A specific example is in sensors, an area underpinned by materials chemistry. The market for sensor systems is estimated to be £310 billion globally and is growing at over 10% per

[32] Office for National Statistics (2015), Annual Business Survey

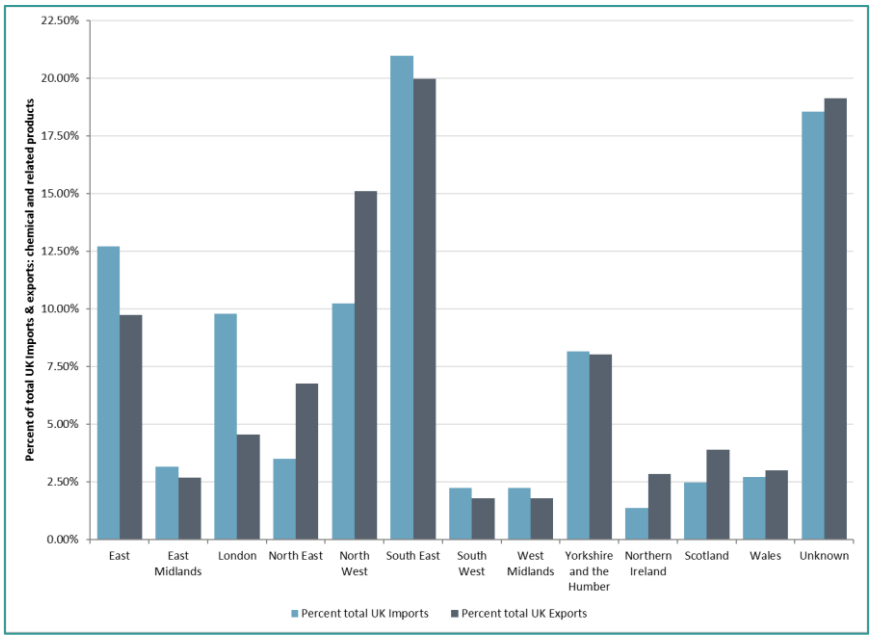
[33] http://www.icheme.org/media_centre/news/2013/~/media/Documents/icheme/Media%20centre/Misc/Strategy%20for%20Delivering%20Chemistry%20Fuelled%20Growth%20of%20the%20UK%20Economy.pdf

annum. The UK sensor industry (impacted on by materials chemistry) is a £13 billion per annum sector supporting 70,000 jobs and producing £6 billion in exports. Around 1.4 million people in the UK are employed in the sensor-aligned professions, of which 159,000 are in the North West and 27,000 are in LCR. [34] The LCR is ideally placed to generate significant economic growth in this field linked to the new Sensor City incubator in the Knowledge Quarter.

5.10 Hence the chemical industry in the UK contributes £75m of Added Value every working day, which is equivalent to £20 billion a year to the UK's GDP. The combined chemicals/ pharmaceuticals trade balance has a daily surplus of £25 million, whilst the rest of manufacturing has a daily deficit of around £300 million. The industry is the nation's number one manufacturing exporter and 500,000 UK jobs depend indirectly on the chemical and pharmaceutical businesses.[35]

5.11 This contribution to the UK economy is achieved by building competitiveness in global supply/value chains. These data are shown in Figure 5-1. For the North-West as a whole, this participation in global value chains is highlighted by the fact that the region generates the greatest added value to chemicals imports when expressed as a proportion of total UK trade in chemicals and related products. Whilst the South-East exports more, it does not add as much value to its chemicals imports. However although there is a reasonable chemicals supply chain in the UK, there is a dearth of chemicals R&D and LCR+ can have a crucial role in tackling this. Our materials chemistry capability builds knowledge leadership directly into UK supply and value chains in a unique way.

Figure 5-1: The balance between imports and exports of chemicals and related products by region, last four quarters to Q3 2016



Source: SDG Economic Development analysis of UK Regional Trade Statistics

[34] See https://news.liverpool.ac.uk/2015/07/13/sensor-city-six-months-on/

[35] Chemistry Growth Strategy Group (2013) Britain's chemical and chemistry-using industries Strategy for delivering chemistry fuelled growth of the UK economy.

5.12 One indication of the degree of connectivity in the broader chemicals global value chain in which the UK chemicals industry sits is that around 30 percent of UK chemicals value-added embodied in UK exports is generated domestically. This is as much as Norway (8.8%), USA (7.8%), Russia (7.4%) and Germany (6.3%), in combination.[36] These 'backward linkages' in the chemicals value chain, together with the 'forward linkages' driven by the multiple countries and industries that purchase UK chemicals exports, demonstrate the wider global connectivity of the LCR+ area – connectivity which radical transformative innovations driven by LCR+ materials chemistry capability can target.

5.13 The national significance of materials chemistry innovation is its potential to further increase the economic impact of the chemicals industry, and the many chemicals-using industries, by two key pathways, which span mature industries, rapidly growing industries, and emerging and potentially 'disruptive' industries:

- By driving product innovation in a diverse range of industries such as low emission synthetic fuels and electric or hybrid vehicles, energy materials, drug delivery and a range of other applications.
- By contributing to productivity growth in 'mature' market segments, e.g. Fast Moving Consumer Goods (FMCG). Maintaining productivity growth in these mature products can involve solving complex production process efficiency challenges, such as how to increase fluid flow rates at specific stages in order to increase overall production throughput rates. It is usual for innovation in these mature industry segments to focus on process efficiencies. With a global population estimated at 8.3bn in 2030 and 60% of these people living in cities, the global market is potentially very high.[37]

Local Science & Innovation Assets

5.14 A map setting out the spatial distribution of a selection these assets, together with wider enabling assets in the City Region's innovation ecosystem is given at Figure 5-3.

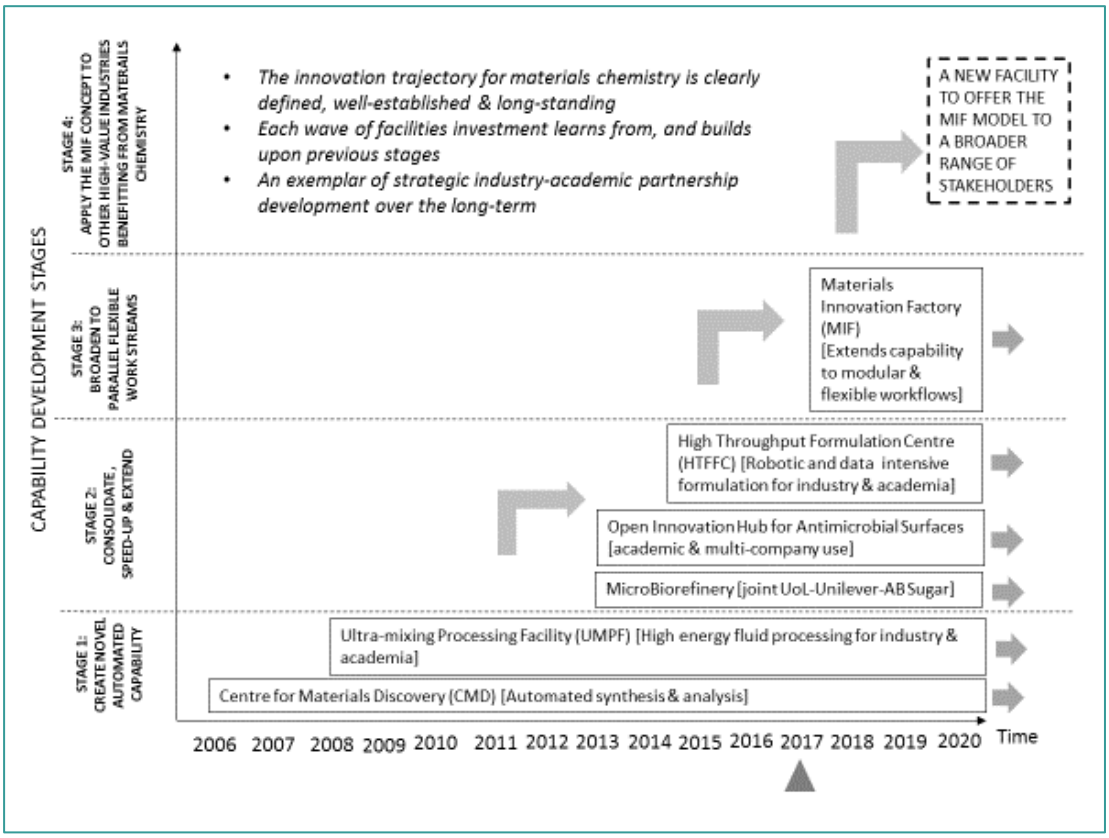
5.15 LCR+ is positioned to be the UK centre of excellence for computationally-enabled materials discovery and innovation. The local science and innovation assets in LCR+ for materials chemistry that power this vision reflect a sustained effort to build effective industry-academic collaboration in research and innovation. This unique collaborative ethos exemplified in MIF has a strong focus on disruptive methods for reducing the cost and lead-times in research and innovation by developing facilities that apply digital simulation and automation to materials chemistry research and innovation processes. Figure 5-2 shows the carefully crafted developmental trajectory of computationally enabled Materials Chemistry in LCR+. Each stage of investment in facilities has contributed to a long-term objective to exploit computational materials discovery and the materials application cycle. This: (a) substitutes computation for more costly and time-consuming 'real' experimental processes,

[36] 2011 data calculated from the OECD-WTO Trade in Value Added (TIVA) database that traces the web of global value chains that drive much of the world economy (these estimates are based on a large-scale and comprehensive input-output dataset that covers all countries and key industry sectors capturing how trade and value added inter-relate).

[37] Chemistry Growth Strategy Group (2013) Britain's chemical and chemistry-using industries Strategy for delivering chemistry fuelled growth of the UK economy.

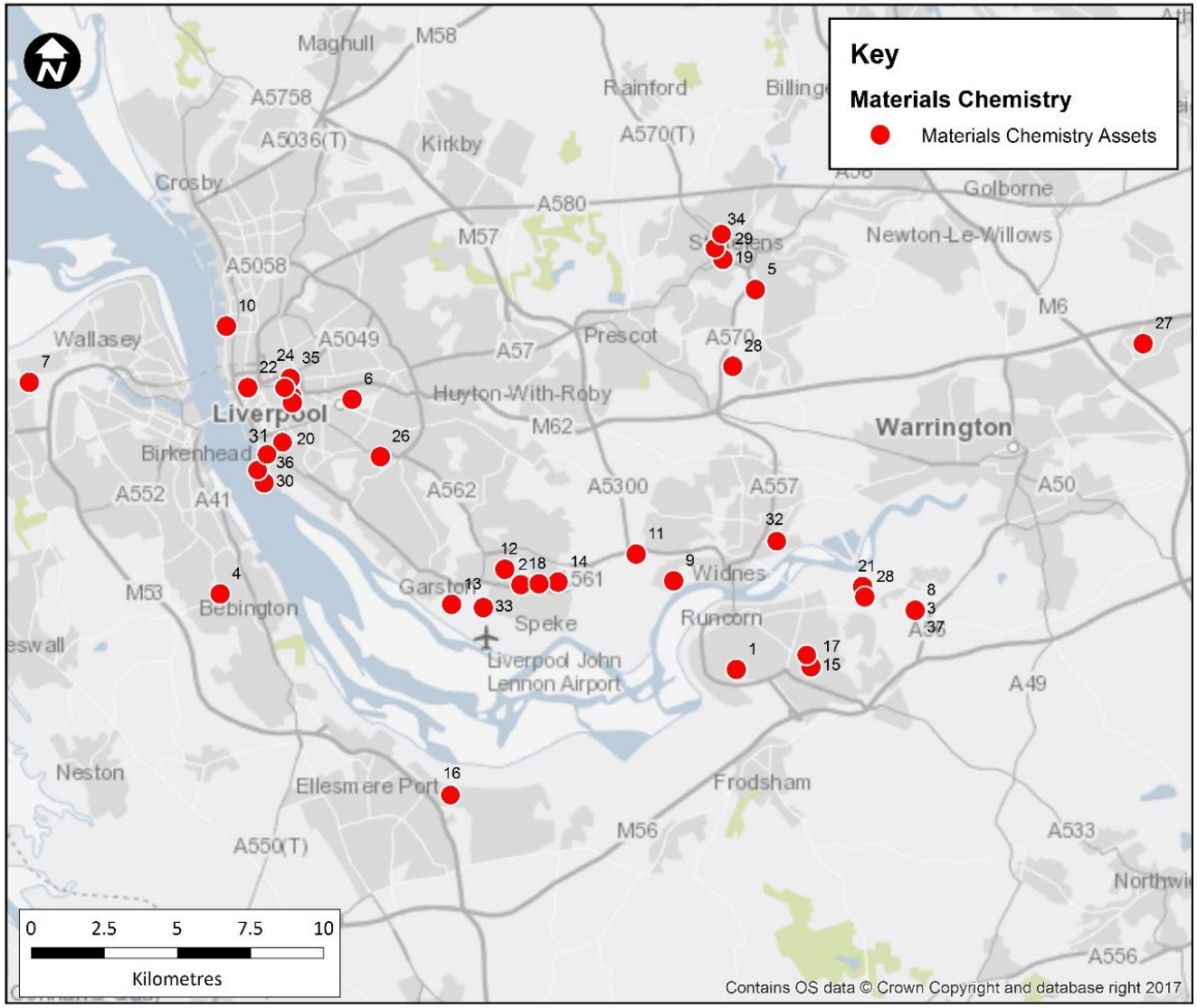
and (b) uses experience from experimentation to guide computational effort. The result is a virtuous cycle of innovation that learns-by-doing, and the process accelerates and gets cheaper as feedback from experimentation drives computational capability.

Figure 5-2: Evolutionary pathway of LCR+ Materials Chemistry capability



Source: Liverpool City Region+ SIA Consortium

Figure 5-3 The spatial distribution of Materials Chemistry Theme assets in the Liverpool City Region (non-exhaustive list)



Key Assets

1. ACAL Energy
2. Astrazeneca
3. ATOS Technologies
4. BAC Mono
5. Bachem
6. Baxter Healthcare Ltd
7. Bristol Myers Squibb
8. Centre of Competence for Cognitive Computing
9. Croda
10. CSL
11. Datalase
12. Eli Lilly/Elanco
13. Gencoa
14. Getrag Ford
15. INEOS ChlorVinyls
16. Innospec
17. Inovyn
18. Jaguar Land Rover
19. Knauf Insulation UK
20. Liverpool Chirochem
21. LPW Technology
22. MTC@LJMU
23. Materials Innovation Factory (MIF)
24. MerseyBIO Incubator
25. MicroBioRefinery (UofL)
26. Morgan/Ceramtec
27. National Nuclear Laboratory
28. NGF Europe Limited
29. NSG Pilkington
30. Open Innovation Hub for Antimicrobial Surfaces
31. RS Clare
32. Saffil
33. Sigmatex
34. Unifrax
35. Unilever Advanced Manufacturing Centre
36. Unipart
37. University of Liverpool
38. Virtual Engineering Centre (VEC)

Liverpool City Region - Science and Innovation Audit 2017

Asset Register: Materials Chemistry Theme

sdg economic development

Created by:	Last Updated:	Scale:
CLacy	23/05/2017	200,000

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5.16 The key assets in this developmental sequence are summarised below:

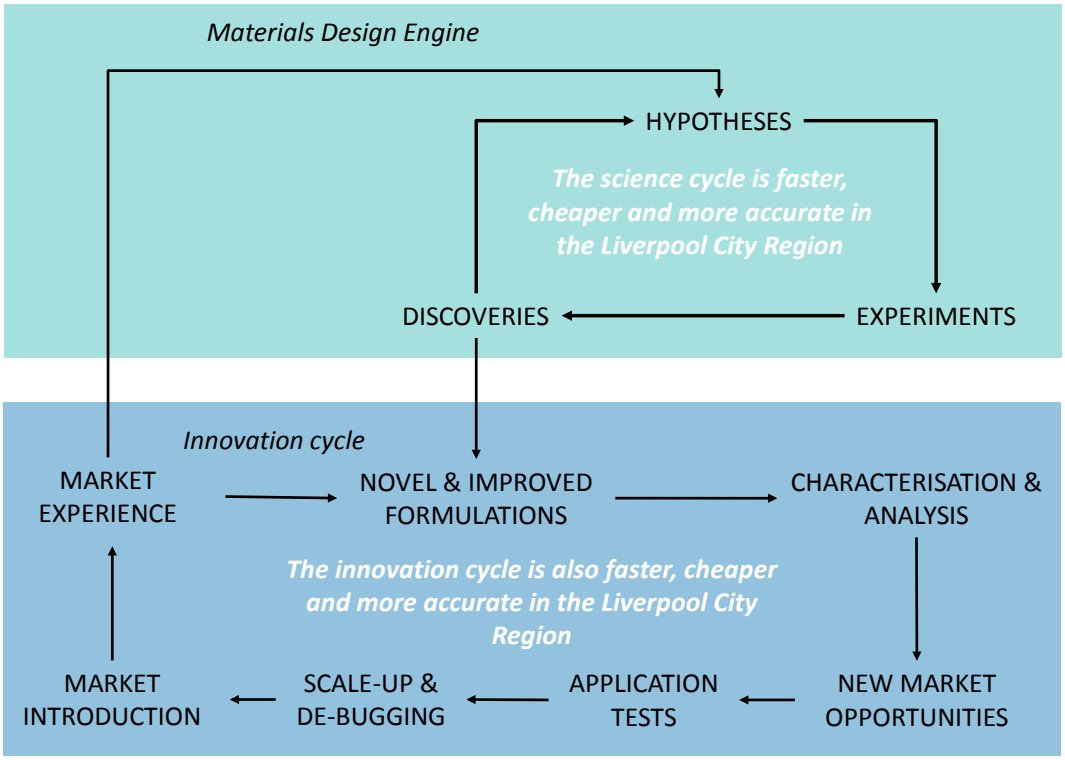
- The **Centre for Materials Discovery** (CMD) was established in 2006. It is a 300m^2, open-plan High Throughput Laboratory with robotic synthesis, formulation and liquid handling platforms are located in close proximity to extensive analytical facilities. It has transformed various areas of materials research, with a particular focus on energy-related applications, polymers, porous materials (2016 RSC Innovation Award), and nanomaterials.
- The **Ultra-mixing Processing Facility (UMPF**), developed in 2011, is a unique high energy fluid processing laboratory, which is accessible to both private and public sector industries/academies for contract research into scalable liquids dispersion processes; it incorporates the latest technology for the development and testing of nano and micro structured materials.
- "The **Open Innovation Hub for Antimicrobial Surfaces** was launched in 2013 and is also a sub-project of the Infection theme (see Chapter 5). OPIHAS is based on translating world-leading expertise in nanoscience from UoL's Surface Science Research Centre into next generation antimicrobial surfaces and materials. There is very significant industry engagement (8 global multi-nationals, 40+ SMEs) and a demonstrable commercialisation pathway – 4 patents filed, clinical trials underway for 1 product and planned in 2018 for 2 others
- The **MicroBiorefinery** is a research facility in the Chemistry Department at the UoL, opened in 2013. It was established in collaboration with Unilever and AB Sugar and provides facilities and expertise to develop novel chemo-catalytic routes and functional materials from biomass and bio-derived feedstock. The MBR is the result of a £2.83m RGF award. The MBR programme also features in the Bioeconomy SIA, demonstrating its national importance.
- The globally unique **High Throughput Formulation Centre**, opened by Unilever in 2014, is an innovation space at Liverpool Science Park as part of a £6.9m project to facilitate cutting edge research into home and personal care products like Dove hair shampoo and Persil laundry liquid. It uses robotic automation and data management to allow Unilever, academia and other UK companies to radically alter the speed and quality of how products are developed and designed.
- The Materials Innovation Factory, the new global state-of-the-art facility that commenced operation in 2017. The MIF focuses on Computer-Aided Materials Design (CAMS) and high-throughput (HT) automation on the materials chemistry research and innovation processes, see Table 5-1.

Table 5-1: The Materials Innovation Factory in summary

- £61M capital investment (building and equipment) with total funding of £74M (CapX + revenue to 2020);
- Established under first round of UK Research Partnerships Infrastructure Fund in 2012. Supported by Sir Henry Royce Institute/EPSRC funding in 2017. Commenced operations in April 2017. Co-location facilities for 300 users (120 industry/180 academic);
- Organised by University of Liverpool in close collaboration with Unilever to develop an industry-leading research institute. The initiative focusses on four areas of expertise where the University of Liverpool has world-leading knowledge and research programmes - Sustainable Feedstocks, Organic/Inorganic Materials, and Genome Sequencing;
- Nanomedicine is an additional thematic area in MIF which forms a sub-project of the Infection theme (see Appendix 9).
- This knowledge and expertise are backed up with 11,500m^2 facilities comprising an open-access area laboratory with a dedicated MIF technical team, and £11m worth of capital equipment. MIF contains Research Hotels, an Analytical Facility, a Formulation Science Laboratory, and Support Labs;
- The modus operandi of this laboratory is the combination of academically driven computational materials discovery and automated materials application testing. In this laboratory, a hypothesis can be tested through computational design, *in silico* modelling, predictive design of experiment and a modular autonomous laboratory; and
- The MIF is a unique example of how academic and industrial excellence can be brought together to achieve a step-change in productivity in the innovation process – faster, cheaper and more precise discover and industrial applications achieved with a lower investment risk profile

5.17 This combination of computationally enabled materials discovery (the materials design engine) and automated physical experimentation (the materials application engine), in the proposed next phase of MIF development following SIA consultations – is a demonstrated success story and has important commercial advantages for firms using the MIF. The step-change in the discovery process efficiency, the ability to discover new materials and assess their properties faster than competitors is a transformational capability – schematically illustrated in Figure 5-2.

Figure 5-2: The MIF Model: materials design engine + materials application engine.



Source: SDG Economic Development

5.18 The efficacy of the MIF model born out of the experience and lessons learned from the Centre for Materials Discovery is illustrated in the following two case studies illustrating the breadth industrial applications – spanning catalysts for synthetic fuels to fast moving consumer goods.

The academic capability underpinning MIF has been recognized nationally through the selection of UoL as a spoke for the Royce institute, and the award by the Leverhulme Trust of a £10m centre for functional materials design.

Case study 1 - Johnson Matthey's new catalysts for making low-emission synthetic fuels

- The University of Liverpool's expertise in materials design and in accelerated materials discovery has direct relevance to UK manufacturing. A recent example is the discovery of new stable catalysts for the manufacture of low-emission synthetic fuels. The complex composition and nanostructure of such materials has meant that traditional development processes to discover and improve catalysts have been slow. By developing a new catalyst discovery workflow that exploited the robotic synthesis capabilities of the Centre for Materials Discovery, UoL worked with Johnson Matthey to develop a new catalyst for the Fischer-Tropsch process which they subsequently patented, despite the crowded nature of the patent space and the difficulty of developing new IP.
- This illustrates how the new automated Materials Chemistry capability, and the creation of new research approaches using it, can offer direct advantage to UK industry with the potential to generate radical technological advances to drive innovation in low emission energy sources – innovations with substantial potential to drive growth in GVA and jobs.

Case study 2 - Unilever - fastest ever Lab to Launch timing for a new molecule

- Key scientists from Unilever R&D at Port Sunlight worked at the Centre for Materials Discovery (CMD) at the University of Liverpool and with one of Unilever's Partner to win chemical suppliers located outside the UK to create a new materials chemistry invention that was incorporated into a Unilever product at its Port Sunlight factory. This combination created a significant acceleration in the ability to innovate from lab to market launch.
- A polymer was invented by a Unilever scientist in the CMD in early 2013. It was new to the World and patented by Unilever. However, by beginning with the end in mind, this chemical has been scaled up by Unilever's commercial supply partner from a research lab scale of 1 gram to 5,000 Tonnes (5,000,000,000 grams) per year production volume and was then incorporated into a significant global launch of a new Unilever laundry liquid in less than 2 years from the initial invention. It is Unilever's current record for fastest ever Lab – Launch timing for a new molecule. This approach is now implemented in the Materials Innovation Factory.

Source: University of Liverpool, 2017

5.19 Investment risks are a major consideration when deciding on innovation projects: the more radical the proposed advance the greater the risks to the funds invested. The MIF significantly reduces these investment risks by reducing the likelihood of wasted experimental work (via computationally enabled insights and ruling out options in theory rather than in practice) whilst also reducing the costs of this physical experimental activity (via automated experimentation). The combined result is that industries using the MIF can generate greater innovation outcomes for a given R&D budget. From a financial perspective, this means that the estimated Net Present Value (NPV) of innovation activities is higher in the MIF environment than elsewhere. This in turn reduces the cost of risk capital for such projects because the 'de-risked' investments are more attractive to investors and attract lower risk premium for the funds provided. The reduced investment risk profile also gives the LCR+ a distinct advantage regarding stimulating SME formation and growth, attracting venture capital, more general inward investment from established corporations and generally building a robust and highly competitive regional innovation ecosystem. The Liverpool Model is an NPV maximiser.

5.20 More generally, this focus on computationally-enabled Materials Chemistry is supported by these assets in the LCR+[38]:

- The UoL's world-leading expertise in several major aspects of materials chemistry, including organic and inorganic materials, nanoparticles and material surfaces; discussed above.
- Unilever's biggest R&D laboratory is based in Port Sunlight (within the LCR) which is the de-facto global hub for research and innovation in FMCG and is home to the new Advanced Manufacturing Centre. This facility, together with the MIF, the Hartree Centre and the University of Manchester, forms the Unilever Science Grid.
- One of the UK's largest chemicals and glass clusters around Ineos Chlor in Runcorn and at Pilkington/NSG in St. Helens/Lathom. This cluster employs 10,000 people and generates in excess of £742m in GVA; and
- One of Europe's largest bio-manufacturing clusters with co-location by Lilly/Elanco, CSL, Actavis, AstraZeneca and Sanofi (Materials Chemistry has important contributions to make to bio-manufacturing).

Local Science & Innovation Talent

5.21 The UoL Department of Chemistry is a relatively small department (34 full-time equivalent Category A staff in REF 2014) but scores extraordinarily well on academic excellence with 99.2% of outputs classified as 4*or 3* - the best performance nationally.[39] As such it is a key cluster of research excellence co-located with Unilever's world-class industrial innovation capability. This UoL pre-eminence in Materials Chemistry is unrivalled in the UK.

5.22 Figure 5-3 demonstrates the pre-eminence of UoL Chemistry performance in REF 2014 when set against the national average for overall score, research output quality (65% of the overall score), research impact (20% of the overall score) and research environment (15% of the overall score).

5.23 For the period 2011-15, the Field Weighted Citation Index (FWCI, measures the ratio of citations achieved relative to subject averages benchmarked as 1.0) is 1.37 for materials science and 1.41 for Materials Chemistry.[40] An alternative view of FWCI performance based on carefully selected keywords generates an even higher FWCI of 2.49[41]. This is more accurate because it focuses on specific research areas in which UoL Materials Chemistry excels.

5.24 A defining feature of LCR+ activity is thought leadership in Materials Chemistry, and the creation of entirely new areas. For example, a new class of materials was invented in the

[38] Appendix 6 contains a full list of theme stakeholders.

[39] The overall score is composed of three dimensions: outputs, impact and environment. The latter covers funding secured and a detailed narrative account of the strategy, achievements, people and staff development approach, infrastructure and facilities and collaborative activities.

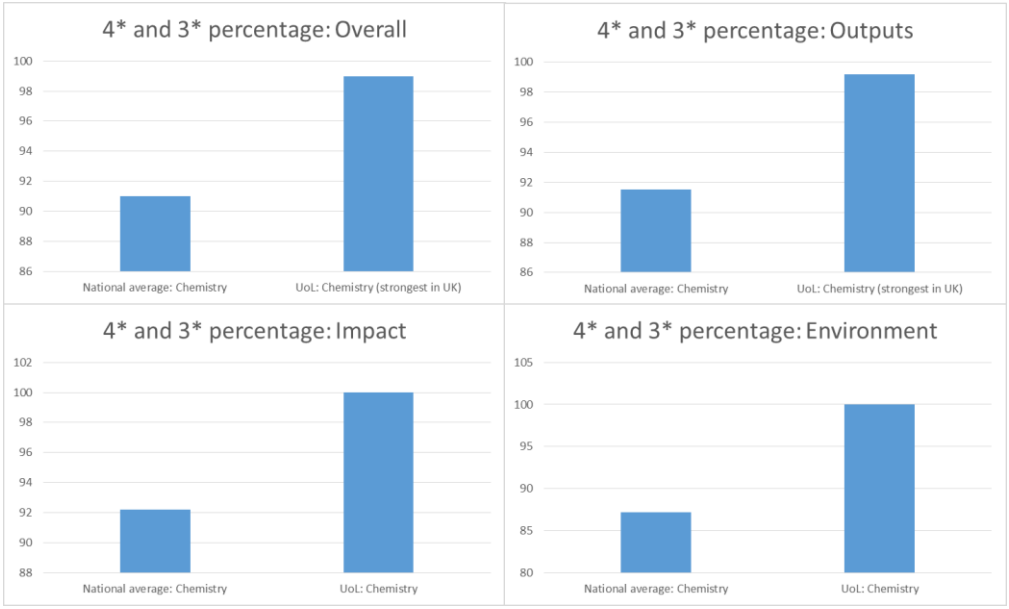
[40] Data and analysis specially provided by Scopus SciVAL courtesy of the University of Liverpool.

[41] The keywords used are: porous materials, polymer synthesis, supramolecular chemistry, carbon dioxide capture, energy storage and production, colloids, supercritical fluids, transition metal oxides, solid oxide fuel cells, MOFs (metal-organic frameworks), superconductivity.

Centre for Materials Discovery in 2007: Conjugated Microporous Polymers (CMP). At least 50 research groups worldwide are now working on these materials, and in 2016, there were more than 60 papers published on CMPs and closely related framework materials. These materials have potential applications in batteries, molecular separations, and sensors for toxic substances, among many others, and this demonstrates the multiplier effect of basic research in materials innovation, outlined above – *this entire area stems from one publication in 2007.*

5.25 The Department published 59 unique patents over the REF 2014 period, of which 25 (over 42%) were published in collaboration with Unilever, Bayer, Johnson Matthey and Thermo Fisher. Details of student numbers and graduate retention can be found in the chapter appendices.

Figure 5-3: REF data for Chemistry, University of Liverpool



Source: HEFC REF 2014 data

5.26 Unilever's Port Sunlight innovation presence employs over 700 scientists working on materials, formulation, physical, biological, process and consumer sciences. Each year this work results in over 100 patent filings and approximately 140 peer-reviewed papers and conference presentations. Unilever attributes much of its success to working across a network of Unilever R&D centres around the world – bringing major global connectivity to LCR+ (discussed further below).

National & International Engagement

5.27 Unilever's national and international engagement is integral to its innovation model by virtue of its open innovation strategy and the ways in which the Port Sunlight laboratory leverages the corporation's global R&D/innovation network. Port Sunlight is the largest of Unilever's global research and development hubs. Three of its eleven key global R&D partners are in the LCR+ (UoL, Hartree Centre, University of Manchester), which represents

the largest concentration of investment in the local ecosystem of any of its global hubs. Aspirations to develop these assets further include the development of a 'FMCG Valley'.

5.28 The UoL Department of Chemistry's research clusters all contribute via synergies to the distinctive LCR+ Materials Chemistry capability. The department's researchers frequently co-publish with international collaborators. An analysis of aggregate LCR+ chemistry publications for the period 2011-15 reveals that 59% (687) had international co-authors and 18% (208) national co-authors.[42] This international and national connectivity is an important asset for the region, and reflects the growing interest in Global Innovation Networks noted in Chapter 3.

Developments in the Wider Funding Landscape

5.29 Funding combines public and private sources and is characterised by the emphasis on collaboration linked to shared 'dual-use' facilities that enable both excellence in academic research and effective innovation to take place in LCR+. The principal sources are: large corporations; SMEs; Research Councils (mainly EPSRC); UK Research Partnerships Infrastructure Fund; ERDF; European Research Council; Royal Society; Universities overseas; BEIS; and Philanthropic organisations. Table 5-2 contains data on research funding by type of source for Materials Chemistry over five years 2012 to 2017. These data show:

- Strong support from UK government and tax payer funded national sources;
- European funding is significant at over 15%;
- A very high overall overseas funding contribution of 24%, and;
- UK Philanthropic is also significant at 11.5%.

Table 5-2 Materials Chemistry Funding

Organisation Type	Sum of Total Funding (£)	Proportion of Funding
UK Government	25,121,213	54.7%
European Government	6,762,827	14.7%
UK Philanthropic	5,269,201	11.4%
UK Business	2,467,891	5.4%
UK Sector Bodies	1,886,030	4.1%
International Government	1,609,457	3.5%
International Sector Bodies	1,012,511	2.2%
International Business	572,223	1.2%
European Business	488,953	1.1%
International Higher Education	441,353	1.0%
European Sector Bodies	234,050	0.5%
International Philanthropic	62,353	0.1%
European Higher Education	22,727	0.1%
UK Higher Education	14,642	<0.1%
Grand Total	**45,965,430**	**100.0%**

Source: data specially provided by the University of Liverpool

[42] Special analysis of SciVAL data.

Conclusions

5.30 The LCR+'s Materials Chemistry capability is a unique industry-academic collaboration – a tangible expression of the distinctive Liverpool Model – materials design engine + materials application engine – exemplified by the MIF, and which is driving cutting-edge research and innovation in a transformational way. Research excellence in both academia and industry is the foundation on which the computationally-enabled Materials Chemistry component of the LCR+ regional innovation system is built. This is the product of a long-term developmental strategy executed via a logical sequencing of investments that complement and build upon each other. This sustained approach has been achieved by building effective industry-academic collaboration via shared facilities using combined funding, culminating in the opening of MIF in 2017.

5.31 There is a clear opportunity to replicate this model for high value chemical product industries other than the current FMCG sector (e.g. new low-emission energy technologies and many others). A major new facility could build local supply chains, assist SMEs, create local high value jobs and attract very substantial inward investment in several materials chemistry related industries. There are also additionally strong synergies between Materials Chemistry, Infection and High Performance and Cognitive Computing. The key differentiator for LCR+ is the close integration of computationally enabled materials design with industrial materials application development. IBM's role in the region (attracted by Hartree and SCD) is particularly significant because this is the only partnership between IBM Research and a publicly funded research organisation in the UK.

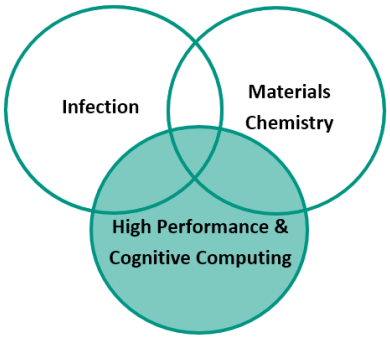
6 In Detail: SIA Theme 3 – High Performance & Cognitive Computing

Headline Messages

- Both as a technology and a market, HP&CC represents a major opportunity, globally and for the UK and its regions and devolved administrations
- The combination of fundamental and applied HP&CC expertise in the LCR places it in the top three areas in the UK
- The ability to attract leading scientists to the growing HP&CC brand and community in the LCR is vital
- Government's commitment to HP&CC in general, and its choice to invest at Hartree in particular is a major foundation on which to build
- IBM UK Research's decision to co-invest at Daresbury as part of Hartree's development is an international endorsement of the sophistication and seriousness of the LCR's offer, and provides access to IBM's global bank of intellectual property
- Some 160 firms with employment of about 2,200 are involved specifically in HC&CC markets and technologies in the LCR
- Investment in Hartree means the facility currently has a computing system in the world's 'top 25', representing a major capital and productivity asset on which to build to lever growth across multiple economic sectors.
- Alongside the University of Liverpool, Liverpool John Moores is a core partner in Sensor City – one of the world's only incubators dedicated to the development and commercialisation of sensors and Internet of Things technologies.

Introduction

6.1 This third Theme is focused on the LCR's excellence in two technology areas of major global significance – High Performance Computing and Cognitive Computing. By these, we mean:



- **High Performance Computing** (HPC): the use of very powerful computers (usually in the form of 'massively parallel' devices) to run advanced application programs efficiently, reliably and quickly.[43]
- **Cognitive Computing (CC):** the simulation of human thought-processes in computerised models; CC involves self-learning systems that use data mining, pattern recognition and natural language processing to mimic human thinking[44] – often referred to in everyday speech as Artificial Intelligence (AI).

[43] Taken from http://searchenterpriselinux.techtarget.com/definition/high-performance-computing. The term applies especially to systems that function above a teraflop (or 10^{12}) floating-point operations per second.
[44] Taken from http://whatis.techtarget.com/definition/cognitive-computing

6.2 HPC is one of LCR's longest standing scientific and applied activities, dating back to the 1960s when the Science and Technology Facilities Council's (STFC) Daresbury Laboratory was at the forefront of using HPC to support the campus' then particle physics work. Since that time, the City Region's HPC capabilities, further developed to include CC, has built in scale, scope and innovation terms to comprise an internationally competitive offer to industry.

National & International Trends & Global Market opportunities

Drivers, Abilities & Opportunities

6.3 Perhaps more than any development or innovation in the global economy, digital technologies are driving fundamental changes in the ways business, societies, and individuals operate. The following are key:

- The steadily increasing power of computing devices, as hardware and software designers bring forward more compact, higher capacity, and more functional processors software platforms;
- The increased connectivity and integration of computing systems, brought about by increasingly standardised operating systems and the development of open standards; generally, and
- The development of the Internet as the core of the world's communication network, with the steady uplift in access speeds and modes;

6.4 Exponential increases in the volumes of data created and stored. For HP&CC in particular, four 'abilities' are key to the way the HP&CC technologies and functionalities are developing. These are:

- The ability to model and simulate in very much more detail, and to vastly increased levels of resolution, and with many more factors;
- The ability to integrate and analyse much larger data sets, and to integrate and synthesis data from multiple different sources;
- The ability to deal with sensor data in real time, so that analyses and simulation become very much real time, and
- The ability to use CC techniques to enable faster decisions-making, learning from previous experience, rather than working from first principles.

6.5 The markets for HP&CC are already large, and set to grow massively over the coming years. Data from American technology specialists IDC Research Inc (at 2016) indicates that the HPC market (broadly classified) will be worth some U$31bn by 2019, with an expected compound annual growth rate of eight per cent over the period[45]. Similarly, the global CC market's size is expected to reach U$50 bn by 2025, per a recent study conducted by Grand View Research Inc (December 2016).

[45] https://www.top500.org/news/idcs-latest-forecast-for-the-hpc-market-2016-is-looking-good/

6.6 In the LCR, with our richness of HP&CC assets, these drivers, abilities, and levels of market growth present real opportunities for development. These include:

- Ensuring the benefits of HP&CC are secured by the UK's business base – as the economic pressure grows to design, produce and maintain/service goods and services more quickly and cheaply, translating technical capability in HP&CC facilities and expertise to business of all sizes is key to driving competitiveness and innovation.
- Solving the new 'power paradigm' – the electrical power requirements of existing architectures powering HP&CC platforms are no longer scalable, and are increasingly a brake on further development. New solutions, built around lower and smarter energy use, need to be found and deployed;
- Tackling Big Data properly – exponential increases in the volume, variety and velocity of data mean that current process approaches will cease to work effectively. New models of data management, integration and processing need to be found if Big Data is going to provide meaningful insight and intelligence. For example, under 'Virtual LCR,' the UoL is proposing a novel *in silico* policy development tool using Big Data analysis, as well as real-time information from LCR citizens via a dedicated app, and
- Democratisation of the HP&CC tools and techniques – making sophisticated and intense computing techniques accessible to the non-expert user must be a priority. HP&CC approaches and the benefits they offer will not scale if the value of Big Data is kept only to skilled data scientists in research institutions.

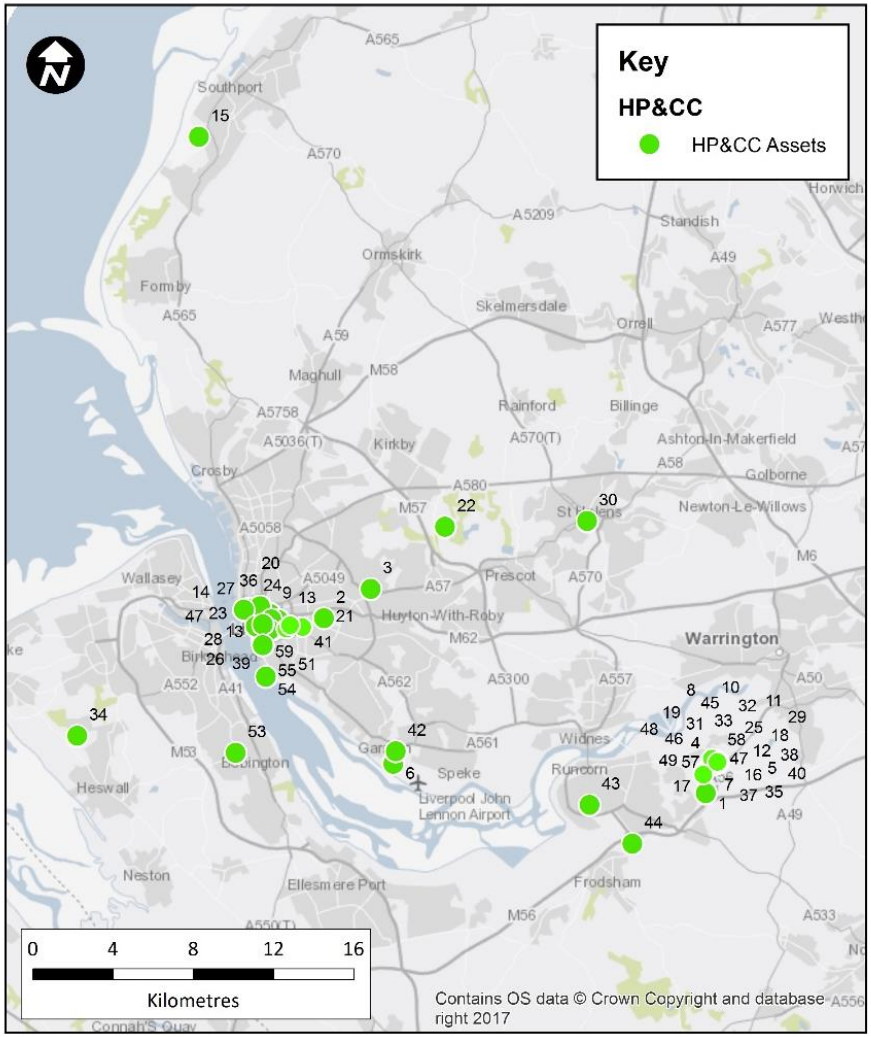
Local Science & Innovation Assets

6.7 Against this background, our HP&CC offer in the City Region has a nationally unique combination of five assets: These are each introduced more fully below:

- The Hartree Centre at Daresbury, where IBM has now located its only UK-based research facility;
- STFC's Scientific Computing Department (SCD) activities at Sci-Tech Daresbury;
- The Virtual Engineering Centre, also at Daresbury;
- The Departments/Schools of Computer Science at the UoL and John Mores University, and
- The City Region's HP&CC business base.

6.8 A map setting out the spatial distribution of these assets, the City Region's emerging HP&CC cluster, and enabling assets in the City Region's innovation ecosystem is at Figure 6-1. A more detailed map of the Daresbury site can be found in Appendix 8.

Figure 6-1: The spatial distribution of HP&CC Theme assets in the Liverpool City Region (non-exhaustive list)



Key Assets

1. ABB
2. AIMES Data Centre
3. Alder Hey Childrens Hospital
4. Atos
5. BioNow
6. Brainboxes Ltd
7. Centre of Competence for Cognitive Computing
8. Chemicals North West
9. Citrus Suite
10. Cockcroft Institute
11. Conveyor Networks
12. Deep Sky Blue
13. DoES Liverpool
14. Draw & Code
15. Hibernia Transatlantic Cable/ FibreOptics
16. IBM Research
17. Innovation Agency (Academic Health Science Network for the North West Coast
18. Integritie (UK) Ltd
19. Intel Parallel Computing Centre (IPCC)
20. Internet Exchange Liverpool (IX Liverpool)
21. IQ Blade Ltd
22. Jobs The Word Ltd
23. Living Lens Enterprise Ltd
24. LJMU Departament of Applied Mathematics & Astrophysics Research Institute
25. LPW Technology
26. Lucid Games
27. Mando Group
28. MCQN Ltd
29. Mellanox Technologies UK Ltd
30. O2 UK Test Bed (St. Helens)
31. OCF Plc
32. Optis Northern Europe Ltd
33. Paratools Ltd
34. Paravizion Ltd
35. Perceptive Engineering Ltd
36. Playrise Digital
37. POWER Acceleration & Design Centre (IBM work with Hartree)
38. QSR International (UK) Ltd
49. Red Ninja Ltd
40. Sci-Tech Daresbury Enterprise Zone
41. Sensor City
42. Shop Direct
43. Spectralworks Ltd
44. Spirit (Data Capture) Ltd
45. STFC Accelerator Science & Technology Centre (ASTeC)
46. STFC Scientific & Computing Department (SCD)
47. Syrenis Ltd
48. Tessella
49. The Hartree Centre
50. The Sensible Code Company Ltd
51. UK Microsoft Associate College (The City of Liverpool College)
52. Uniform
53. Unilever Advanced Manufacturing Centre
54. University of Liverpool
55. University of Liverpool Department of Computer Science
56. Valuechain Technology Ltd
57. Virtual Engineering Centre (VEC)
58. Wadaro Ltd
59. We Are Nova Limited

Liverpool City Region - Science and Innovation Audit 2017

Asset Register: HP&CC Theme

sdg economic development

Created by:	Last Updated:	Scale:
CLacy	25/05/2017	300,000

\\sdgworld.net\Data\Manchester\Users\CLacy\Private\LCR SIA Asset Map\HPCC.mxd

The Hartree Centre

6.9 The Hartree Centre was established in 2012 at Sci-Tech Daresbury to support UK industry in the effective adoption of HPC. The Centre has been the focus for three linked and reinforcing rounds of government funding so far:

- An initial UK Government investment of £37.5 million, largely derived from the national e-Infrastructure fund (2011);
- A further £19 million of capital investment (in 2013) to address two further 'forces of change' in the HPC arena: first, the growing need for large-scale data and analytics competence (recognising the exponential increases in the volume and variety of data being created); and second, to pursue advances in the energy efficiency of HPC machines, and
- Some £115.5 million of investment (in June 2015, running out over five years) to establish Hartree as the UK Centre of Excellence in Cognitive Systems and Big Data. With a clear focus on developing new approaches, this investment allows Daresbury to deliver computing capability to a range of industrial users and partner organisations. Moreover, it also delivers a transformational capacity for UK industry to extract value from the vast and readily available array of big data, so accelerating development and adoption processes by industry.

6.10 Alongside Government investment, this last phase is being co-funded by IBM in the form of access to its global IP (including IBM Watson) and onsite expertise. This is valued at £200 million, and involves establishing an IBM Research base of around 30 staff at Hartree. The facility is IBM's only R&D facility in the UK, and as such a major endorsement of the City Region's attractiveness for HP&CC activity. IBMs presence will add to the existing Hartree headcount of 50 data scientists and specialists.

6.11 By combining its world-class facilities with access to its specialists and computational scientists, Hartree enables organisations of all sizes to produce better outcomes, products and services more quickly and cost-effectively than they can through conventional R&D workflows. It is unique in the range and power of its facilities and specialist staff, sitting between the academic-facing supercomputing facilities at universities like Edinburgh and companies like Amazon or Microsoft, who rent access to their cloud-based systems by the hour.

6.12 The Hartree Centre has recently acquired a new supercomputer, the UK's first Bull Sequana X1000, one of the most powerful supercomputers in the world, capable of performing 3.4 $x10^{15}$ (petaflop) calculations per second. This comes through a new strategic partnership with Atos UK&I.

The Virtual Engineering Centre (VEC)

6.13 Led by the UoL's School of Engineering, and established at Sci-Tech Daresbury in 2010 with public resources, the VEC works to support R&D for firms and consortia in the Aerospace, Automotive, Energy, Medical Nuclear and adjacent sectors. Co-working with Hartree is a

core element of the VEC's expertise in Advanced Virtual Engineering (including advanced modelling, simulation, and immersive visualisation technologies).

6.14 The VEC employs 20 high-quality engineering and computer science specialists, three of whom are funded by Hartree, helping further to ensure cross linkages. The VEC's client base ranges from large original equipment manufacturer (OEMs) (e.g. Bentley Motors, BAE Systems, National Nuclear Laboratory) to small technology providers (e.g. Valuechain and Optis), many of whom have located to Sci-Tech Daresbury to gain access to VEC and Hartree expertise.

6.15 Building on experience, a new Virtual Innovation Centre (VIC) has now been established in Liverpool to build on the City's growing capability in digital innovation. Similarly, a VEC@Alder Hey is linking the VEC to a dedicated Innovation Hub at Liverpool's Alder Hey Hospital, with the initiative identifying how emerging modelling and Big Data techniques can be applied to improving the 'patient journey'. IBM Watson is being used to underpin this work and help realise Alder Hey's ambitious vision to be the world's first "Living Hospital".

Table 6-1: HP&CC in action in the Liverpool City Region

Unilever plc, Port Sunlight, UK

- Commitment, in the company's recent Global Strategy, to move to a *'Digital First'* approach in all its activities. At Port Sunlight, one of two UK R&D centres, this is driving all R&D being undertaken 'in silico' (i.e. digital space), offering the potential for major reductions in R&D processes and the opportunity to do things 'right first time';
- Hartree is part of Unilever's so-called Science Grid, preferred academic partners who are world-leading in science and complementary to Unilever's own science and technology skills. Other partners in the Science Grid are the University of Liverpool (around Materials Chemistry), and Manchester (around Materials Processing and Bioscience); and
- Unilever has a long-standing relationship with the Scientific Computing Department and, more recently, Hartree. Annual spend (now with Hartree) is typically £150k pa. Nineteen distinct projects with SCD/Hartree since 2010, as part of long term programme of using Daresbury to enable the move to 'in-silico' R&D activity.
- Recent projects include:
    - The Virtual Pouring Project (2015): using Hartree's expertise to simulate liquid pouring, as part of bottle design for new products. Input cost to Unilever about £10k, potential benefits of up to £20m (gross) of annualised incremental turnover generated by faster time-to-market, if/when fully implemented globally;
    - Manufacturing Production Optimisation Project (2015): using Hartree's expertise to identify bottlenecks in one factory's filling line, with goal of reducing unwanted down-time and increase productivity. Input cost to Unilever about £60k; on operational implementation of project, potential for 10% improvement in line productivity, equivalent to 3.6m more bottles/year, with potential increased sales on implementation of around £37m/year (gross); and
    - Computer Aided Formulation Project (ongoing): A collaboration developing computer simulations tools to predict how ingredients come together to form the liquid structures underpinning many of Unilever's typical products (e.g. shampoo, liquid detergents, etc.). Input cost to Unilever about £80k, key business impacts will improve product quality and faster product development, with an estimated 80% reduction in development time on the critical path to launch. No hard data

yet on gross effects on turnover/cost base. Similar tools have been deployed already within Unilever across more than 150 users, with 1000s of formulations simulated annually. (Such tools are estimated to have saved more than 5,000 years on microbiological challenge studies).

- Company views Hartree as a vital strategic partner *('Hartree is a key consideration for Unilever's remaining at Port Sunlight'*) and expects fully to be working with Hartree for at least five years to progress its in silico agenda. Does see Hartree's expertise as being able to add very significant value to Unilever's R&D processes for the future.

Source: Vice President Operations and Open Innovation, Unilever plc

The Departments/Schools of Computer Science at the University of Liverpool and Liverpool John Moores University

University of Liverpool

6.16 Educating some 700 undergraduates and around 150 postgraduates on taught/doctoral programmes annually, and with an academic staff of 40, the last UK Research Excellence Framework identified the UoL as one of the top three centres in the UK for Computer Science-related published research. It also has over 1,000 people enrolled in its online Masters programmes.

6.17 Organisationally, the Department of Computer Science is part of the School of Electrical Engineering, Electronics, and Computer Science which, together with three additional schools, constitute the Faculty of Science and Engineering. With two research sections, Algorithms and Artificial Intelligence, that underpin more focussed research groups within and across these topics, the Department works closely with a wide range of industry partners including AstraZeneca, BAE, Dstl, IBM, NNL, Rolls Royce and Unilever to develop technologies and applications in cutting-edge fields that harness its research on algorithms and AI. The School has close working links with the Hartree Centre and the VEC (which it oversees), and in collaboration delivers a joint Masters Course in Big Data, teaching 20 students a year explicitly to help address the increasing critical shortage of national expertise in Big Data.

6.18 The Department is a key partner in 'LCR 4.0', a UK-leading initiative to drive forward 'Fourth Industrial Revolution' thinking in our City Region. Other partners in LCR 4.0, which operates as a UK-leading self-standing initiative, include Hartree, the VEC, LJMU, Sensor City (a partnership between UoL and LJMU) and the LCR LEP. The School and Hartree are working together currently on a bid for a new Digital Innovation Factory (DIF), which will bring Hartree's and the VEC's HP&CC offer to the University's city centre campus, co-locating it with academic, manufacturing and robotics specialists.

Liverpool John Moores University (LJMU)

6.19 The Faculty of Engineering and Technology (FET) hosts the Departments of Computing and Applied Mathematics and the Astrophysics Research Institute. The Computing Department has a strong track record of collaborating with industry, having previously used its expertise to work with organisations such as the BBC, Panasonic, Thales and Unilever, together with

recent projects under the iCure initiative. The Department also works with local, regional, and national organisations through student placement (including over 600+ placement provider links), research, consultancy, and short-course activity. In REF2014, the Computing Department (then part of the School of Computing and Mathematical Sciences) submitted to the Unit of Assessment 11, Computer Science and Informatics. Eighty percent of its research impact within this Unit was rated as being at 'international level'.

6.20 The linked Department for Applied Mathematics leads the recently approved £5million ERDF co-funded LCR Activate project to create a Digital and Creative Industries SME accelerator. This will involve Hartree in developing relevant infrastructures to support new products and services in the City Region across 4 specific fields: HPC and big data analytics, cognitive computing, cloud computing, and merging data.

6.21 FET more generally has an impressive publication output, with a high proportion of papers in leading journals and nationally leading citation rates[46]. In addition, it has secured significant levels of external funding, including €14 million of EU funding for its work with Aniketos, €2.6 million for the work with the *'What to do with the Wi-Fi Wild West'* (Wi-5) project and £40,000 for a Virtual Cloud-Based Cyber Security Training Platform (VIBRANT) project. Computing-related capacity in FET includes over 1,000 FTE undergraduates across the its Departments (900 FTE undergraduates, 35 FTE Post-Graduates (Taught), 80 FTE Post Graduates (Research) and six Post-Doctoral Research Assistants)[47]. Together with graduate flows and academic resources at the UoL's Computing School, these 'people assets' are important components in building a resilient and durable HP&CC cluster and skills base in our City Region.

6.22 Alongside the UoL, Liverpool John Moores is a core partner in Sensor City – one of the world's only incubators dedicated to the development and commercialisation of sensors and IoT technologies.

The business base and associated supply chain

6.23 For the specific purpose of developing this SIA theme , Hartree commissioned bespoke research to start to map out the HP&CC business base and supply chain in the City Region, i.e., firms with *specific skills* in HP&CC technologies, as opposed to users of generalised computing technologies which is a much larger cohort. Using novel scraping technologies to parse web and Twitter activity and feeds, and working to a clearly-defined set of HP&CC-related keywords[48], this preliminary work identified:

- Over 160 firms whose web and Twitter activities/feed suggest they are active seriously in the HP&CC space generally in the LCR;

[46] SciVAL data for period 2012/16, extracted in Spring 2017 and analysed by SDG Economic Development

[47] Liverpool John Moores University REF Submission 2014 'Unit of Assessment: 11 - Computer Science and Informatics', Liverpool John Moores University Department of Computing Science website, https://www.ljmu.ac.uk/about-us/faculties/faculty-of-engineering-and-technology/department-of-computer-science

[48] Including, inter alia, algorithm, artificial intelligence, augmented reality, big data, blockchain, cognitive computing computational fluid dynamics, computational grid, dark data, data science, deep learning, energy efficient computing, Hartree, high performance computing, IBM Watson, machine learning, massively parallel, and virtual reality

- Of these, some 40 plus firms who might be described as comprising the 'core HP&CC cluster' in the LCR. These firms range from HP&CC majors (such as IBM, in the form of its UK R&D Centre at Hartree, and Atos's facility at Daresbury) and through to specialist smaller providers such as Perceptive Engineering Services (providing leading-edge predictive control and diagnostics tools for industrial processes) and Deep Sky Blue (who use HPC-type technologies and automation to reduce lead times), and
- In the core cluster group and the associated suppliers, employment in the LCR of about 2,220.

Local Science & Innovation Talent

People

6.24 As with our other SIA themes, maintaining world-leading standards and research requires a ready supply ofsuitably talented researchers, developers and engineers.

6.25 Currently, SCD, Hartree, VEC and IBM employ about 150 full-time equivalent employees on the Daresbury site. The professions covered include scientists, computer technologists, systems administrators, business development, project management, marketing and administration. When complete, the expansion of Hartree alone will add a further 200 highly skilled jobs to the 50 or so already created, with more in UK businesses because of collaboration with Hartree and SCD.

6.26 The two academic departments, employ around 70 people. These numbers are small, but have real room to increase markedly as the collaboration envisaged by this Theme – *'technologists with academics with business users'* – builds momentum by using assets of depth and calibre, including Scafell Pike, the Atos Bull Supercomputer at Daresbury, which is presently one of the Top 25 HPC systems in the world.

6.27 The ability to attract leading scientists who wish to be associated with the cachet, profile, and type of work associated with the growing HP&CC brand and community in the LCR is vital. In this context, IBM's decision to co-locate its newly established UK research office at Daresbury, as part of Hartree's and the wider HP&CC's development, is highly helpful and potentially 'game-changing'. It should help to attract leading researchers to the City Region. Twenty employees already work in the facility, out of the total of the 30 that IBM is committed to.

6.28 More generally, the LCR HP&CC community has a responsibility to build (people and scientific community) capacity in its areas of expertise. To this end, Hartree runs several training courses for staff, academia, and industry throughout the year. Since 2013, some 170 attendees from around the world have participated in Hartree's occasional Summer Schools. These activities, underpinned with personal relationships, are vital in keeping SCD, Hartree, VEC, IBM and academic departments at the centre of international HP&CC thinking and networks. Separately, the UoL and Hartree have developed a new MSc in Big Data, this to help address the growing labour market shortage for expert specialists – both hardware and software – in the Big Data area.

Research Excellence

6.29 Research excellence is reported most usually in terms of Research Excellence Framework (REF) performance. For this Theme, however, REF scores are of limited value, given that the majority of partners operate within a business rather than university environment. Formal data on the research excellence of SCD, Hartree, and VEC activities are therefore not systematised easily, which is clearly a constraint in assessing performance.

6.30 Having said that, of 90 project assignments undertaken by Hartree since 2012, 50 or so have had a '*material economic impact'* on the organisation concerned. Typically, this impact has been to bring forward development and innovation more quickly than would otherwise have happened, in some cases by as much as six years. Given that 85 percent of Hartree's external client base are blue-chip firms, it is reasonable to infer that the economic impact of these acceleration effects is significant. Hartree estimates that the likely associated return (actual and anticipated) on the circa £60million capital investment since 2012 (excluding the ongoing current Phase 3 investment will exceed £60million.

6.31 With respect to REF, Figure A8-2 at Appendix 8 reports on REF2014 for the UoL's Computing Science and Informatics Submission. The key points are:

- In terms of overall REF2014 performance, the UoL performs significantly better than the national average, achieving nine percentage points more than the overall average, and
- The UoL's performance in the 'Output' domain is particularly noteworthy, achieving some 17 percentage points more than the national average.[49]

National & International Engagement

6.32 The Witty Review (2013) gave the City Region a high national rating for Big Data; more widely, the following non-exhaustive examples give a flavour of the LCR's national and international links and relationships:

- SCD supports a large suite of UK collaborative computing projects (CCPs) and high-end computing (HEC) projects, funded by EPSRC. In addition, there are specific projects (like CCP4 in Protein Crystallography), funded by BBSRC. BBSRC and Innovate UK are funding the UK Biofilms Programme with SCD to establish a Biofilms Innovation Knowledge Centre (IKC), which UoL's Open Innovation Hub for Antimicrobial Surfaces is in the final running for;
- Hartree is one of six partners in the ERDF-funded and UK-leading LCR 4.0 project (alongside UoL, the VEC, LJMU, Sesnro City and the LCR LEP) aimed at revolutionising the productivity of the LCR's SME manufacturing base via the application of sensor and IoT technologies, which has the potential to be rolled out on a wider basis;
- It is also one of six organisations selected by the Digital Catapult in 2016 to be an Internet of Things UK Boost Partner to lead the roll-out of Low Power Wide Area Networks across the UK (this links the Hartree's wider UK role in developing more energy efficient

[49] Further data on comparative performance are provided in Appendix 5, Figure A5-7.

computing, with a £19m government investment funding research on at power use in HPC applications);

- More widely, Hartree's international relationships include the Barcelona Computing Centre in Spain and Lawrence Livermore National Laboratory in California, USA, and Hartree is an active participant in Horizon2020 funded Partnership for Advanced Computing in Europe (PRACE)[50] projects, where its focus is on supporting industry and on optimising software to run more efficiently on larger supercomputers, and
- Collaboration with Sellafield Ltd and the National Nuclear Laboratory is bringing together expertise from the Universities of Liverpool, Sheffield and Surrey to develop autonomous robots to tackle nuclear waste reduction. UoL is also one of four UK universities undertaking research which aims to deliver smarter, more reliable sensor based systems; ABB, British Geological Survey, CENSIS, Freescale, Rolls-Royce, Thales and Transport Scotland are involved. Internationally, the map in the HP&CC Appendix 8 demonstrates the global reach of UoL's Computer Science collaborations.

Developments in the Wider Funding Landscape

6.33 The resourcing base for the Theme is broad and diverse (Table 6-2). It includes, for example, institutional funding (e.g. for the two universities – in the case of the UoL some £27m pa from HEFCE alone – and £4m pa revenue from EPSRC for SCD/Hartree's activities). Specific 'strategic' investment from government (for the establishment and development of Hartree) is at over £170m, with industry investment steadily growing, not least £200m of in-kind support from IBM UK. Project funding is also significant, e.g. in support of low-energy research (Hartree, £19m), and the development of new BioFilms (SCD, £13m). Although Brexit could have implications in terms of partners' ability to access to European S&T (grant and business investment) funding sources in future, the wider base of our Theme's resourcing is significant, and at a scale to deliver change, impact and, crucially, certainty.

[50] An association of 24 European countries.

Table 6-2 Research funding by type of source for HP&CC (UoL)

Organisation Type		Sum of Total Funding (£)	Proportion of Funding
UK Government		27,087,223	74.6%
European Sector Bodies		3,318,156	9.1%
UK Business		1,971,497	5.4%
European Union		1,894,713	5.2%
UK Philanthropic		1,330,272	3.7%
European Business		332,783	0.9%
International Higher Education		100,355	0.3%
International Business		91,130	0.3%
UK Business		59,355	0.2%
International Government		37,796	0.1%
European Government		36,072	0.1%
International Sector Bodies		14,876	0.0%
UK Sector Bodies		11,437	0.0%
European Higher Education		7,579	0.0%
Grand Total		**36,293,244**	**100.0%**

Source: specially produced by University of Liverpool, 2017

6.34 While facilities are currently world-class the pace of technological change means that re-investment is required on a 4-year basis. This is a key focus for us.

Conclusion

6.35 Our HP&CC assets and capability are UK-leading and internationally significant. They provide a vital resource for delivering the prospective UK Industrial Strategy as the world undergoes the '4th Industrial Revolution' and as digital technology becomes ever more pervasive in the new 'globalised model'. As such, our HP&CC Theme has two roles to play. First, it provides the opportunity to build and grow an LCR-centred HP&CC 'sector' leading the thinking, advancement and commercialisation of HP&CC technologies. Second, it has the capability and capacity to act as a 'service' to the City Region economy, promoting, diffusing and embedding HP&CC methods and techniques across the LCR's industry and services bases, and establishing the UK's first cognitive business ecosystem.

7 Revising our Hypotheses and Ambitions, and Proposals for Action

Headline Messages

- Our SIA process was driven by three high-level hypotheses and ambitions
- The testing of these hypotheses has led to revising and sharpening our ambitions
- Partners have developed proposals to realise these ambitions and to yield regional and national economic and productivity growth plus achieve international impact
- Each theme has identified one flagship proposal to maximise the respective smart specialisation assets, capabilities and strengths and have commercialisation outcomes
- Partners have also developed cross-theme projects to exploit latent synergies
- Partners identified an additional hypothesis linked to the Industrial Strategy - that the LCR's advanced innovation ecosystem, cross-sector partnership and devolution/ governance arrangements make us ideally suited to adopt and apply an even greater place-based approach to delivering on the specific proposals set out in the SIA and wider commercialisation agenda, while also further strengthening external collaborations.

Findings against the Starting Hypotheses and the Ambitions

7.1 Our SIA process has been driven by three high-level hypotheses and their associated ambitions, originally defined when developing our Expression of Interest to undertake a Round 2 SIA. The process has been one of 'entrepreneurial discovery', by working together to understand the scope for linking and creating synergies *across* our Themes being at least as important as understanding the capacities and capabilities we bring *within* each Theme area. This has heightened understanding of both what we need to do to 'stay ahead' in the areas where we already have comparative advantage and how to develop 'routeways to new excellence'.

7.2 Table 7-1 indicates, all three of our original hypotheses remain valid at their core, but we have sought to sharpen and clarify these where appropriate. Similarly, our ambitions remain largely as anticipated, but again have been refined to reflect the learning and understanding we have experienced as we look to progress our agendas in the future.

7.3 Moreover, the positivity of the SIA process has given rise to a new fourth hypothesis to explore with government, and directly linked to the Industrial Strategy: that **the LCR's advanced innovation ecosystem, cross-sector partnership and devolution/governance arrangements make us ideally suited to adopt and apply an even greater place-based approach to delivering on the specific proposals set out in the SIA and wider commercialisation agenda, while also further strengthening external collaborations**. The associated ambition is: **For the LCR to be a national exemplar of place-based and innovation-driven economic growth that supports the UK Industrial Strategy**.

Table 7-1: Initial, revised and new hypotheses and ambitions

Initial Hypotheses & Ambitions	Lessons & Responses	Revised Ambitions
Infection **Initial Hypothesis:** Linking and enhancing the LCR's world-leading knowledge, research and facilities in Infection can, with wider collaboration, catalyse an internationally significant cluster of companies that will generate economic productivity and growth for the LCR, Northern Powerhouse and the UK. **Initial Ambition:** Support the development of a cluster of high-growth companies to take advantage of global market opportunities in Infection.	The SIA confirmed that the City Region has: • World-leading assets and expertise, with the largest concentration of translational-focused public sector RD&I infectious diseases expertise in the UK, and international science and innovation networks that are unbeaten in the field; • A century-long track record of academic-industry collaboration; and • An excellent current track record of accessing research funding from national and international sources. Partners learned that the City Region must: • Develop a targeted inward investment strategy that leverages its excellence in research into infectious disease, and the combination of world-leading facilities and expertise offered by the three Themes – by building on the achievements of and, lessons learned from, the Knowledge Quarter development; • Continue to invest in its research assets to maintain its world-leading status in infectious disease research; • Re-double its efforts to attract, develop, and retain the skills and talent required to grow the supply chain in the City Region; and • Ensure that relevant support regimes (access to finance, wider business support services, inward investment expertise, etc.) are in place if the growth of a locally based cluster of firms active in the Infection R&D space is to be realised.	**Revised Hypothesis:** Linking and enhancing the LCR's world-leading knowledge, research and facilities in Infection can, in partnership with identified 'anchor companies', catalyse an internationally-significant cluster of companies that will generate economic productivity and growth for the LCR, the Northern Powerhouse, and the UK. **Revised Ambition:** To consolidate the LCR's position as an international centre of excellence in tackling infectious diseases, and create a cluster of anchor and high growth companies to take advantage of global market opportunities in infection.

Initial Hypotheses & Ambitions	Lessons & Responses	Revised Ambitions
Materials Chemistry **Initial Hypothesis** Linking and enhancing the world class Materials Chemistry assets and capabilities in the LCR, and wider North of England, can deliver a step change in regional and national productivity growth, through competitive advantage in digital materials design. **Initial Ambition** Transform the productivity in Chemicals & Process Industries, and create a world-leading Fast Moving Consumer Goods (FMCG) cluster and IP pipeline.	The SIA confirmed that the City Region has: • World-leading expertise in materials chemistry; • A superb track record of accessing research funding from national and international sources; and • A unique Liverpool Model for university-industry collaboration which has been developed over several intermediate stages in the past 15 years. Partners learned that the City Region: • Has a significant opportunity to become a globally significant player in high-value chemical industries, underpinned by academic excellence; • Should move to exploit the unique and distinctive contribution that the Liverpool Model can make to the LCR+ area; and • Must ensure that relevant support mechanisms (access to finance, wider business support services, inward investment expertise, etc.) are in place to foster opportunities for new materials chemistry-related ventures.	**Revised Hypothesis** Linking and enhancing the world-class Materials Chemistry assets and capabilities in the LCR and the wider North of England can deliver a step change in regional and national productivity growth, through competitive advantage in digital materials design. LCR+ has a unique opportunity to create a world-leading cluster of high value chemicals production industries around our academic materials chemistry base and the Liverpool model, positioning LCR+ as a globally significant player in this hugely important sector. **Revised Ambition** To apply the LCR's world class materials chemistry capabilities and commercialisation model to provide transformational opportunities for mature UK sectors, create new high-growth industries, and become a recognised global leader.
High Performance & Cognitive Computing **Initial Hypothesis:** The nationally significant High Performance Computing (HPC) and cognitive computing e-infrastructure capabilities at STFC's Hartree Centre and elsewhere in LCR can scale and accelerate productivity, skills and growth across a range of industrial sectors, including Materials Chemistry and Infection.	The SIA confirmed that the City Region has: • An emerging cluster of HP&CC capability, which is already of national class and, in terms of computing power, is international class; • Achieved a major 'result' in attracting IBM to locate its UK R&D Centre alongside Hartree; • An opportunity for HP&CC in the LCR to be developed both as a 'sector' in its own right, and as a key 'enabling service' for the Infection and Materials Chemistry themes, and the wider economy. Partners learned that the City Region must:	**Revised Hypothesis:** The internationally significant High Performance Computing (HPC) and Cognitive Computing e-infrastructure capabilities at Daresbury (Hartree, Scientific Computing, and the Virtual Engineering Centre) support by academia and the supply chain in the LCR, and IBM's UK Research Centre, can scale and accelerate productivity, skills and growth across LCR's business sectors, including Infection and Materials Chemistry.

Initial Hypotheses & Ambitions	Lessons & Responses	Revised Ambitions
Initial Ambition: Ensure world-leading High Performance Computing and Cognitive Computing accelerates cross-sector growth, and supports the development of a world-class business cluster in disruptive technologies around Sci-Tech Daresbury	• Broaden the approach to include both industry and service sector user bases, and reflect the multi-partner grouping that LCR's HP&CC actors comprise. • Continue to work to ensure that the different components of its HP&CC offer are spliced together effectively; • Move the focus of HP&CC activity closer to the business density of the City Region; proposals for a Hartree presence 'in the city', and the Digital Innovation Factory will be essential for this to happen; • Ensure strong and vibrant links with centres of excellence elsewhere in the UK and internationally should remain a priority; and • Safeguard the future 'in-LCR' of IBM's R&D Centre and Atos operation, and the activities of others, by packing around these primes a resilient supply chain of local HP&CC providers and partners.	**Revised Ambition:** To harness the LCR's world-leading High Performance and Cognitive Computing capabilities to accelerate cross-sector growth and productivity, public sector transformation, and develop a world-class data-centric and disruptive digital technologies cluster.
		New Hypothesis The LCR's advanced innovation ecosystem, cross-sector partnership and devolution/governance arrangements make us ideally suited to adopt and apply an even greater place-based approach to delivering on the specific proposals set out in the SIA and wider commercialisation agenda, while also further strengthening external collaborations. **New Ambition** For the LCR to be a national exemplar of place-based and innovation-driven economic growth that supports the UK Industrial Strategy.

Developing and selecting Our Proposals for Action

7.4 The SIA process brought together key stakeholders who were not necessarily always familiar with each other's assets and expertise. This was particularly the case when people from one specialism had the opportunity to meet their peers from another. The process also provided a new context within which long-standing collaborators could think through how best to develop the City Region's innovation ecosystem – empowered by devolution and unconstrained by the dictates of individual funding regimes.

7.5 The SIA process involved a series of thematic and cross-cutting workshops, which facilitated interaction between partners and the cross-fertilisation of ideas between themes. These workshops were followed up by site visits and bilateral and multilateral business meetings at which partners, and potential partners, discussed various ideas and projects at different stages of development. The scale and range of ideas discussed is indicative of the healthy pipeline of investable ideas and proposals in LCR.

7.6 Following the workshops and meetings, key partners reviewed project proposals to inform the development of the propositions that are set out below, which were reviewed against the following criteria:

- Is the project clearly based on science and innovation – rather than broader economic development?
- Does the project build on a demonstrable unique strength of the Liverpool City Region?
- Is the proposal based on world-leading science and innovation activity?
- Does the proposal have strong business and/or wider sponsorship?
- Is the proposal strategically aligned – with the Government's Industrial Strategy, Innovate UK's investment priorities, the Liverpool City Region Growth Plan, and the prime economic capabilities identified in the Northern Powerhouse Independent Economic Review? and
- Will the project yield significant impact locally, nationally and internationally, in terms of quantifiable outcomes, e.g. jobs/GVA/productivity, and qualitative outcomes, e.g. profile and reputation?

Our Proposals

7.7 The tables below provide summaries of our three proposal, driven out of the SIA process, to take our Science and Innovation Audit forward. Appendix 9 provides more information on the business cases for each of the three proposals.

Infection

Project Title	Centre of Excellence for Infectious Diseases Research + (CEIDR +)
Leads	Liverpool School of Tropical Medicine (LSTM) and the University of Liverpool (UoL)
Partner Organisations	**Core Partners** Royal Liverpool & Broadgreen University Hospital, Alder Hey Children's Hospital Trust, Liverpool Clinical Laboratories, The Innovation Agency **Affiliate partners** Liverpool Health Partners, Liverpool Knowledge Quarter **Business** Collaborative programmes with large pharmaceutical companies with operations within and outside the Liverpool City Region; local companies include Seqirus, AZ/Medimmune and Elanco; plus SMEs including MAST Diagnostics, Perfectus Biomed, Arcis Biotechnology, Biofortuna, Pro-lab Diagnostics and Global Biodiagnostics, Gencoa and Vodus Medical and digital health companies.
Strategic Case	The LCR forms one of three main concentrations of health and life science clusters in the UK. In this context, LSTM and UoL Liverpool have the largest concentration of translational-focused public sector R&D&I infectious diseases expertise in the UK. CEIDR will unlock the economic growth potential of this world-class research asset to develop innovative healthcare technologies, working closely with Liverpool Health Partners, Liverpool City Region LEP, local NHS Trusts and Industry, among others, to develop and support the implementation of industry, academic and NHS innovations. The exemplar proposals to be taken forward by CEIDR will collaborate with large pharmaceutical companies and high-growth SMEs attracting investment, creating local employment and maximising economic benefit.
Project Description	CEIDR's first phase (2017-2020) will build a portfolio of projects with collaborating companies. This will catalyse the second phase (post 2020) where we anticipate a new bespoke facility stimulated by increased SME spinouts and demand from collaborating companies for co-location. Three, among many possible CEIDR projects, are outlined as exemplars: • Discovery and Development of Next Generation Anti-infective Drugs • Discovery and development of vaccines • Consumer products for prevention of emerging arboviral diseases (ZIKA+) Two other projects illustrate the ways in which CEIDR will interact with the other two SIA Themes: "Nano medicine" and the intended "Biofilms Innovation and Knowledge Centre" involving an extensive national consortium led by UoL. The first phase of CEIDR will create 4 posts to engage companies and support their R&D projects and product development programmes. Based on the size and scope of Liverpool's Infection capacity, CEIDR is forecast to create 252 gross direct and indirect jobs (138 net additional) and £42 million in cumulative net additional GVA in the region over 10 years.
Timeline and Milestones	**2017-2020**: CEIDR's first phase, including Discovery and Development of Next Generation Anti-infective Drugs, Discovery and development of vaccines, Consumer products for prevention of emerging arboviral diseases (ZIKA+), and Nano medicine and Biofilms Innovation and Knowledge Centre. **Post-2020**: CEIDR's second phase, including a new bespoke facility for spinouts and SME co-location.

Materials Chemistry

Project Title	MIF Nexus
Leads	Co-leaders University of Liverpool & Unilever
Partner Organisations	**Core Partners**: University of Liverpool; Unilever; NSG Pilkington. **Affiliate partners (initial):** Croda; Bristol Myers Squibb; ACAL energy; C Tech Innovation; Chemistry Growth Partnership; Ceres Power; Gencoa / Pegasuss; ITM Power; Johnson Matthey; Liverpool Chirochem; Morgan/Ceramtec; National Nuclear Laboratory.
Strategic Case	Materials chemistry is a key driver of competitiveness in a wide range of export-intensive UK industries: the chemicals industry itself, fast moving consumer goods, automotive, aerospace, nuclear/other energy and many others. As such, this a key element of the government's Industrial Strategy "driving progress in technologies where the UK can build on our existing areas of industrial and research strength". Advances in materials chemistry have the potential to provide transformational opportunities for mature industries and drive the growth of entire new industries with major export potential, notably in new low emission energy technologies and advanced energy storage. A new cutting-edge collaborative research and open innovation facility has come on-stream in 2017 that is capable of high-throughput automated and computationally enabled materials chemistry discovery and applications testing. This is the Materials Innovation Factory (MIF) - the product of a 20-year strategic partnership between Unilever and the University of Liverpool. The facility has co-location 'innovation hotel' facilities for 300 users (120 industry/180 academic) and combines world-leading academic thought leadership with robust and streamlined industry-grade management, organisational and data-handling capability. The combined impact of this integrated innovation capability is the fastest, cheapest and most precise materials discovery, applications testing and prototyping in the world. As such, the MIF is an exemplar of Industry 4.0 innovation capability (the use of advanced computation and automation to drive productivity growth and competitiveness). However, MIF focusses on one sector (Fast Moving Consumer Goods) and therefore cannot service the very wide range of industries and innovative start-ups that stand to benefit from a broader scope MIF Nexus facility able to meet both UK and global demand.
Project Description	The proposed project was developed directly from the SIA process. MIF Nexus will support: major companies through access to shared robotic testing, scale-up and proof-of-concept facilities; SMEs through access to synthesis and characterization services and facilities they would not otherwise afford; Start-ups and spin-outs through access to expertise and pump-priming support. It will comprise a Materials Design Engine focussed on academic research of industrial relevance and several Materials Applications Engines specific to industry sectors. The integrated facility will help to de-risk investment in new materials for a wide variety of applications, most importantly in a manner that will facilitate investment in major transformational and potentially disruptive technologies of global significance. This will be achieved by decreasing the levels of investment faced for these high-reward opportunities in a manner unique to this facility. As such, MIF Nexus will create a virtuous circle of cumulative economic impacts based on attracting risk capital able to exploit this unique 'investment ready' translational facility. The facility business model is based on accelerating the development of new advanced materials, creating a commercial capability in materials design that will attract investment, encouraging corporate re-location and, itself, will generate revenue from services provided - funds for re-investment in evolving the facility's capabilities over the long-term. (Theme will also actively lead/support our SIA's cross-cutting projects with the two other Themes. These projects are BioFilms (led jointly with Infection), Product Design/Efficacy through Optimising Placement and Drug Delivery Technologies/Antimicrobials (led by Infection).
Timeline and Milestones	Planning and scoping of the project will begin in late 2017, with a start-date for build in mid-2018 and start of operations in mid-2020, although an earlier start on site is achievable depending on decision making timescales.

High Performance and Cognitive Computing

Project Title	'Deep Change'
Lead	STFC Hartree Centre
Partner Organisations	The wider HP&CC cluster in the LCR - STFC's Scientific Computing Department (SCD), the Virtual Engineering Centre (VEC), Departments/Schools of Computing at Liverpool and Liverpool John Moores Universities, IBM UK's Research Centre, and Atos
Strategic Case	The technology and methods which high-performance and cognitive computing (HP&CC) offer have the potential to alter radically (i) the ways firms run their businesses, and (ii) how public services are developed and delivered for their populations. HP&CC technologies allow for greater insight and intelligence to be extracted from data routinely collected by business and public sector agencies, allowing products and services to be re-positioned more quickly and more appropriately than previously possible. The ability to use HP&CC to model and simulate real-world systems – for example to understand flows in manufacturing, transport, or infection system environments, or to test virtual components before they are produced physically – means products and services (private and public) can be developed more quickly, more cost-efficiently, and more predictably, so reducing risks and barriers to innovation. Such shifts in the conventional ways we develop things has the potential to transform the way businesses and public services perform and operate across the UK. These greater insights and improved efficiencies have a potential for real and substantial improvements in speed-to-market, operating efficiency and productivity, all delivering substantial benefits to the businesses, communities, and workers. For our City Region, our growing HP&CC cluster, built on Hartree, IBM's sole research facility in the UK, and co-location with major HP&CC vendors such as Atos means we are positioned pre-eminently to show how pervasive adoption of HP&CC technologies can benefit our City Region, as well as being progressed and mainstreamed for national benefit.
Project Description	Deep Change is a path-finding three-stage programme designed to defuse and embed a pervasive understanding of HP&CC technologies and methods across all parts of the Liverpool economy, and develop a model for eventually national application. Building on existing HP&CC activity, it will be delivered using the hardware platform expertise of Hartree, the fundamental science capabilities of SCD, the applied project experience of the VEC, the international understanding of HP&CC technologies and the proposed Digital Innovation Factory in Liverpool University, and the inclusive outreach expertise of Liverpool John Moores, Deep Change will have three phases; (i) *Discovery*, a broad-based outreach component, designed over a five-year period to benefit 12,500 firms, organisations, and/or individuals, focused on developing understanding of HP&CC technologies and their benefits; (ii) *Accelerator*, identifying from the pool of *Discovery* beneficiaries some 200 organisations (both private and public sector) with potential to engage with HP&CC major vendors (e.g. in Liverpool, IBM UK and Atos in particular) to co-address HP&CC challenges and opportunities; and (iii) *Rising Stars* which, from within the *Accelerator* cohort, will identify and develop 50 organisations with real HP&CC capacities and capabilities to offer expertise, services, and/or products at an international level. The Rising Stars will have the potential to create very significant volumes of higher value-added jobs, contributing directly to our economic well-being. The project will be focused on the City Region, but will operate with strong links to other part of the UK and internationally, especially in terms of where other major HP&CC vendors are located. (Separately the HP&CC Theme will also actively support our SIA's cross-cutting projects with the two other Themes. These projects are BioFilms (led jointly by Infection and Materials Chemistry), Product Design/Efficacy through Optimising Placement and Drug Delivery Technologies/Antimicrobials (also led by Infection), and Computational Solutions to Materials (led by Materials Chemistry).
Timeline and Milestones	Pilot programme to run Nov 17 – Nov 18. Programme mainstreaming, and delivery Jan 19 – Dec 21, with *Discovery*, *Accelerator*, and *Rising Star* components introduced sequentially.

8 To summarise . . . and then to make it happen

Key messages from our SIA Process

8.1 In terms of our three Theme areas, building on from our Starting Hypotheses, testing these against the data – quantitative and qualitative – and making sure our analyses are thoroughly checked and challenged by partners, our concluding messages are as follows:

- **For Infection:**

✓ Infection is a global problem, accounting for seven of the top 20 causes of mortality;

✓ The City Region has world-class facilities, expertise and track record in developing public-private partnerships, both domestically and internationally, in tackling Infection;

✓ Partners in the City Region have developed the 'Liverpool Advantage', an approach that supports research, innovation and product development for infection diagnosis, treatment and control;

✓ As well as generating greater local economic benefit by attracting firms in the global supply chain to the City Region, partners will enhance the global public good achieved by research led from the City Region, as proximity and improved collaboration should reduce the time it takes to move from initial findings to market;

✓ The University of Liverpool and Liverpool School of Tropical Medicine have formalised joint working by launching their 'Centre of Excellence in Infectious Disease Research' (CEIDR);

✓ The SIA process helped partners to identify areas where collaboration between the three SIA themes could add value to ongoing work and help to build a City Region offer based on a unique combination of world-leading research and innovation strengths;

✓ Interactions are being developed between CEIDR and the other two SIA Themes to facilitate development of products to prevent, treat or diagnose infectious diseases will need;

✓ CEIDR will work with businesses to harness partners' expertise, track-record in forming public-private partnerships, and pipeline approach to translate new products, and

✓ CEIDR will enhance the worldwide reputation of Liverpool and the LCR, through its work to tackle global diseases.

- **For Materials Chemistry:**

✓ Materials chemistry lies at the heart of several high value chemical industries and supply chains (e.g. aerospace and automotive);

- ✓ The University of Liverpool is world-leading in Materials Chemistry as evidenced by REF2014 and other metrics;
- ✓ The Materials Innovation Factory is built on the twin pillars of computationally-enabled materials design ("the materials design engine") and automated high-throughput applications development and testing (the "materials application engine");
- ✓ MIF is a unique LCR+ asset demonstrating the added value of University-industry collaboration, and is a strong and distinct spoke of the Royce institute;
- ✓ MIF will create academic benefit for the University and the wider global scientific community, and local economic benefit and high value jobs, ensuring competitive advantage for the industrial companies engaged;
- ✓ The Open Access Innovation model implemented in MIF for Fast Moving Consumer Goods (FMCG) can now be replicated for other materials chemistry-aligned high value chemicals industries (e.g. catalysis, pharma, coatings, energy storage);
- ✓ The LCR+ materials chemistry capability therefore builds knowledge leadership directly into UK value chains in a unique way, and
- ✓ Therefore, LCR+ has the opportunity to be a world-leading 'Industry 4.0' innovation centre for chemical industries through the development of a broader-scoped MIF-type facility.

- ■ **For HPC&CC:**

- ✓ Both as a technology and a market, HP&CC represents a major opportunity, globally and for the UK and its regions and devolved administrations;
- ✓ The combination of fundamental and applied HP&CC expertise in the LCR places it in the top three areas in the UK;
- ✓ Government's commitment to HP&CC in general, and its choice to invest at Hartree in particular is a major foundation on which to build;
- ✓ IBM UK Research's decision to co-invest at Daresbury as part of Hartree's development is an international endorsement of the sophistication and seriousness of the LCR's offer, and provides access to IBM's global bank of intellectual property;
- ✓ Some 160 firms with employment of about 2,200 are involved specifically in HC&CC markets and technologies in the LCR, and
- ✓ Investment in Hartree means the facility currently has a computing system in the world's 'top 25', representing a major capital and productivity asset on which to build to lever growth across multiple economic sectors. While individually these themes offer very real science, innovation and commercialisation opportunities going forward, equally important are the synergies and overlaps between them, plus associated collaborations, which our SIA process has shown to exist across them all.

8.2 On the process side, LCR partners' experience is that the audit – both as an analytical exercise and as a coming together to work creatively and cooperatively – has been a very positive experience, acting as a catalyst to form new relationships and strengthen existing ones. It has also highlighted the ongoing need to ensure effective engagement of SMEs to maximise local economic impact of our science and innovation strengths.

8.3 The evidence that our consortium has worked well practically, is to have achieved a very significant output in a relatively short space of time. Partners have been united in looking beyond their institutional and geographic boundaries to strategically consider the challenges of commercialisation, inclusive growth, and productivity at regional, Northern and national levels. Exploring cross-boundary issues and opportunities for our three Themes has been particularly rewarding and, much in keeping with smart specialisation principles, has helped to identify our 'new routeways to excellence'.

8.4 For this reason, it is our intention to continue to work as a consortium to take forward our SIA agenda using the governance and working arrangements developed through the audit process (see below).

8.5 By the same token, we have evolved, added to, and revised some of our associated thinking along the way. For example, our work on Infection highlighted the role this theme can play in raising our science and innovation profile internationally, while our work on Materials Chemistry suggested scope to potentially extend innovation models developed re. the Fast-Moving Consumer Goods sector across the wider manufacturing base. Our work on HP&CC has highlighted opportunities to further support public sector reform via big data analytics, whereas the initial mindset that these technologies were best applied to private sector activities. We will apply all of these lessons in the coming months and years.

8.6 Vital as the three smart-specialisation themes examined in this SIA are, they are also integral to levering cross-sector economic growth across the wider LCR innovation ecosystem. This will involve exploiting other LCR assets and capabilities, including, but not exclusive to, opportunities identified within the other Wave 2 SIAs that the LCR is involved in (i.e. Offshore & Subsea Technologies, and BIO-Economy), plus relevant potential Wave 3 SIAs. It will also involve linking to and building on other major innovation-related projects already approved and/or being delivered (e.g. LCR 4.0 and LCR Activate) plus prospective revenue and capital initiatives being considered for Single Investment Fund support and identified in the LCR Growth Strategy (and associated forthcoming Action Plan).

And making it happen?

8.7 As important as writing strategies and undertaking audits are, their real purpose is in informing the delivery of prioritised, evidence-based actions that will achieve meaningful impact.

8.8 In this context, there are two aspects of 'making it happen' we want to highlight in concluding this process, namely governance and indicative actions for our first 300 days.

Governance Arrangements

8.9 This SIA has been developed by the consortium of six core partners below. The process has worked smoothly and effectively to produce this document, and we are very keen to

maintain the momentum we have built as we go forward – working in partnership with government.

Table 8-1: Partners involved in developing this SIA

Liverpool City Council, on behalf of the Liverpool City Region Combined Authority; **Liverpool City Region Local Enterprise Partnership;** **Liverpool School of Tropical Medicine;**	**Science and Technology Facilities Council;** **Unilever plc, and** **University of Liverpool.**

8.10 Accordingly, we intend that our forward SIA activities continue to be overseen by a slightly modified Executive Group comprising the following high-level actors, whose involvement reflects our commitment to realising the SIA ambitions as an integral element of our City Region's wider forward agenda:

- Professor Janet Beer, Vice Chancellor, University of Liverpool;
- Ged Fitzgerald (Chair), Chief Executive, Liverpool City Council;
- Dr. Jon Hague, Vice President Operations Open Innovation, Unilever, and Chair of the LCR Innovation Board;
- Professor Janet Hemingway, Director, Liverpool School of Tropical Medicine, and
- Professor Susan Smith, Head of STFC Daresbury Laboratory.

8.11 The SIA's Executive Group will operate as a as a dedicated Sub-Group of the Liverpool City Region's Innovation Board, facilitated by the LCR Local Enterprise Partnership, and which is chaired by Dr. Jon Hague from Unilever, reflecting the Board's primary focus on commercialisation.

8.12 The Executive Group will be supported by a Project Delivery Group which will meet regularly to take forward and track the proposals identified in this SIA.

8.13 More generally, the SIA Executive Group will be underpinned by our wider SIA partnership structure, which has developed progressively over the last six months. This structure has three layers:

- Core Partners, comprising the SIA Executive Group's organisations, and select other bodies with a direct lead role in the ongoing direction and oversight of the SIA and its development and delivery;
- Delivery Partners, who have a direct role or responsibility for a specific SIA element and/or key project, and
- Wider Enabling Partners, both regionally and nationally, who do not have an immediate, direct role in the SIA, but nevertheless have clear strategic/operational interest in its forward development and delivery, the changes it will bring about, and/or key constituent projects or components.

8.14 This integrated partnership structure is set out in Appendix 1.

Our First 300 Days

8.15 Over the next 10 or so months, we will be taking our SIA forward in the following ways:

- Following approval by BEIS of our SIA, we will have a formal launch event in early Autumn 2017 to signal publicly that our SIA is 'up and running', and now part of our strategic

infrastructure for the City Region – this will form part of ongoing work to build and strengthen partnership working;

- Building on from this, in Autumn 2017 we will launch a cycle of six-monthly visits to the LCR, inviting partnerships from other UK (and potential international) areas to come to Liverpool, see first-hand the SIA-driven projects we are progressing (and their lead organisations), and to start to build the virtuous circles of knowledge- and experience-sharing with science and innovation communities elsewhere;
- Throughout late Summer and early Autumn 2017, we will move to implementation with our Theme proposals, and their component parts, developing this through a formal business planning process, ready for practical launch in late Autumn. We are mindful of the need to make sure that the phasing of our implementation is well-managed, so there will be clear prioritisation of activities as each one is launched;
- As implementation commences, we will put in place a formal monitoring and evaluation plan so that the economy, efficiency, and effectiveness of our SIA objectives and activities can be tracked, and their value assessed;
- We will firmly commit to our SIA Executive meeting on a four-weekly basis following SIA approval, moving to six weekly by late autumn, to ensure implementation is being achieved as intended, and
- In early 2018, we will start looking at producing a *'One Year On'* SIA update report and to present this at a stakeholder event that could potentially form part of the International Business Festival in Liverpool in June 2018. Partners will also engage with Innovate UK and other stakeholders to maximise the impact of this event. We will give detailed consideration in due course to the content of the update, but it may be appropriate to emulate something like the Massachusetts Innovation Index, which on an annualised basis reports on how a defined set of science and innovation indicators are moving in response to innovation policy and action.

8.16 These activities will clearly need more detailed delineation and consideration as we move forward, and are simply intended to provide an insight into current thinking and reflect our commitment to future delivery, as, for us, the SIA is the start of a process, not the end.

Resources

8.17 This document is not a bid, or a formal case of funding. Rather, it is a clear, definitive, and assured assessment of our science and innovation strengths and potentials and, where through focused knowledge-based work driven in our City Region, we can play our part in building a thriving and resilient UK economy.

8.18 Much of what the document looks to do can be done in our own strength, and through our strong and productive links with partners. Resources are available, or likely, for a good number of the things we need and want to progress. But there will be occasions when requests and asks will need to be made of Whitehall. When these arise, we do not ask for special favours or 'its Liverpool's turn' goodwill. Rather, we ask only to be treated as equals, with decisions made on our evidenced excellence, and a clear and unambiguous commitment from us to deliver to quality, time, and with real innovation.

Closing Thoughts . . .

8.19 As we have commented elsewhere, we have found the SIA a very helpful process in forming new relationships and galvanising existing ones. Critically, the SIA process has provided a clear and definitive agenda – yes, on a consensual basis, but also playing to highest common factors – for us to take forward as a partnership. As a consequence, above-and-beyond the specific learning we have identified in each of our three Theme areas, we are now much more confident as a partnership in our ability to:

- Think innovatively, challenge constructively, and plan realistically. We are now clearer about our 'investability' as a centre for UK science and innovation, and confident fully in our own ability to deliver added value, arguably at a proportionally higher level than might be the case by re-investing in competitor areas which have already benefited from significant science and innovation funding;
- Work collectively for the long-term – to borrow a phrase from elsewhere our expectation is that *'the partnership that SIAs [verb] together stays together', and*
- Engage with businesses, large and sophisticated yes, but small and agile as well. Indeed, by bringing our mainstream business support efforts alongside our specific SIA Ambitions we anticipate a very significant increase in our ability to scale and grow our SME sector.

. . . and Accepting the Challenge

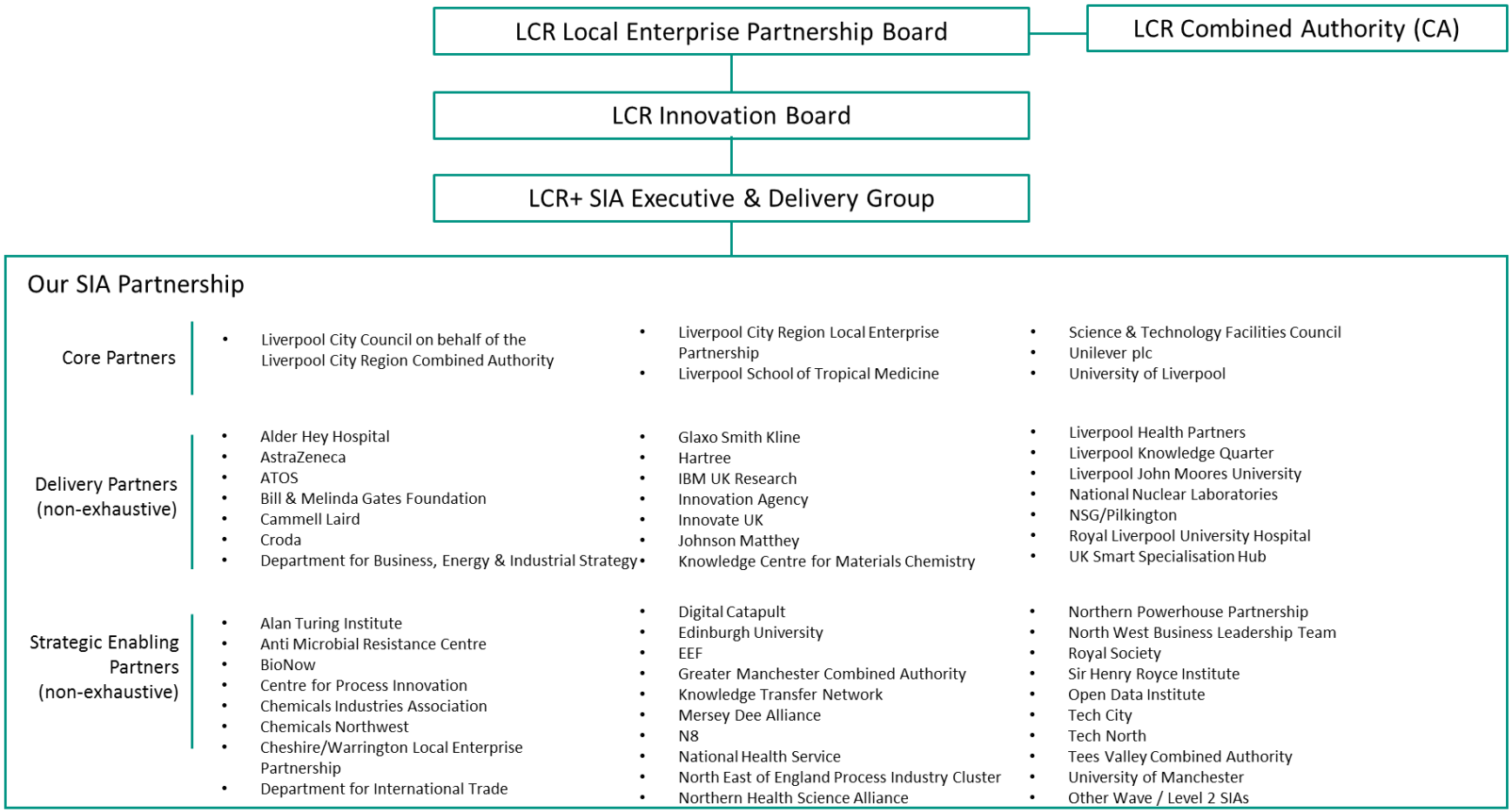
8.20 In closing, the development and implementation of this SIA presents a major opportunity for our City Region, and those organisations within it working to advance science and innovation for the inclusive benefit of its people, businesses, and wider economy. In a world of increasingly rapid market and technological change, where we must be ever more expert, agile, and foresighted, this SIA provides the basis for us to argue our case for science and innovation with commitment, conviction and enthusiasm.

8.21 Through the formation of our SIA Executive Group, lead partners have already committed actively to this SIA, and in partnership with government will provide the resources to carry our SIA Ambitions forward. Wider partners are also now in place alongside the Executive Group to provide their inputs, support, and capabilities to drive the SIA forward.

8.22 Whatever the scope and scale of the part you can play in our SIA, we hope you will feel able to play it, and to work with us to deliver our SIA ambitions. This is because they matter and can make a difference, not just for our place – the Liverpool City Region – but also for the wider North and indeed the rest of the UK.

Appendices

Appendix 1: Governance arrangements and key stakeholders

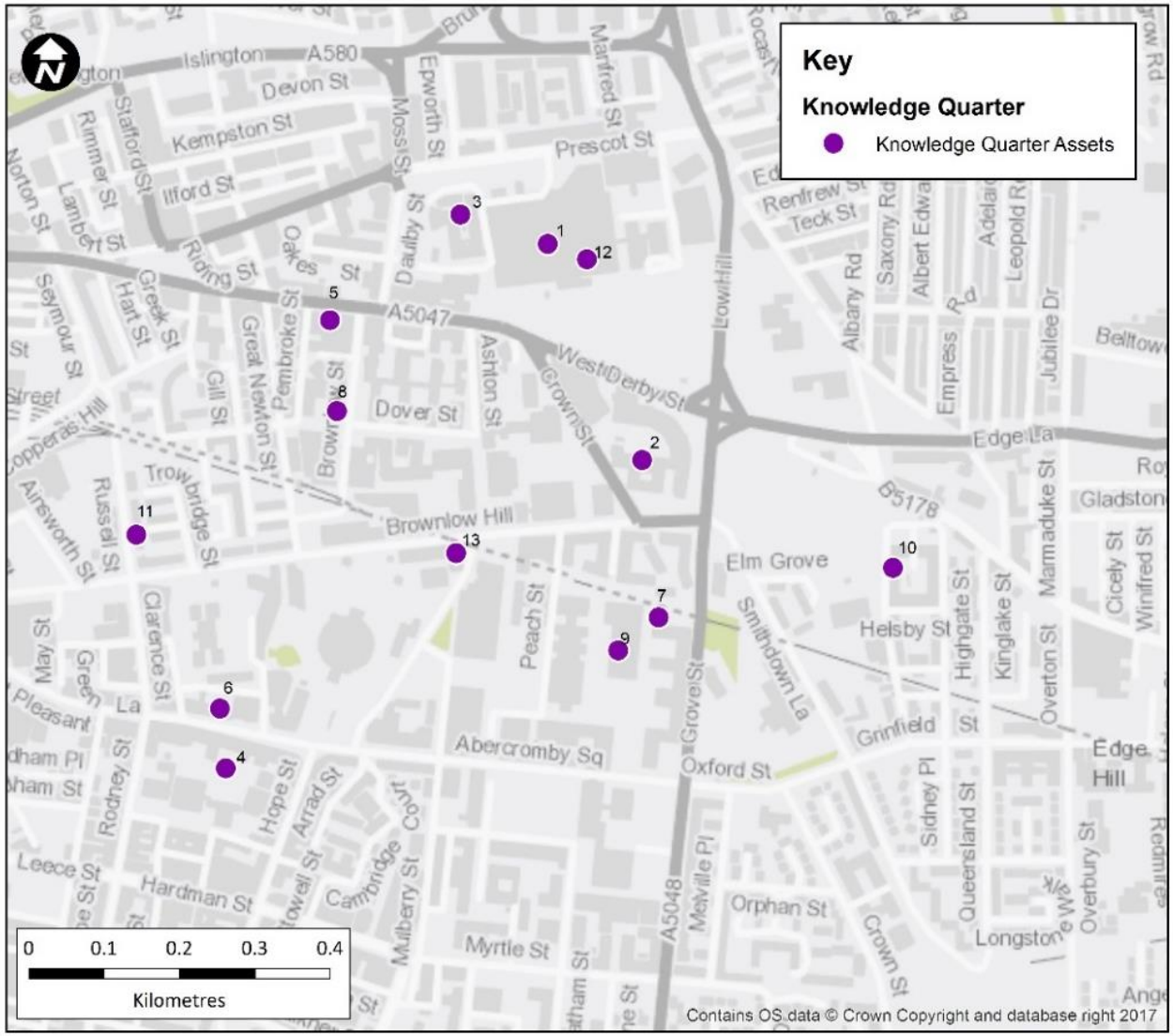


Appendix 2: Key economic characteristics and comparator city regions

	Liverpool City Region	Greater Manchester	Leeds City Region	D2N2	Sheffield City Region	North East	Greater Bham & Solihull	West of England	England
Economically Active*	718,700	1,356,700	1,519,400	1,102,500	891,700	970,600	953,000	595,800	28,001,500
Economic Activity rate*	72.3%	75.2%	77.0%	78.2%	74.8%	76.1%	73.9%	80.2%	78.1%
Economically Inactive (working age population) *	266,200	437,400	440,000	296,300	290,800	295,700	325,500	141,800	7,553,100
Economic Inactivity rate*	27.7%	24.8%	23.0%	21.8%	25.2%	23.9%	26.1%	19.8%	21.9%
In Employment (working age population) *	658,000	1,241,800	1,397,100	1,017,300	811,300	879,000	858,800	551,400	25,640,300
Employees (%, working age population) *	89.8	86.8	86.2	87.4	86.0	89.3	88.0	85.2	84.9
Self-employed (%, working age population) *	10.0	12.8	13.2	12.0	13.4	10.0	11.7	14.4	14.6
Employment rate*	68.4%	70.5%	73.2%	74.8%	70.3%	70.9%	68.9%	77.2%	74.3%
Unemployment rate†	5.5%	6.3%	4.9%	4.3%	6.0%	6.8%	6.8%	3.7%	5.0%
Job Density‡	0.70	0.78	0.81	0.76	0.72	0.72	0.80	0.89	0.84
Business Count§	39,215	91,590	101,695	71,965	56,355	50,700	66,120	43,815	2,213,650
Share of All England Businesses (%)§	2%	4%	5%	3%	3%	2%	3%	2%	-
Business Density[1]	38.7	49.0	51.5	49.6	44.7	39.6	49.3	58.5	61.0
Earnings by place of work (weekly gross pay, £)[2]	504.10	499.00	501.90	492.00	492.20	493.90	535.20	493.90	544.20
Business Enterprise R&D Expenditure (BERD, £)[3]	553.87	201.06	399.42	1,260.66	170.72	321.87	389.27	1,021.90	811.05

* APS, January 2016-December 2016, numbers are for those aged 16 and over (unless otherwise specified), % is proportion of working age population (16-64);
† APS, January 2016-December 2016, % is proportion of economically active ‡ ONS job density, 2015
§ ONS UK Business Counts (enterprises), 2016
[1] ONS population estimates/APS, number of businesses per 1,000 of the working age population (16-64), 2015; [2] ONS Survey of Hours and Earnings, 2016 (work-place based); [3] ONS BERD and BRES data, 2013 (£ per FTE employed)

Appendix 3: Map of Liverpool Knowledge Quarter



Key Assets

1. Accelerator and CEIDR (Centre of Excellence in Infectious Diseases Research)
2. Health & Life Sciences Campus, including the Liverpool Bio Innovation Hub and Biobank
3. Liverpool Clinical Laboratories
4. Liverpool John Moores University
5. Liverpool School of Tropical Medicine
6. Liverpool Science Park (Base of Liverpool Health Partners)
7. Materials Innovation Factory (MIF)
8. National Oceanography Centre
9. Open Innovation Hub for Antimicrobial Surfaces
10. Paddington Village
11. Senior City University Enterprise Zone
12. The Royal Liverpool & Broadgreen University Hospital and The Clatterbridge Cancer Centre
13. University of Liverpool

Liverpool City Region - Science and Innovation Audit 2017

Asset Register: The Knowledge Quarter

sdg economic development

Created by:	Last Updated:	Scale:
CLacy	23/05/2017	8,000

\\sdgworld.net\Data\Manchester\Users\CLacy\Private\LCR SIA Asset Map\Knowledge Quarter.mxd

Appendix 4: LCR+ SIA Conference 7 March 2017

Attendee	Organisation
Alan Evans	Wirral Council
Alan Welby	Liverpool John Moores University
Alice Lamb	Liverpool City Region Local Enterprise Partnership (LEP)
Alison Kennedy	Hartree Centre, STFC
Alison Mitchell	Sensor City
Andrew Basu-McGowan	Smart Specialisation Hub/Knowledge Transfer Network
Andy Cooper	University of Liverpool
Andy Grant	Atos
Andy Hulme	Cheshire & Warrington LEP
Andy Mitchell	Perceptive Engineering
Andy Rose	Liverpool City Region Local Enterprise Partnership (LEP)
Anthony Hollander	University of Liverpool
Bernard Molloy	Unipart
Beverly Taylor	Seqirus
Bob Crawford	C-Tech Innovation
Brian McCarthy	Knowledge Transfer Network
Caitriona Lacy	Steer Davies Gleave
Caroline corless	Liverpool Clinical Labroatories
Catherine Garnell	Liverpool City Council
Claire Trinder	Science & Technology Facilities Council (STFC)
Colin Sinclair	Liverpool Knowledge Quarter
Cristina Rosemberg	Technopolis
Darren Budd	BASF
Edward Pyzer-Knapp	IBM
Emma Hughes	Chase Innovation Partners Ltd.
Enitan Carrol	Alder Hey
Evan Grant	IBM
Gary Thompson	Liverpool City Region Combined Authority
Ged Fitzgerald	Liverpool City Council
Geoff Davison	Bionow
Grant Mitchell	Croda
Gregg Stott	Liverpool City Council
Hakim Yadi	Northern Health Service Alliance (NHSA)
Janet Hemmingway	Liverpool School of Tropical Medicine
Jiwu Ruan	Chirochem
John Conti-Ramsden	Knowledge Centre for Materials Chemistry
John Stairman	Amec Foster Wheeler
John Whaling	Liverpool City Region Local Enterprise Partnership (LEP)
Jon Hague	Unilever
Jonathon Mitchener	Innovate UK
Karen Linley	University of Liverpool
Katharine Robertson	Science & Technology Facilities Council (STFC)
Katherine Tomlinson	Flexera Software
Kim MacLean	Smart Specialisation Hub/Knowledge Transfer Network

Attendee	Organisation
Lee Omar	Red Ninja
Lien Ngo	Innovate UK
Mark Bankhead	National Nuclear Laboratory
Mark Basnett	Liverpool City Region Local Enterprise Partnership (LEP)
Mark Dickens	St.Helens Council
Mark Forster	Science & Technology Facilities Council (STFC)
Mark Matthews	Steer Davies Gleave
Mark Newman	Unilever
Marten Wijdekop	Centre for Process Innovation (CPI)
Martin Thompson	Liverpool City Council
Massimo Noro	Unilever
Matt Chapman	Knowledge Transfer Network
Matt Rosseinsky	University of Liverpool
Michael Contaldo	New Economy Manchester
Michael Gleaves	Hartree Centre, STFC
Mike Tobyn	Bristol Myers Squibb
Neil French	University of Liverpool
Neville Freeman	Nanoflex
Nick Goldspink	N8
Nick van DIjk	ITM Power
Nigel Jones	Department for International Trade
Paolo Lisboa	Liverpool John Moores University
Paul Jeffrey	Technopolis
Penny Wilson	Innovate UK
Peter Jackson	Anti-Microbial Resistance Centre, Alderley Park
Peter Timmins	LCR Health & Life Science Board
Peter Winstanley	Liverpool School of Tropical Medicine
Rick Holland	Innovate UK
Ronan McGrath	University of Liverpool
Ross Burton	Smart Specialisation Hub/Knowledge Transfer Network
Samantha Westgate	Perfectus Biomed
Sarah Jackson	University of Liverpool
Scott Dickinson	Steer Davies Gleave
Sheila Honey	Department for Business, Energy & Industrial Strategy
Simon Pringle	Steer Davies Gleave
Simon Reid	Liverpool City Region Local Enterprise Partnership (LEP)
Stephen Barnwell	Unilever
Steve McBride	Knowledge Centre for Materials Chemistry
Steven Powell	Royal Liverpool Life Sciences Accelerator
Su Varma	NSG Pilkington
Susan Smith	Science & Technology Facilities Council (STFC)
Susan Suttle	University of Liverpool
Tim Leather	Halton Council

Summary of Discussions

Key points raised by workshop speakers and participants were as follows.

- **Ged Fitzgerald**, Chief Executive Liverpool City Council and Head of Paid Service Liverpool City Region Combined Authority, opened the workshop by contextualising the discussion. He highlighted that while LCR has considerable scientific and innovation strengths, it has a deficit of 18,000 businesses relative to the UK average. Partners in the City Region are working to address this gap, and the SIA is an important part of that work.
- **Rick Holland**, NW Regional Manager Innovate UK, noted that increased funding for science, and research and innovation is the first pillar in the Government's emerging Industrial Strategy. He concluded by highlighting 'live' and 'up-and-coming' calls for bids for Innovate UK funding in relation to manufacturing and materials, infrastructure systems, health and life sciences, emerging and enabling technologies, and an open bidding round.
- **Prof. Anthony Hollander**, University of Liverpool, reported that Liverpool is developing its 'model' for research and innovation with the Materials Innovation Factory, and needed to develop collaboration between the SIA's three themes: Materials Chemistry, High Performance Computing & Cognitive Computing, and Infection.
- **Simon Pringle**, SDG Economic Development, set out the challenge for the day. The SIA needs to highlight the City Region's distinctive offer as a cluster of pure and applied excellence that is globally connected; plus the 'public good' impact of the Liverpool School of Tropical Medicine.
- **Prof. Ronan McGrath**, University of Liverpool was the theme lead for the breakout session on Materials Chemistry. The session covered many issues, including the development of relationships between research and innovation capability in the City Region. Specific ideas arising out of the session included: remote access, an insight service, development of links between the 'Liverpool Advantage' (faster, cheaper and more accurate materials chemistry) and venture capital and supply chain development. The session also highlighted the potential to use cognitive computing (from Hartree) to address the complexity challenges associated with materials chemistry.
- **Dr. Katharine Robertson**, Science & Technology Facilities Council, was the theme lead for the breakout session on the High Performance Computing & Cognitive Computing. The session learned that there are four main strands to Hartree's work: healthcare, materials chemistry, engineering and enabling technology. Hartree is the first presence of IBM Research in UK and, as such, the co-investment of IBM and Government is genuinely unique. The group discussed the need for the SIA to develop an offer that is built on accessibility, availability and affordability – which is promoted through greater visibility. The session highlighted the need for case studies to demonstrate the opportunities available and the need to develop a 'roadmap' for potential projects. It also raised the importance of skills to the development of the City Region's offer.
- **Prof. Janet Hemingway**, Liverpool School of Tropical Medicine, was the theme lead for the breakout session on Infection. She introduced the Centre of Excellence in Infectious Diseases Research (CEIDR), a collaboration between the University of Liverpool and the School. The session highlighted the City Region's world-class facilities and expertise, and its track record in developing

public-private partnerships, both domestically and internationally. An area for improvement was identified as the time taken to move from proof of concept to adoption – it was indicated that stronger links with industry could help improve performance here. The session discussed opportunities for greater collaboration with the City Region's Materials Chemistry and High Performance Computing & Cognitive Computing. The ideas included working with Hartree on modelling movement (physical activity and infection mapping) and virtual screening, and collaboration with colleagues working in Materials Chemistry in relation to materials for formulation, nano-medicine to reduce toxicity and dosage, surfaces, and drug delivery systems to reduce the need for cold chains.

- **Attendees then joined a plenary session** facilitated by Simon Pringle. The discussion explored synergies between the three themes, along with issues related to the wider operating environment. Issues raised included access to venture capital and investment; skills development, attraction and retention; the relatively low-cost business environment that the City Region offers; and how business might access the City Region's expertise, including via a one-stop shop, remote/digital access, and a 'research hotel'.
- **Dr. Jon Hague**, Vice President Operations & Open Innovation Unilever and Chair of the Liverpool City Region Innovation Board, closed the session by emphasising the SIA's role in helping to generate economic prosperity in the City Region and the North. He highlighted that the City Region is world class in Materials Chemistry, High Performance Computing & Cognitive Computing, and Infection and must market these strengths effectively. He also noted the need for a clear single interface for industry to access the City Region's world-class science and innovation assets and expertise. He said the biggest worry or risk highlighted in the workshop was the issue of skills. He concluded with the message that the City Region needs to develop investable propositions that deliver an economic impact as a result of the SIA.

Appendix 5: Additional material relating to Chapter 2

Regional Trade Statistics

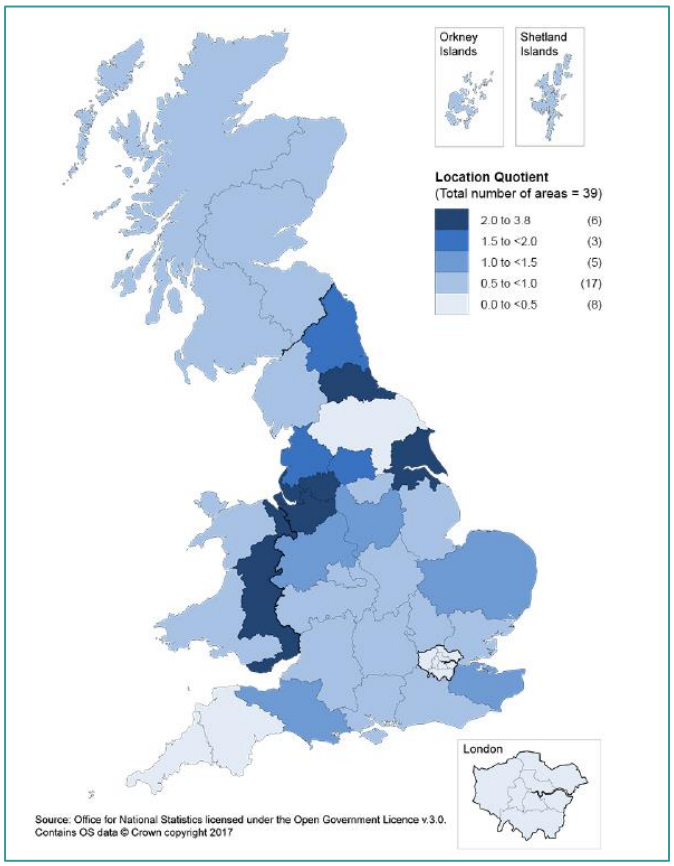
UK official statistics provide estimates on UK regions' imports and exports. These are only broadly indicative because they are based on allocating imports and exports to regions based on shares of employment in relevant sectors. One feature of all trade statistics is that whilst the coverage of physical commodities is comprehensive the coverage of trade in services is far weaker. In fact, no official estimates of regional trade in services are produced currently.

In the context of the themes in this SIA, this means that it is possible only to provide estimates of the North-West region's imports and exports for 'Chemicals and Related Products' (relevant to the materials chemistry theme). It is not possible to provide such officially-produced estimates for the High Performance and Cognitive Computing theme or for the Infection Theme.

Industry location quotients

The following map (Figure A5-1) shows how production of Chemicals and Chemical Products is distributed across the UK based on shares of employment. A location quotient of 1.0 indicates that the local share of total employee jobs in an industry is equal to the local share of total employee jobs relative to Great Britain. A location quotient greater than 1.0 indicates a relative concentration of the industry in the geographic area while a location quotient of less than 1.0 indicates there is not a relative concentration of that industry in the area. LQs are published for both employment and local businesses.

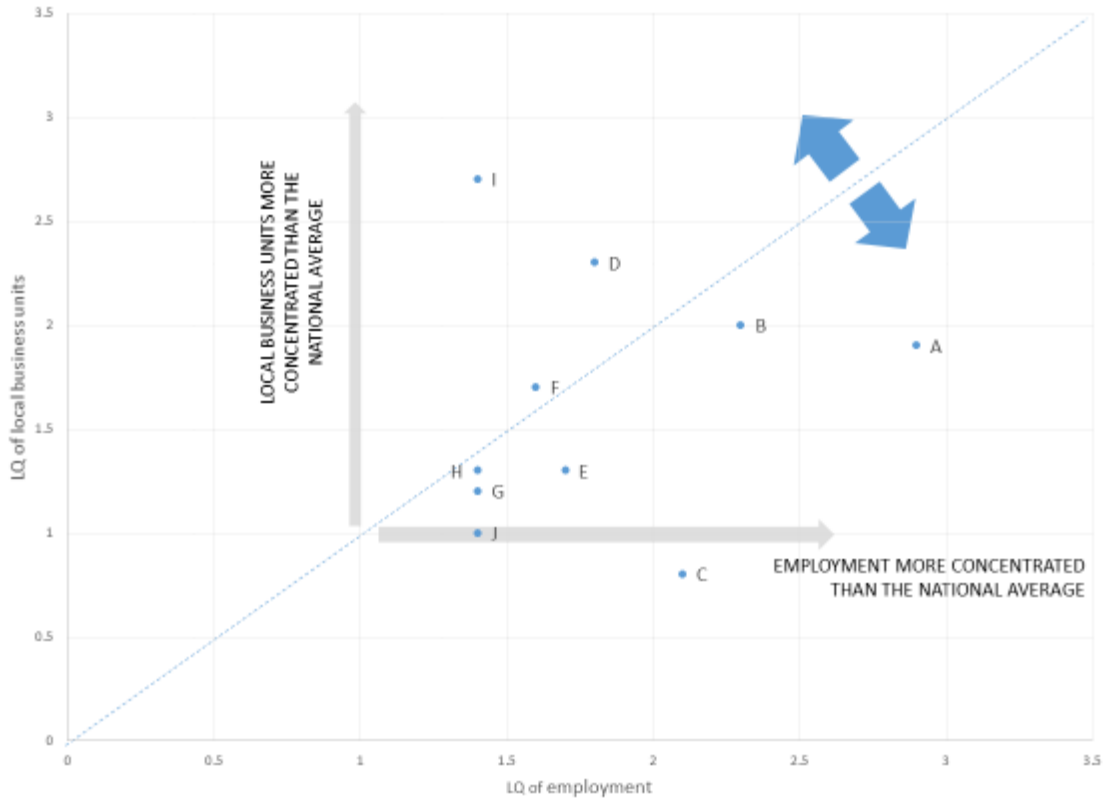
Figure A5-1: The national distribution of production in Chemicals and Chemical Products



Source: ONS (2017)Location quotient data and industrial specialisation for local authorities.

A closer look at LQs in the LCR can be found in the following plot of the employment LQ versus the local business LQ. This highlights the importance of the 'manufacture of basic pharmaceutical products and preparations' and 'manufacture of chemicals and chemical products' as concentrations of employment in the LCR.

Figure A5-2: Location Quotients for key sectors in the LCR



Source; SDG-Economic Development using data from the Technopolis data quarry

Index to points in the LCR LQ chart

(A) Manufacture of basic pharmaceutical products and preparations

(B) Manufacture of chemicals and chemical products

(C) Manufacture of motor vehicles, trailers and semi-trailers

(D) Gambling and betting activities

(E) Manufacture of other non-metallic mineral products

(F) Remediation activities and other waste management services

(G) Human health activities

(H) Security and investigation activities

(I) Manufacture of coke and refined petroleum products

(J) Public administration and defence; compulsory social security

The relationship between REF 2014 and Citation Performance evidence

The 2014 Research Excellence Framework (REF) provides a robust assessment of an SIA area's mix of performance broken down by scientific production (output counts), scientific quality (judged by peers and informed by metrics). These data can be used to demonstrate areas of research specialisation, and excellence, judged both against national and international standards.

The following analysis of REF 2014 data provides the baseline assessment, which, in line with the SIA guidelines, is augmented by data extracted from Elsevier SciVAL (using Scopus data). The SciVAL data, whilst more up-to-date, must be treated with some caution. This is because it is now the consensus view amongst senior research policy experts that research excellence is best judged (as with all science as a process) by peers – with these judgements *informed* by metrics but not driven exclusively by metrics[51].

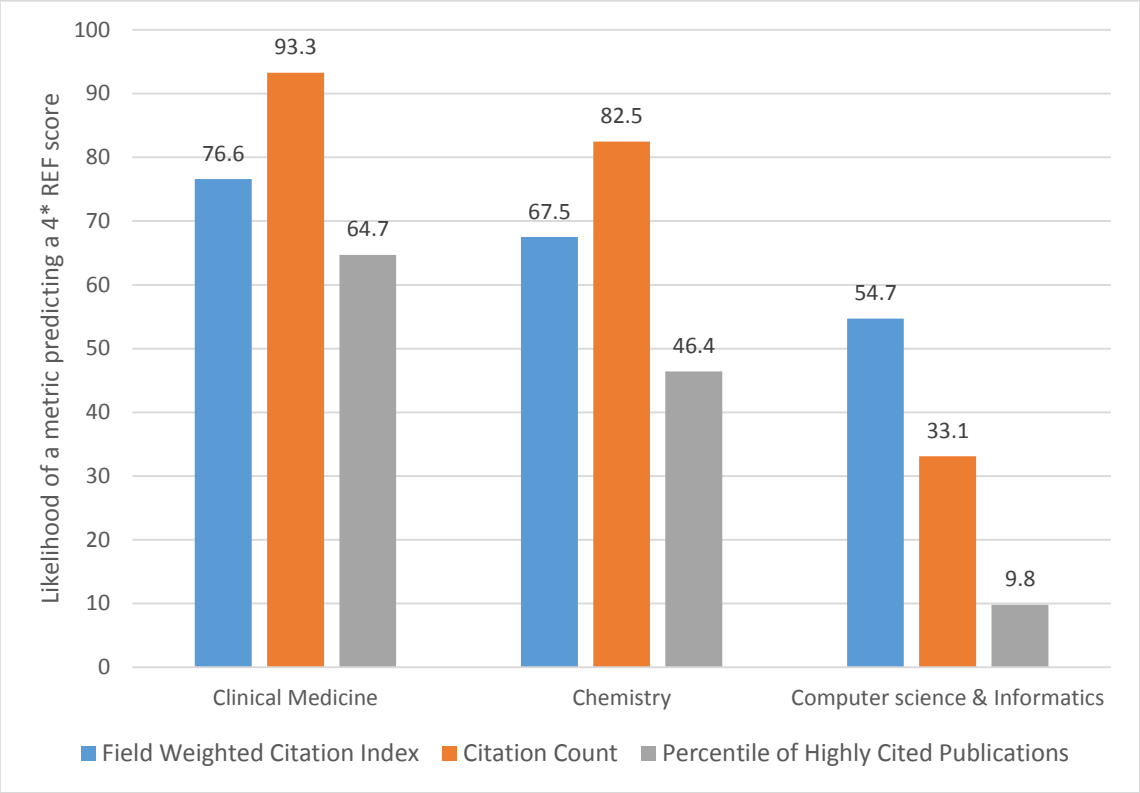
Given this, the SciVAL data are best treated as a means of confirming the continued relevance of the REF 2014 findings. SciVAL data also have the advantage of allowing the nature and extent of national and international *connectivity* in research to be demonstrated (by examining co-authorship patterns). This provides a more detailed picture of collaboration networks than the REF 2014 results, for which collaboration is covered in the 'environment' narratives rather than in headline metrics. In general, major scientific advances are associated with international collaboration. Hence the outputs from international projects tend to attract higher citation rates and generate place-based outcomes (for both research and innovation applications) that benefit from this international connectivity.

REF 2014 Evidence

The overall research 'footprint' of the City Region is easily grasped by considering its overall performance in REF 2014 in terms of the proportion of research outputs judged by peers to be world-leading in terms of originality, significance and rigour (4*) and internationally excellent in these criteria (3*). Figure A5-4 presents this profile for the University of Liverpool. This plots the UoL's excellence footprint by subject. This shows clear research excellence in subjects aligned with the three SIA themes.

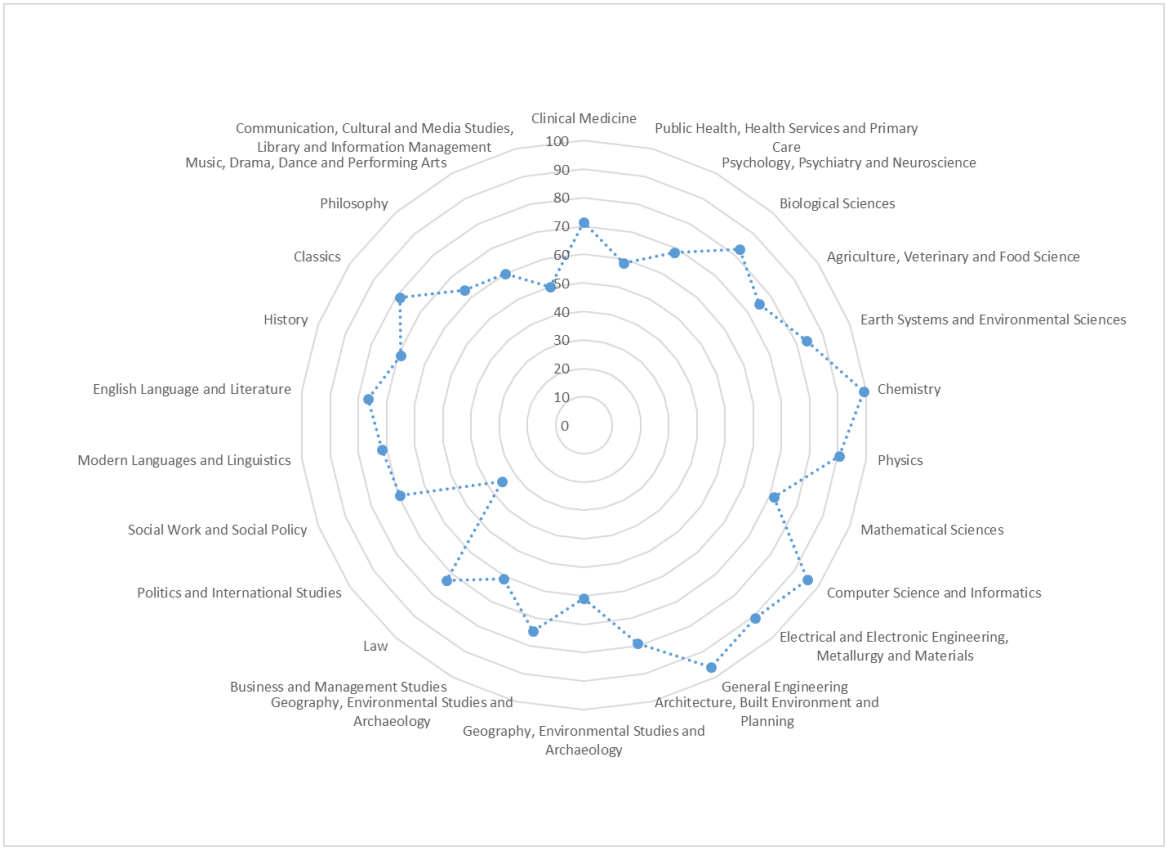
[51] See Wilsdon et al (2015) The Metrics Tide: Report of the Independent Review of the Role of Metrics in Research Assessment and Management. Higher Education Funding Council.

Figure A5-3: Correlation analysis of REF 2014 Scores and Metrics, all UK HEI institutions



Source: Correlation Analysis of REF 2014 scores and metrics, HEFC, 2015

Figure A5-4: Research excellence profile for the University of Liverpool



Source: SDG Economic Development analysis of REF 2014 data

The joint University of Liverpool - Liverpool School of Tropical Medicine REF 2014 submission, naturally, has a highly specialised research excellence footprint – which is presented in the following table. These data demonstrate clear international excellence in clinical medicine (which is the aggregate category that reflects the specific focus on infectious diseases). Nearly 55% of research outputs in clinical medicine are classed as internationally excellent (3*) and 16.4% as world leading (4*). Public Health, Health Services and Primary Care[52] scores more highly overall, with 32.1% of outputs classed as 'world-leading' (4*) and 42.7% classed as 'internationally excellent' (3*).

Table A5-2: Liverpool of School of Tropical Medicine's research excellence

	Proportion of Output 4*	Proportion of Output 3*	Proportion of Output 2*	Proportion of Output 1*	Proportion of Output unclassified
Clinical Medicine	16.4	54.8	27.1	1	0.7
Public Health, Health Services and Primary Care	32.1	42.7	22.9	2.3	0

Source: REF 2014 Data

Evidence from Scopus SciVAL

Given that the REF 2014 data relates to the period 2008 to 2013, a more up-to-date, though partial, picture of academic performance for the three SIA themes of Infection, Materials Chemistry, and High Performance & Cognitive Computing has been produced using Scopus SciVAL data. The results are in the following table. Because LCR research capability in these Themes is based on combining specific research capabilities with more general capabilities (for example, Materials Chemistry draws upon other aspects of Chemistry where necessary), we have produced a combined Subject and Theme-based perspective. These results cover the combined outputs from all LCR+ universities and include outputs from the Liverpool NHS Trusts.

Whilst SciVAL has existing categories for theme-specific research for Materials Chemistry and for infectious diseases there is no such direct match for high performance and cognitive computing. Consequently, a bespoke grouping of Artificial Intelligence, Hardware and Architecture, Signal Processing and Statistics, Probability and Uncertainty has been used as a broad indicator for High Performance and Cognitive Computing publications performance[53]. For the Infection Theme, the 'Infectious Diseases' category is augmented by 'Medical Microbiology' and by 'Immunology' and 'microbiology'.[54]

This category-based analysis is augmented by an alternative perspective based on the use of carefully selected keywords to identify research publications. This results in a more precise definition.

The key points to emerge are that:

[52] A joint submission with the University of Warwick in REF 2014.

[53] Publications associated with the Hartree advanced computing facility have not been included in this bibliometric analysis because these are mainly produced by researchers from other regions who use the facility rather than by researchers located within LCR+. This national use is, however, itself an indicator of the importance of this research asset.

[54] The SciVAL data also allow LCR research performance in Veterinary research to be assessed – performance here is strong with 8.4% of UK publications and 10% of outputs in the top 10% journals.

Table A5-2: Summary of combined academic publications performance for the SIA's three Themes, 2011-15

	Number of publications	Number of national (only) collaborations	Number of international collaborations	Share of UK publications	Share of national collaborations	Share of international collaborations	Number of publications top 10%	Share of publications top 10%	Field Weighted Citation Index	Field Weighted Citation Index (UK only)	Percent of pubs with national collaborators	Percent of pubs with international collaborators	Percent of publications in top 10%
Infection Theme													
Microbiology (Medical)	340	67	235	7.0	9.3	8.2	75	9.6	1.99	1.55	19.7	69.1	22.1
Infectious Diseases	1426	208	1106	9.6	11.2	11.2	315	11.1	2.00	1.82	14.6	77.6	22.1
Immunology and Microbiology	1411	254	1013	4.8	7.3	5.3	251	4.7	1.68	1.68	18.0	71.8	17.8
Total from above [55](see note 1)	3177	529	2354	6.5	10.5	7.41	641	7.1	1.86	1.71	16.7	74.1	20.2
Keyword based definition	946	184	621	4.68	7.39	4.9	42	1.0	2.35	2.03	19.5	65.6	4.4
Materials Chemistry Theme													
Keyword based definition	267	66	132	2.77	7.27	2.27	61	3.08	2.49	1.89	24.7	494	22.8
Chemistry	1161	208	687	2.4	4.3	2.5	204	2.5	1.62	1.19	17.9	59.2	17.6
Materials Science	1191	178	726	2.3	3.7	2.4	192	2.3	1.37	1.07	14.9	61.0	16.1
Materials Chemistry	214	32	125	2.1	3.1	2.2	29	2.0	1.41	1.05	15.0	58.4	13.6
Keyword based definition	267	66	132	2.77	7.27	2.27	61	3.08	2.49	1.89	24.7	494	22.8
High Performance & Cognitive Computing Theme													
Computer Science	2065	275	1141	2.5	4.1	2.7	302	2.2	0.96	1.01	13.3	55.3	14.6
Core theme areas combined (see note 1)	841	121	449	3.2	5.5	3.2	146	3.3	1.02	1.51	14.4	53.4	17.4
Keyword based definition	1747	273	1040	3.06	4.74	3.32	368	3.42	2.11	1.78	15.6	59.5	21.1

Source: Scopus SciVAL analysis provided by the University of Liverpool

- The **Infection** Theme performs strongly, with field weighted citation rates between 1.5 and 2.0 times higher than global averages for the most relevant subject classifications. This strong citation performance is associated with high percentages of papers with international collaborators and around one-fifth of these publications lying in the top ten per cent of cited papers. The more precise keyword-based definition yields an even higher field weighted citation rate of 2.35 times global averages[56];
- For the **Materials Chemistry** Theme, citation rates are between 1.4 and 1.6 times higher than global averages for these fields. The percent of publications with international collaborators is also high (between 58% and 61%), as are the percent of publications lying in the top ten per cent of cited papers. The more precise keyword-based definition yields a field weighted citation rate of 2.49 times the global average[5758]; and
- Regarding **High Performance and Cognitive Computing**, and as noted above, there are well-known limitations to the use of this type of data to track performance, mainly because conference papers play an important role and this type of output is not well covered by such data. This type of limitation is why the REF is the preferred method for assessing research quality. Despite this limitation, the more precise keyword based definition still yields a strong field weighted citation rate of 2.11 times the global average.

An international calibration of Field Weighted Citation Impact performance provides one indicator of research excellence. The following data use the specially developed keyword definitions described above. It plots collected Liverpool City Region performance against all other discrete universities and research institutes with a FWCI of 2.0 and above.[59]

Figure A5-5, the analysis for the LCR's **Infection Theme** (highlighted in black, and based on the targeted keyword definition), shows that performance is strong in global terms, but not dominant in the UK. In this case, the Liverpool City Region is the 7th ranked in the UK in FWCI performance and 44th in global terms. Similarly, the scale of research output is smaller than average (68 percent) and the proportion of papers with collaborators greater than average.

Identical analsysis in Figure A5-6 shows that the **Materials Chemistry Theme** (highlighted in black) is the strongest in the UK using the targeted keyword definition, ranked 13th in global terms and ahead of both Cambridge and Oxford (the only other UK universities with a FWCI above 2.0 and highlighted in grey). In comparison with these other elite institutions, the scale of both research teams and outputs is relatively small and the proportion of publications involving collaboration relatively high. LCR outputs are just over 30 percent of the average for all institutions with a FWCI of 2.0 and above.

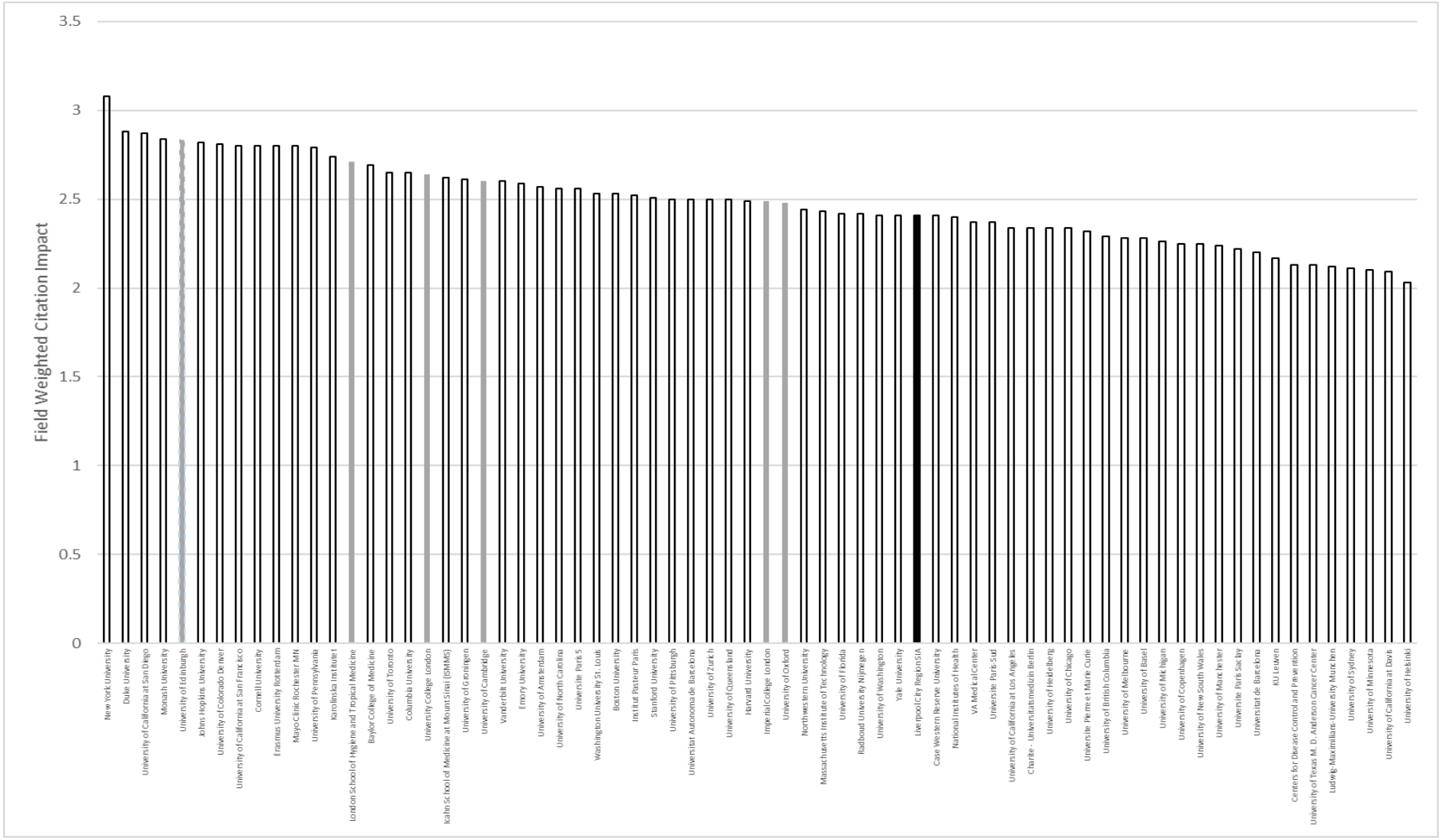
This type of analysis of FWCI performance in the High Performance & Cognitive Computing Theme is harder to produce for technical reasons associated with difficulties in handling joint publications, and also because of difficulties in capturing publications associated with government research facilities using SciVAL data.

[56] The keywords used were: Immunology, Molecular biology, Virology, Microbiology, Parasitology, Vector biology, Infectious diseases.
[57] The keywords used were: porous materials, polymer synthesis, supramolecular chemistry, carbon dioxide capture, energy storage and production, colloids, supercritical fluids, transition metal oxides, solid oxide fuel cells, MOFs (metal-organic frameworks), Superconductivity.
[58] The keywords used were: Big data, Analytics, Signal Processing, Data Science, High Performance Computing, Cognitive Computing.
[59] This analysis covers the period 2012 to 2016.

However, this ranking can be provided for universities in Europe, as in Figure A5-7 below. In this case, the Liverpool City Region is ranked number 10 in the UK and number 47 in Europe. Whilst the scale of outputs is, as with the other two Themes, relatively small, in this context, the proportion of publications with collaborators is broadly in line with the average for universities with a FWCI of 2.0 and above.

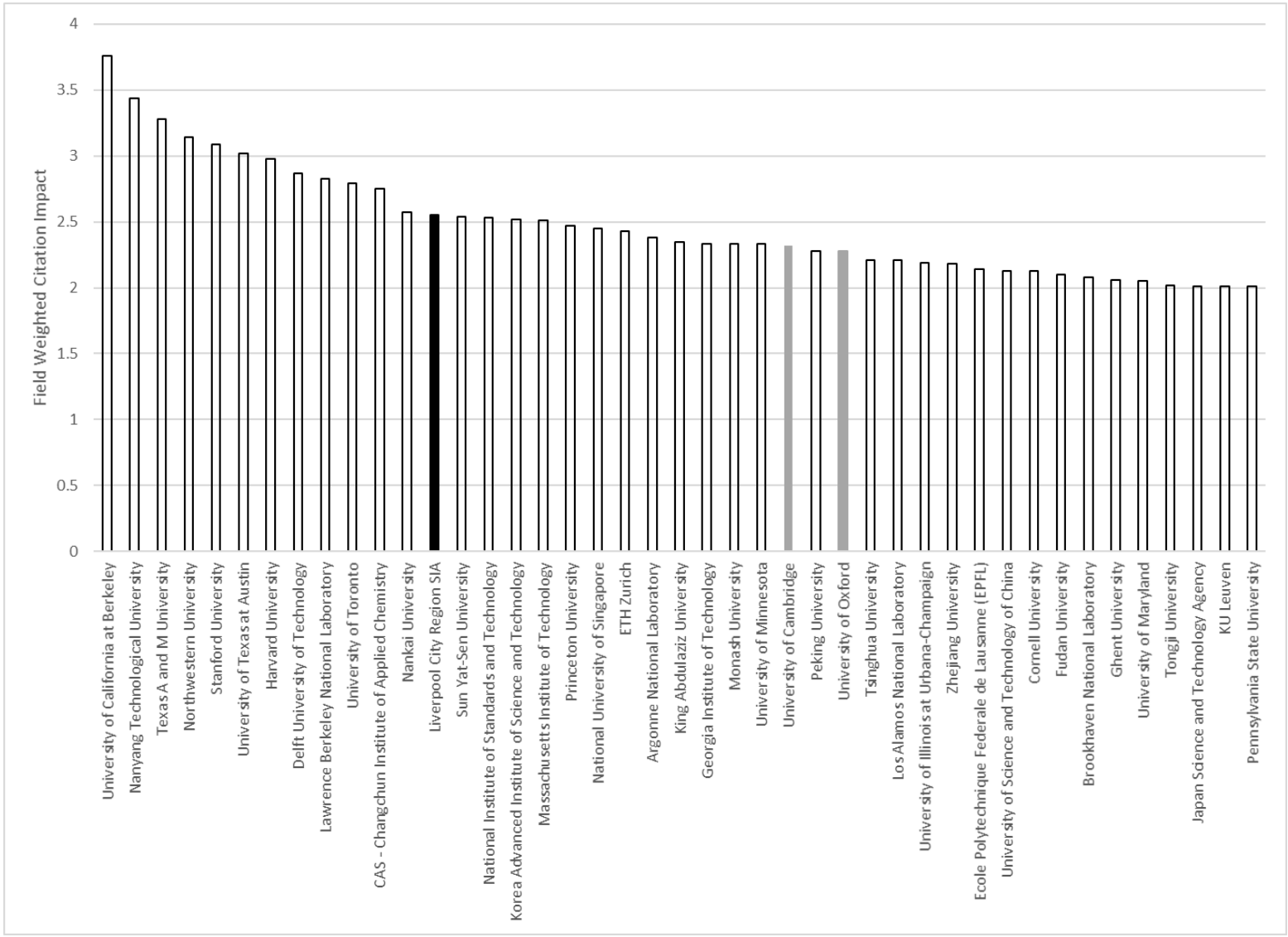
Overall, the message from this benchmarking profile is that the Liverpool City Region is a strong specialised performer when set against elite institutions for the three Themes.

Figure A5-5: Ranked Field Weighted Citation Impact for the Liverpool City Region Infection Theme



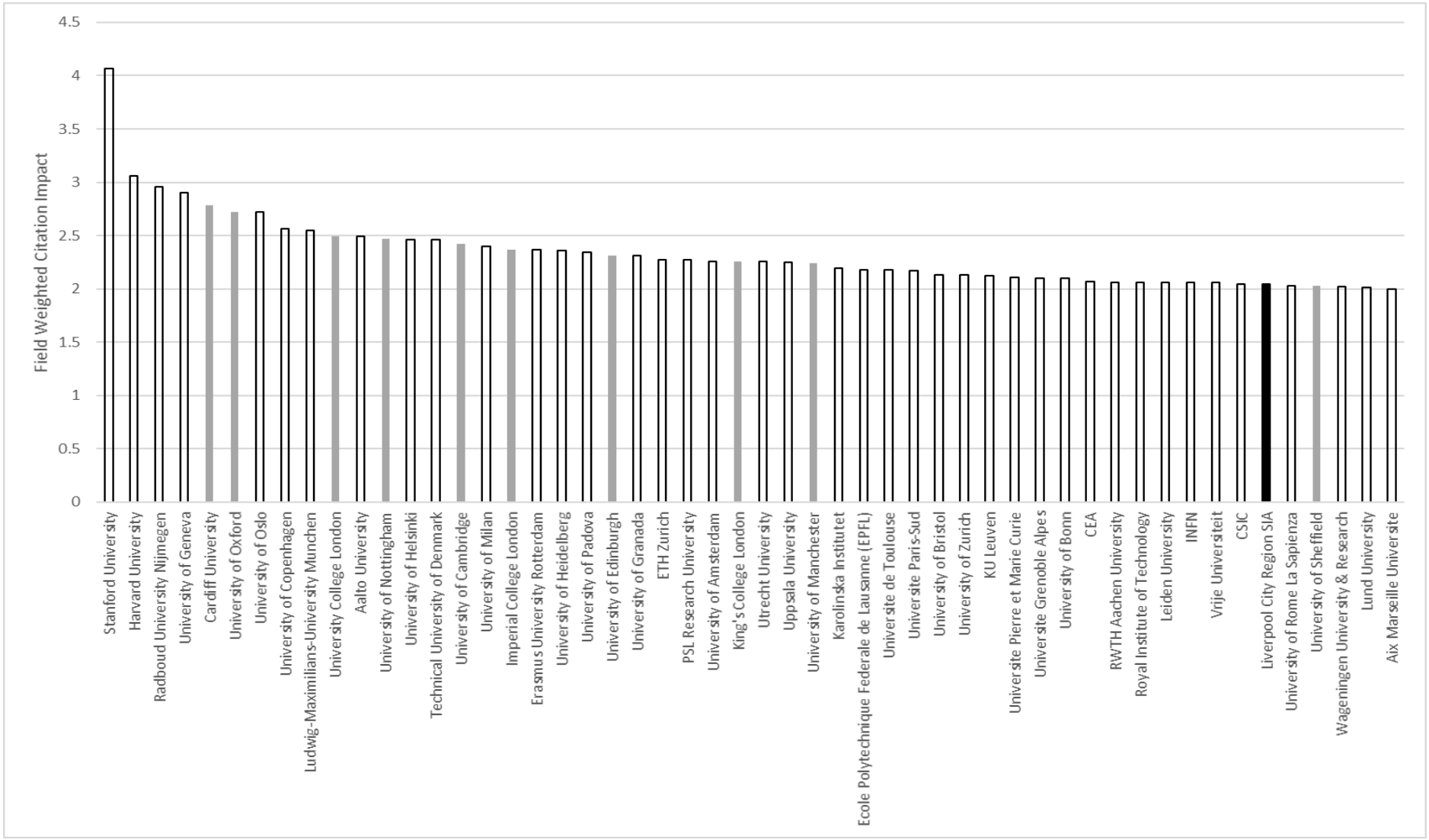
Source: Scopus SciVAL analysis provided by the University of Liverpool

Figure A5-6: Ranked Field Weighted Citation Impact for the Liverpool City Region Materials Chemistry Theme



Source: Scopus SciVAL analysis provided by the University of Liverpool

Figure A5-7 Ranked Field Weighted Citation Impact for the Liverpool City Region High Performance & Cognitive Computing Theme (Europe only)



Source: Scopus SciVAL analysis provided by the University of Liverpool

Appendix 6: Additional material relating to Infection

Figure A6-1 Map of international academic collaborations for LCR Infection papers, 2011-2016

Source: Scopus SciVAL data extracted by the University of Liverpool on behalf of the LCR+ Consortium

Appendix 7: Additional material relating to Materials Chemistry

The 'Liverpool Model'

As defined by Matt Reed, Senior Open Innovation Director at Unilever, the distinctive Liverpool Model has the following characteristics.

- A University of Liverpool hosted **Open Access** innovation facility comprising:
  - Specialised space, differentiated equipment, differentiated methodology and software platforms;
  - Skilled technical support staff for flexible deployment (not-academics);
  - Focal point for an extended network of hi-tech equipment/service providers; and
  - Academic thought leadership with professional management and business engagement.
- This type of Open Access facility, based at the University campus, needs to include private spaces for commercial partners and for academic work. The facility is funded by three different sources:
  - At least one large anchor tenant/partner (in order to locate some of their staff with a significant science and innovation asset base);
  - The University's own funds (in anticipation of significant research grant income);
  - Regional, National, and/or European Government co-funding (in anticipation of new high value jobs and economic impact); and
  - All partners keep their own arising IP and share in common platform improvements.

This type of facility is **Open Access to All:** Any 3rd party, any SME, any academic (University of Liverpool and others) can use the open access parts of the facility under Fair, Reasonable and Non-Discriminatory commercial terms (it is FRAND but not FREE).

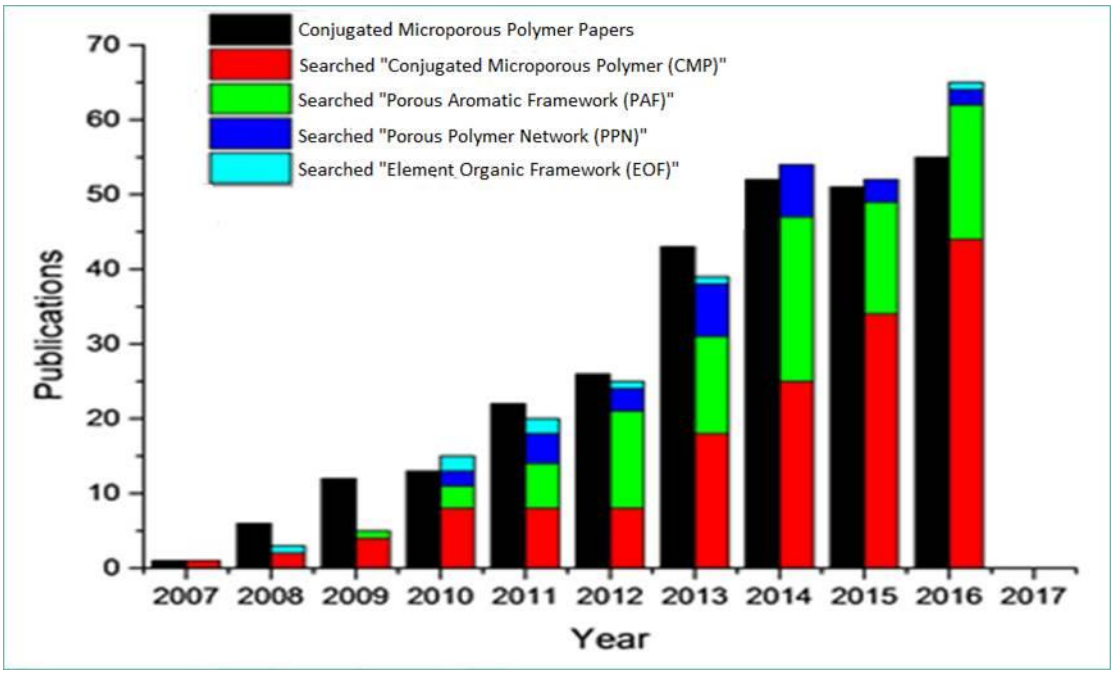
Materials Chemistry Theme stakeholders

Unilever	
Johnson Matthey	Centre for Process Innovation (CPI)
Ceres Power	ACAL energy
NSG Pilkington	Porvair
AstraZeneca	NNL
Redx Pharma	C Tech Innovation
Liverpool Chirochem	Sensor CIty
Morgan/Ceramtec	LCR 4.0
Renishaw	ITM Power
Gencoa / Pegasuss	Croda
Sensor City partners	Chemistry Growth Partnership
VEC partners	

Source: Liverpool City Region+ SIA Consortium

The example of Conjugated Microporous Polymers

This graph demonstrates how University of Liverpool Materials Chemistry research excellence created the entire new field of conjugated microporous polymers.



Source: Jet-Sing M. Lee, University of Liverpool PhD Student, Personal communication.

Global Connectivity

Figure A7-1 Map of international academic collaborations for LCR Materials Chemistry, 2011-2016

Source: Scopus SciVAL data extracted by the University of Liverpool on behalf of the LCR+ Consortium

Human Capital

When tracked six months after leaving, University of Liverpool Chemistry graduates originally from Liverpool have a retention rate of 60%, with 33.3% working elsewhere in the UK and 6.7% working overseas at that point. Just over 17% of leavers who came to Liverpool to study were still in the region six months after graduation. This points to a potential supply of highly trained chemistry graduate for the LCR+.

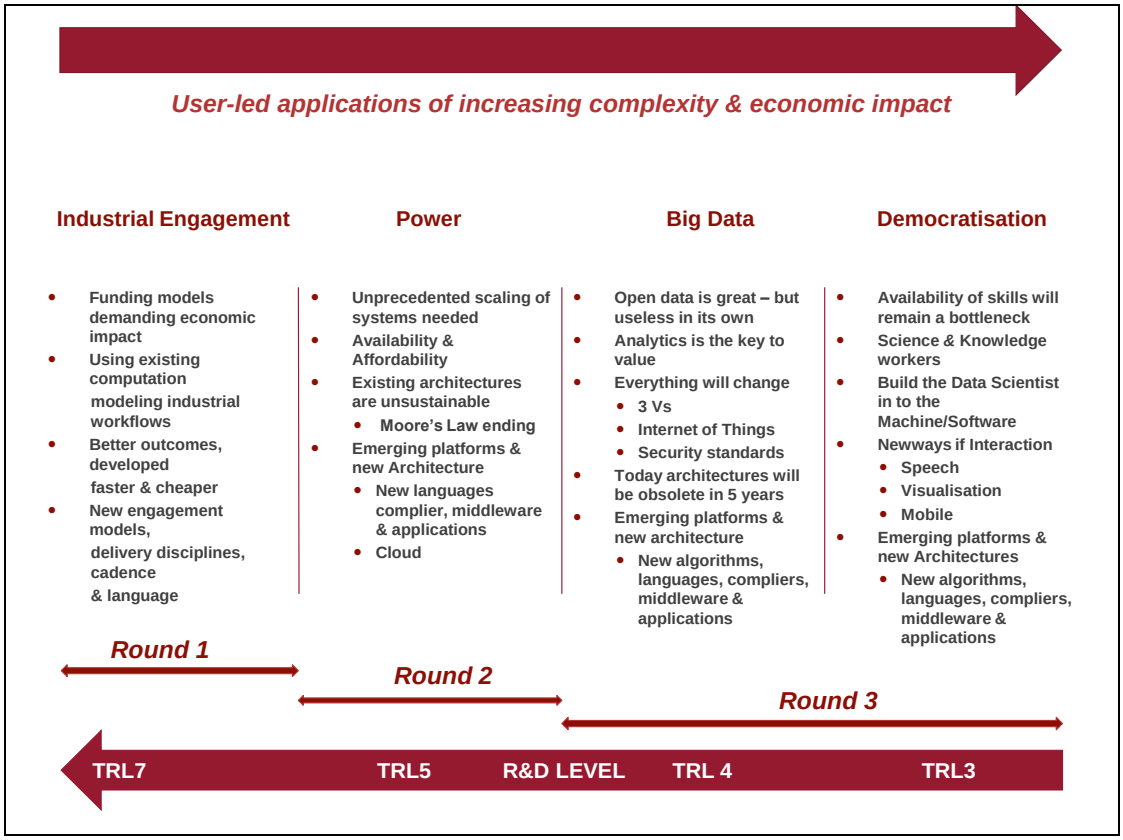
Table A7-2: Chemistry Graduate retention

	Working in Liverpool City Region	Working elsewhere in UK	Working outside UK
Leavers originally from Liverpool City Region	60.00%	33.33%	6.67%
Leavers originally from outside Liverpool City Region	17.24%	75.86%	6.90%
All leavers	30.77%	53.85%	15.38%

Source: Data specially provided by the University of Liverpool

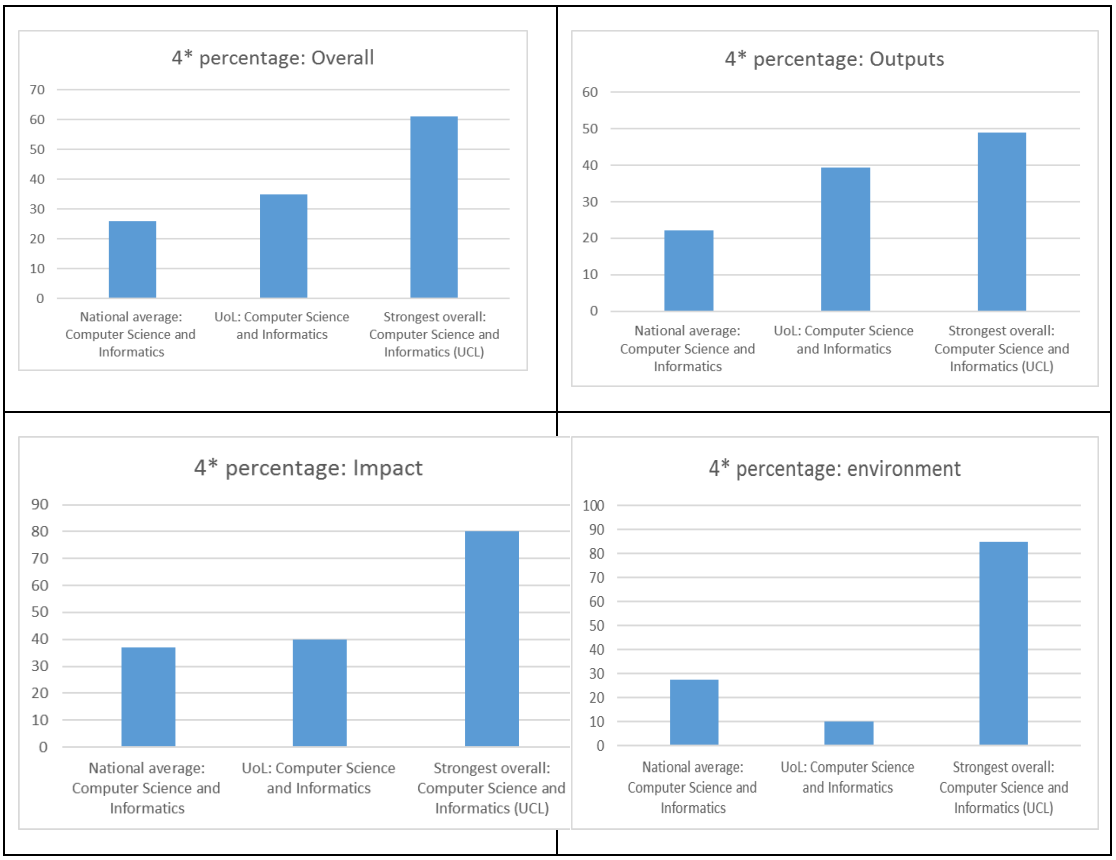
Appendix 8: Additional material relating to HP&CC

Figure A8-1 Evolution of The Hartree Centre's activities in HP&CC



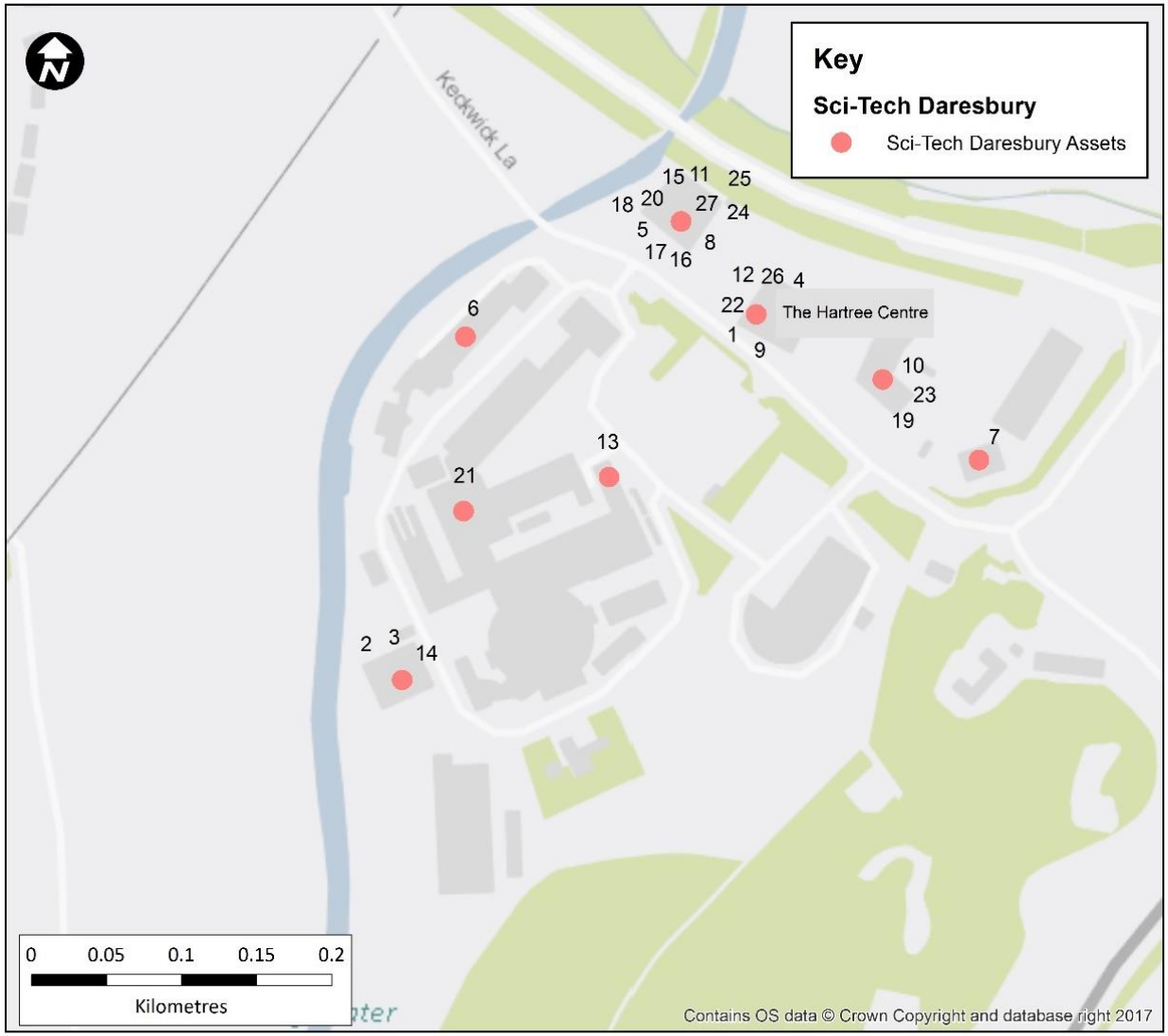
Source: BIS Business Case for Autumn Statement 2015 – Hartree Centre Evolution Version 6.5, 19 March 2015

Figure A8-2 REF 2014 data for University of Liverpool, Computing Science & Informatics



Source: REF2014

Figure A8-3 **Map of assets and occupants at Sci-Tech Daresbury**



Key Assets

1. ATOS Technologies
2. BioNow
3. Campus Technology Hub, Sci-Tech Daresbury
4. Centre of Competence for Cognitive Computing
5. Chemicals North West
6. Cockcroft Institute
7. Conveyor Networks
8. Deep Sky Blue
9. IBM Research
10. Innovation Agency (Academic Health Science Network for the North West Coast)
11. Integritie (UK) Ltd
12. Intel Parallel Computing Centre (IPCC)
13. ITAC (Innovations Technology Access Centre)
14. LPW Technology
15. Mellanox Technologies UK Ltd
16. OCF
17. Optis Northern Europe Ltd
18. Paratools Ltd
19. Perceptive Engineering Ltd
20. QSR International
21. STFC Accelerator Science & Technology Centre (ASTeC)
22. STFC Scientific & Computing Department (SCD)
23. Syrenis Ltd
24. Tessella
25. Valuechain Technology Ltd
26. Virtual Engineering Centre (VEC)
27. Wadaro Ltd

Liverpool City Region - Science and Innovation Audit 2017

Asset Register: Sci-Tech Daresbury

sdg economic development

Created by:	Last Updated:	Scale:
CLacy	25/05/2017	4,000

\\sdgworld.net\Data\Manchester\Users\CLacy\Private\LCR SIA Asset Map\Daresbury.mxd

Figure A8-4 The global reach of LCR+ Computer Science Research (based on University of Liverpool

Source: Scopus SciVAL data extracted by the University of Liverpool on behalf of the LCR+ Consortium

Appendix 9: Theme-level project proposals in detail

This Appendix presents the detailed proposal to progress each of our Theme areas. Each proposal is written to a standard template with the following common elements:

- The proposal's title;
- The Lead Organisation;
- Support and enabling partner organisations;
- A description of the project;
- The cases for the proposal – Strategic, Economic, Financial, Commercial and Managerial (i.e. aligned with the Five Case Model); and
- Timeline and Milestones.

These templates are intended to provide a clear, coherent and comprehensive depiction of each proposal for each Theme. Over the coming weeks and months, these will be developed and progressed to formal Outline and then Full Business Case documents.

Infection

Project Title	Centre of Excellence for Infectious Diseases Research + (CEIDR +)
Lead Organisation	Liverpool School of Tropical Medicine and the University of Liverpool
Partner Organisations	**Core Partners** • Royal Liverpool and Broadgreen University Hospitals – CEIDR brings together a range of highly specialised facilities within the Royal Liverpool and Broadgreen University Hospitals. • Alder Hey Children's Hospital Trust – CEIDR will partner with Alder Hey to develop paediatric formulations for infants and children. • Liverpool Clinical Laboratories – CEIDR will partner with LCL as it develops novel diagnostics and interventions. • The Innovation Agency – CEIDR will collaborate with the IA in its mission to catalyse uptake of innovation, and benefitting from the IA role in connecting local government, NHS and business **Affiliate partners** • Liverpool Health Partners – CEIDR will provide access to patient populations in the North West of England through its links with Liverpool Health Partners. • Liverpool Knowledge Quarter – providing coherent approach to the LCR's Knowledge Quarter assets, a single point of contact for business investors to bring maximum benefit across all the facilities and activities. **Large pharmaceutical companies** • We undertake collaborative programmes with large pharmaceutical companies with operations within and outside the Liverpool City Region. Links with local companies (including Seqirus, AZ/Medimmune and Elanco) will maximise job creation/economic benefit within the region. **SMEs** • CEIDR will collaborate with innovative SMEs within the region to maximise job creation/economic benefit within the region. Regional SMEs of relevance include those that focus on infectious diseases diagnostics (including MAST Diagnostics, Perfectus Biomed, Arcis Biotechnology, Biofortuna, Pro-lab Diagnostics and Global Biodiagnostics), antimicrobial surfaces (including Gencoa and Vodus Medical), insecticides (including Yanco) and digital health companies.

Infection

Project Description

The health and life sciences sectors are of critical importance for the LCR, with more than £1 billion in recent investment in local infrastructure across the NHS, universities and industry. LSTM and UoL have the largest concentration of translational-focused public sector R&D&I infectious diseases expertise in the UK. CEIDR will unlock the economic growth potential of this world-class research asset to develop innovative healthcare technologies, working closely with Liverpool Health Partners, Liverpool City Region LEP, local NHS Trusts and Industry, among others to develop and support the implementation of industry, academic and NHS innovations.

CEIDR's first phase (2017-2020) will build a portfolio of projects with extensive numbers of collaborating companies. This will catalyse the second phase (post 2020) where we anticipate a new bespoke facility either on the Paddington Village site or on that vacated by the current Royal NHS facility, stimulated by increased SME spin-outs and demand from collaborating companies for co-location. This activity will support existing local companies (both large and small) aims to create a sub-cluster of new infection companies in the Liverpool City Region that will form part of the broader Northern Life Sciences cluster. For example, one of CEIDR's initial focus areas will be on combatting antimicrobial resistance, through the expansion of our expertise to undertake pharmacokinetic (PK) / pharmacodynamic (PD) studies used by companies in developing new antimicrobial drugs. In addition, initiatives will galvanise the use of regional clinical trials expertise and test-beds to evaluate and commercialise industry, academic and NHS products for local and other populations.

UoL/LSTM have an extensive track-record that includes: partnership with major philanthropic and public bodies (e.g. BMGF, DFID and WHO), access to patient populations (both UK and overseas, and in neonates, children and the critically ill), and strong existing relationships with pharmaceutical and healthcare companies.

CEIDR has a very strong fit with growth policy for the LCR and will assist in delivering the wider vision of the Local Enterprise Partnership and Knowledge Quarter as a world-class destination for science & innovation. It will form part of the ecosystem central to the LCR Growth Strategy.

The first phase of CEIDR will create 4 direct posts who will engage with companies to provide the expertise and facilities they need for their R&D projects and product development programmes. Based on the size and scope of Liverpool's infection capacity, CEIDR is forecast to create 252 gross direct and indirect jobs (138 net additional) and £42 million in cumulative net additional GVA in the region over 10 years. A second capital phase is planned to build dedicated CEIDR space for specialist laboratories for businesses to use and additional incubation space.

Three, among many possible CEIDR projects, are outlined here as exemplars:

- Discovery and Development of Next Generation Anti-infective Drugs: tuberculosis as an example;
- Discovery and development of vaccines

Infection

- Consumer products for prevention of emerging arboviral diseases (ZIKA+).

In addition, two projects that illustrate the ways in which CEIDR could interact with the other two SIA Themes, Materials and High Performance Computing, are proposed, namely, Nano medicine and Biofilms Innovation and Knowledge Centre.

Strategic Case	**Discovery and Development of Next Generation Anti-infective Drugs** TB is responsible for 1.5 million deaths annually. Current first-line therapy lasts for six months and 8.8% of sufferers worldwide are infected with rifampicin-resistant organisms for which second-line treatment lasting more than 18 months may be required. Shorter, more effective treatment with novel or repurposed drugs is urgently needed. Successful drug development in TB remains highly dependent on commercial and public sector partnership. CEIDR hosts the PreDiCT-TB consortium, a public-private partnership with the three leading pharmaceutical companies in the field (GSK, Sanofi and Janssen) and with 18 other academic institutions in Europe. PreDiCT-TB pioneered a model-based approach to pre-clinical development linked explicitly to a framework for simulation of clinical trials and a proposed development pathway. The project also addressed fundamental issues in TB pharmacodynamics related to persistence behaviour and methods by which this aspect of treatment could be measured and overcome. PreDiCT-TB showed how essential academic institutions are to innovation in this area and how critical such innovations will be to expanding investment by the pharmaceutical industry in TB drug development both nationally and in the LCR. The TB Innovation Platform aims to create a public-sector centre of excellence in TB drug development in the UK. The project aims to integrate and strengthen LCR-based capabilities and to expand the scope of activity to new areas of in vitro and in vivo work, making CEIDR a natural vehicle for drug development efforts across a broad spectrum of infectious diseases with public and commercial partners. **Discovery and development of vaccines** Within the collaborative framework of CEIDR sits a Centre for Vaccine Development which seeks to (i) develop and evaluate novel vaccines against major global causes of illness and death (ii) better understand and improve the performance of existing vaccines; (iii) generate evidence to inform vaccine policy nationally and internationally; (iv) share pre-clinical expertise amongst human and veterinary vaccinologists; and (v) train and educate a new generation of vaccine scientists. The vaccine centre works with GSK, Takeda, Sanofi Pasteur and Zoetis on a range of human and veterinary vaccines. Improved access to manufacturing capacity and speed of production of GMP quality products poses a significant opportunity for expanding vaccine development, bridging the gap between pre-clinical animal models and the move to first in man studies, both strong in Liverpool, with a suitable vaccine antigen and delivery

system. Industrial partners including Seqirus and Astra Zeneca/Medimmune in Speke provide these opportunities for partnership.

Consumer products for prevention of emerging arboviral diseases (ZIKA+)

Outbreaks of new or re-emergent infectious diseases by their very nature are difficult if not impossible to predict, but when they occur cause major problems, as we have seen from the recent outbreaks of Zika and Ebola and earlier H1N1 bird flu epidemics. These have the potential for massive detrimental economic effects on the countries affected, and can cause short medium and long term issues for the national health services.

While we know that epidemic outbreaks driven by arboviruses will occur intermittently, and WHO has convened an expert group to stratify, from the known arboviruses, those most likely to trigger an epidemic, the level of uncertainty is too great, and the market size for any one product too small for any commercial entity to take on the risk of developing products for the prevention and control of these epidemics in isolation. Much of the expertise in understanding and handling these arboviruses and their vectors also resides in academia, particularly in Liverpool. This has already been recognised with a recent Bill and Melinda Gates award of several million US$ to provide a platform for initial assessment of new products for Aedes control.

The objective of the proposal is to expand the testing platform for the testing of new products for Aedes control to: (1) expand these to include rapid diagnostics, (2) increase the capacity to develop this into a high throughput facility that can be accessed by multiple companies simultaneously and (3) generate the Target Product Profile norms for new Aedes consumer and public health products; all these aims have relevance to companies both nationally and in the LCR.

Illustrations of the way in which CEIDR will interact with the other two SIA Themes.

- Interaction with ‘Materials’: Nanomedicine
  - There is an opportunity for translational activity building on the strengths in drug delivery, nanomedicine and antimicrobial science and innovation existing at the UoL and LSTM. There is already a strong base for nanomedicine activity, with current funding of more than £12M. This includes the only UK-based core facility within the European Nanomedicine Characterisation Laboratory (H2020 funded). Activities will encompass pharmacokinetics and pharmacogenetics research, which will be integrated clinical trials. The co-location of pharmacologists and chemists to the Materials Innovation Factory (MIF), scheduled for early 2017, should further accelerate this cross-cutting activity. Examples of current activity include NIH pharmacokinetic modelling as part of the NIH and USAID-funded OPTIMIZE consortium, a $50M initiative aimed at optimisation of HIV therapies in low and middle income countries. The work has clear relevance to UK pharmaceutical companies.

Infection

- Interaction with 'Materials' and HP&CC: Development of a 'Biofilms Innovation and Knowledge Centre'
  - This builds on the work of the existing 'Open Innovation Hub for Antimicrobial Surfaces' (OPIHAS), which is already translating internationally leading expertise from UoL's UK IRC in Surface Science, one of the major centres of its kind in Europe. The activity , incubated by a £3m ERDF programme, has competitively won collaborative projects worth £6m from Innovate UK grants since 2014, partnering with some of the largest global companies such as Akzo Nobel, Ansell, Croda, dePuy Synthes, Smith & Nephew, Scapa, Unilever and Walgreens Boots and a number of innovative SMEs. OPIHAS combines physical, biological and clinical sciences to develop next generation anti-infective surfaces and materials that are key in infection prevention and control. Our world-leading expertise in surface science and nanotechnology is providing unique insights on success-parameters for manufacturing future disruptive technologies across many industrial sectors, ranging from healthcare, marine, consumer products to coatings. OPIHAS already has a demonstrable commercialisation pathway – four patents are filed, and clinical trials are underway for one, and will take place in 2018 for two others. While located in the Infection theme, and cross-linking to Materials it also benefits from synergies with the HP&CC Theme, where multiscale modelling will help drive knowledge-based innovation. Scale-up of this activity is now planned to consolidate the current position and exploit global research/commercial potential. The planned BIKC will be in conjunction with Edinburgh, Nottingham, Southampton + 10 other Universities, with Liverpool leading the surface and materials design.
- Interaction with 'High Performance Computing': Improving product design and efficacy through optimising placement
  - Products designed to prevent infectious disease transmission are often tested in artificial systems, or designed to be placed at the point where 'expert' opinion suggests they will have the greatest traction. Products in the development phase, or early operational testing often look very promising only to fail when they are deployed in real-life situations. The technology is now available to track the movement of microbes, parasites or viruses over time in 3 dimensions, alongside tracking human and secondary vector movements. Hence for example we can start to track how resistant bacteria enter a hospital environment, how they move around the building and how they are carried by patients, staff and visitors. Products aimed at stopping this spread can then be optimally designed and placed at points where onward transmission into the wards or to patients is greatest. Similarly, with infectious diseases that have an insect vector, we can assess the movement of the insect vectors over time and design products that maximally reduce human transmission. This requires accurate monitoring of the impact of the product on the insect and human behaviour. While the technology has recently become available to do this level of sophisticated tracking, the data generated from 24hrs of tracking currently requires several weeks of detailed analysis.

Infection

	We aim to develop an Open Innovation Hub for 3D monitoring by linking the work of various academic groups in Liverpool with the High-speed computing abilities at Daresbury/Hartree will allow us to reduce the time taken to integrate the tracking of movement of various disease agents, their human and secondary hosts. Speeding up this process will increase the inherent value of the cutting-edge technology we already have in Liverpool, increasing collaboration with a raft of companies developing products for the prevention of vector borne diseases. Because this technology should bring a generic benefit to product development in this space, it is important that in initial development it is not owned and control by any one commercial entity.
Economic Case	The CEIDR platform represent one of the largest critical masses in translational science in infectious diseases in the world. It is an internationally recognised part of the knowledge economy in the North-West, critical components of the Liverpool Bio-Campus and Knowledge Quarter, and linked to LCR test-beds for commercialisation. The sector is a key part of the strategy for medium to long-term economic growth in Liverpool and the North-West. CEIDR responds to a national and international requirement for better prevention, diagnosis and treatment of a range of infectious diseases that are a global problem. Providing cost effective solutions to anti-microbial resistance and facilitating development of a healthy pipeline of new antibiotics will, for example, remove, in the words of the UK Governments Chief Medical Advisor, the greatest threat to the current NHS service in the UK. In this area, the case for public private partnerships to share development risks and provide a pipeline of products for the greater public good is well established (and builds on LSTM experience to-date with corporate accelerators – see below). Driving CEIDR as an internationally renowned centre for RD & I in this area has the potential for direct effects on the LCR economy, through increased jobs, capacity development and local manufacturing, and in improved local NHS-based healthcare. It also has the potential for larger economic gains for the UK as a whole, attracting substantive overseas investment and knowhow and establishing the UK as a strong base for multi-national collaboration in infection.
Financial Case	This area has been growing in financial importance to the LCR over the last decade. The portfolio of activity in infection RD & I over this period has grown from <£10 Million in 2005 to over £600m in 2016. In 2015-6 there was a 188% increase in funding, much of it driven by major investment from US based philanthropic donors. While this organic growth is impressive, there is the potential to increase this significantly and ensure that the R & D offering, platform technologies and access to patients that are brought together in CEIDR are more obvious outside the LCR. We already have an excellent entry into the global R & D funding in infection and should be able to more than double inward investment over the next 5 years if we are selective with the programmes and partnerships that are established and

Infection

	fostered under the CEIDR umbrella. Further investment is needed to ensure that the LCR can market CEIDR and its major component projects effectively, house the rapid expansion of activities in high quality purpose built facilities, support the expanding requirements for a skilled workforce and interact efficiently and effectively with industrial collaborators. To ensure that CEIDR nurtures and supports local SMEs there is a need for support for pilot projects, particularly with SMEs and start-ups, to get R & D activity to the point where it is more readily supported by standard Venture Capital or business angel funding. A pilot scheme already operated out of LSTM for the last 3 years has provided a 300% leverage on investment and is now starting to attract and triage ideas, skills and expertise from the UK more broadly through CEIDR.
Management Case	CEIDR lends itself to development of Public Private Partnership (PPP)/corporate accelerator models. For example, the Gates Foundation has already indicated a willingness to fund 'Zika+' (above) by providing $2M seed funding to develop the initial prototype testing through LSTM, and Unilever, Godrej, Vestergaard and SC Johnson are already indicating that they are keen to set up new development activities utilising the prototype facility. The PPP model in this space is already well defined and the LCR has expertise in running these at Scale through LSTM which hosts the Innovative Vector Control Consortium (IVCC) and Anti-Wolbachia Consortium (AWOL)and other initiatives that have already operated successfully from a Liverpool base for over a decade generating more than £290m revenue over this period. The same PPP approach is also being used, within the CEIDR umbrella, to address development of diagnostics, vaccines and drugs (as briefly illustrated in the examples above) all of which are relevant to UK companies, many of which are established in LCR and the wider Northwest, and will provide a focus of further investment.
Timeline and milestones	2017-2020: CEIDR's first phase, including Discovery and Development of Next Generation Anti-infective Drugs, Discovery and development of vaccines, Consumer products for prevention of emerging arboviral diseases (ZIKA+), and Nano medicine and Biofilms Innovation and Knowledge Centre. Post-2020: CEIDR's second phase, including a new bespoke facility for spinouts and SME co-location.

Elapsed time/ongoing activty	
Start of activity	o
End of activity	⧫

Component	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul-18	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19
1.1 CEIDR launch	o	⧫																																		
1.2 CEIDR implementation	o																																			
2.1 Discovery and Development of Next Generation Anti-infective Drugs - project development					o								⧫																							
2.2 Discovery and Development of Next Generation Anti-infective Drugs													o																							
3.1 Discovery and development of vaccines - project development									o								⧫																			
3.2 Discovery and development of vaccines																	o																			
4.1 Consumer products for prevention of emerging arboviral diseases (ZIKA+) - project development													o								⧫															
4.2 Consumer products for prevention of emerging arboviral diseases (ZIKA+)																					o															

Materials Chemistry

Project Title	MIF Nexus
Lead Organisation	Co-leaders University of Liverpool & Unilever
Partner Organisations	**Core Partners:** • University of Liverpool; • Unilever; • NSG Pilkington. **Affiliate partners (initial):** • Croda; • Bristol Myers Squibb; • ACAL energy; • C Tech Innovation; • Chemistry Growth Partnership; • Ceres Power; • Gencoa / Pegasuss; • ITM Power; • Johnson Matthey; • Liverpool Chirochem; • Morgan/Ceramtec; • National Nuclear Laboratory.
Project Description	MIF Nexus will be a new translational facility building on the existing model exemplified by the Materials Innovation Factory (MIF). The model implemented in MIF is a combination of computationally-enabled materials design (the “materials design engine”) with an automated “materials applications engine”. In MIF, materials design is provided through the University of Liverpool’s world-leading Materials Chemistry expertise; Unilever plc drive the materials applications engine which is tailored to their Fast-Moving Consumer Goods (FMCG) markets.

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This successful model will be replicated and extended for several other materials chemistry-related high value industries in MIF Nexus, through the further co-location of the academic materials design capability with several sector specific “materials application engines”. MIF Nexus will focus on high value chemical industries (outside the Fast Moving Consumer Goods sector already implemented in MIF) which are underpinned by materials chemistry. The sectors being considered are:

Energy materials:

Materials chemistry needs lie at the heart of the enablers required for low carbon energy production and pollutants (incl. CO2) removal. Major challenges include non-precious metal catalysts for electrolysis (to enable the use of hydrogen for transport and heating) and for fuel cells; low cost redox battery materials for grid-scale energy storage to support the growing use of variable renewable energy sources; and routes to accumulate and capture pollutants and then destroy them using catalysts.

Decarbonisation is a further priority area. This involves developing low carbon fuels enabled by the associated catalysts, battery technology – stated as a priority for the Industrial Strategy Challenges Fund, fuel cells, porous materials and energy harvesting. This would link closely to the University’s Stephenson Institute for Renewable Energy whose key strengths include energy storage and photovoltaics.

Interfaces/coatings Manufacturing & Process Technologies:

This targets the enhancement of function through the transformational processing of new materials to provide:

- Rapid and free form prototyping of new materials to assess manufacturability;
- Digital - Additive manufacturing of new materials for high value and bespoke products. Enabling autonomous and intelligent manufacturing (LCR4.0);
- Energy efficient and sustainable process technologies (extending beyond thermo-chemical) for new materials – “cradle to grave” materials utilisation;
- Nanoscale control of assembly and patterning of surface and interface treatments / coatings / films; and
- Incorporating a range of advanced processing tools with the potential to become an HVM Catapult in Materials Process Technologies.

Catalysts for sustainable manufacturing:

This involves the use of advanced sorbents and renewable feedstocks enabled by separations and catalysts.

Pharmaceuticals:

This particularly involves the design and testing of the non-active excipient materials involved in the formulation process in the

pharmaceutical industry.

Key Components

MIF Nexus will be the final link in a chain of developments at University of Liverpool and the Liverpool City Region over the past 20 years. These include the UK's centre of excellence in Surface Science working on applications in advanced functional materials, wetting and corrosion, bio-interfaces, chiral separations, energy (established 1998); the Centre for materials Discovery (established 2006), and the Materials Innovation Factory (established 2017). These are existing highly successful initiatives based on knowledge leadership in materials innovation.

Wider Existing Context

Key related elements within the wider LCR context include:

- The Hartree Centre which will enable computational insights to new materials problems and help provide enhanced understanding of existing materials used in industrial processes;
- Unilever Open Innovation Park: reconfiguration of Port Sunlight to create a major open innovation hub focused on modern consumer industry manufacturing;
- Unilever Packaging & Supply Chain Initiative: exploring innovative solutions to packaging (including dramatically reduced environmental impacts);
- Prospective UK packaging innovation and applications cluster at Port Sunlight;
- Rocksavage International Energy Technology Park: Targeting the development of leading-edge chemical design, formulation & production of energy related materials;
- ChemBioCat Centre at the University of Liverpool, (part of the York-led BioEconomy SIA);
- the proposed Off-site Advanced Module Development Centre project concept led by Cammell Laird, both in terms of the materials and advanced manufacturing involved and also in terms of the digitally enabled engineering approach which parallels that being taken in the Materials Innovation Factory;
- The University of Liverpool provides the Materials Chemistry "spoke" of the Royce Institute; and
- The Centre for Process Innovation, part of the High Value Manufacturing Catapult based in the North-East.

Strategic Case	**Background to the Project** The proposed project was developed directly from the SIA process. An initial Materials Chemistry scoping workshop was held on 24th February with a range of key academic and industrial stakeholders. The idea of MIF II was conceived at this workshop, along with a long-

Materials Chemistry

list of other ideas. These were refined and presented at the general Science and Innovation Audit workshop held on 7th March. Following feedback at this workshop, a short-list of 3 materials chemistry projects including what was originally termed 'MIF II' and 2 inter-theme projects was developed and presented at an SIA project group meeting on 28th March.

Finally, following input from the SIA strategy board, the 2 other materials projects (Process technologies centre for high value manufacturing of new and advanced materials, and Environmental / Energy Solutions) were merged into a single core project (MIF Nexus) and the inter-theme projects were incorporated into the Infection and High Performance and Cognitive Computing themes.

Rationale for public sector intervention

Investment in a new translational facility based on the MIF model will provide a place-based anchor for a key element of the government's Industrial Strategy "driving progress in technologies where the UK can build on our existing areas of industrial and research strength". It will contribute to many of the Pillars of the Industrial Strategy, particularly:

- Investing in science, research & innovation;
- Delivering affordable energy & clean growth; Supporting businesses to start & grow;
- Cultivating world-leading sectors;
- Creating the right local institutions.

It will also build on previous government investment, most specifically in MIF (through the Research Partnership Investment Fund).

The UK has ambition to be continue to be a world-leader in chemical industries as expressed in the strategic vision of the Chemistry Growth Strategy Group "By 2030, the UK chemical industry will have further reinforced its position as the country's leading manufacturing exporter and enabled the chemistry-using industries to increase their gross value added contribution to the UK economy by 50%, from £195 billion to £300 billion".

The LCR region is home to many of Britain's leading chemical manufacturing companies. The MIF project has demonstrated the potential for place-based translational facilities to ease the path to innovation in a specific sector (Fast Moving Consumer Goods), with Unilever as an anchor tenant.

Objectives and Impact

MIF Nexus will be a major asset in helping deliver the LCR Growth Plan and Strategic Economic Plan. Building on key City Region assets, and world-leading excellence in Materials Chemistry, MIF Nexus will support the future growth of both chemistry-related industries and drive innovation in the wide range of other industries that benefit from such advances.

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	In addition to supporting academic science and existing industrial partners, MIF Nexus will also act as a catalyst to further stimulate a place-based innovation ecosystem for applications of materials chemistry within LCR that is more like the vibrant biomedical and digital ecosystems seen in Cambridge and London. This materials chemistry ecosystem will lead to the creation of new start-up companies and begin to attract Venture Capital investment into materials chemistry based innovation.
Economic Case	The project will have a significant economic impact in the Liverpool City Region, and make a major contribution to the innovation ecosystem. MIF Nexus will support: • Major companies through access to shared robotic testing, scale-up and proof-of-concept facilities; • SMEs through access to synthesis and characterization services and facilities they would not otherwise afford; • Start-ups and spin-outs through access to expertise and pump-priming support. The facility will help to de-risk investment in new materials for a wide variety of applications, most importantly in a manner that will facilitate investment in major transformational and potentially disruptive technologies of global significance. This will be achieved by decreasing the levels of investment faced for these high-reward opportunities in a manner unique to this facility. As such, MIF Nexus will create a virtuous circle of cumulative economic impacts based on attracting risk capital able to exploit this unique 'investment ready' translational facility. By accelerating the development of new advanced materials, MIF Nexus will create a commercial capability in materials design that will attract investment, encourage corporate re-location and, itself, generate revenue from services provided -funds for re-investment in evolving the facilities capabilities over the long-term.
Financial Case	MIF Nexus is at the Idea stage. Elements of the MIF Nexus proposal have been previously developed in a proposal to EPSRC for a process technologies centre for HVM, with the goal of establishing this element LCR as a go-to region for developing coating processes, product development requiring coating technologies, translational capabilities for new functional materials to be deployed as coatings, all designed with for sustainability (feedstocks, low energy processes). The next stages will involve scoping out the scale and costing of the project, including purpose-built and equipped laboratory space, proprietary industrial space, innovation laboratories and facilities for business interfacing. This Financial Case will be based on the MIF model that combines:

Materials Chemistry

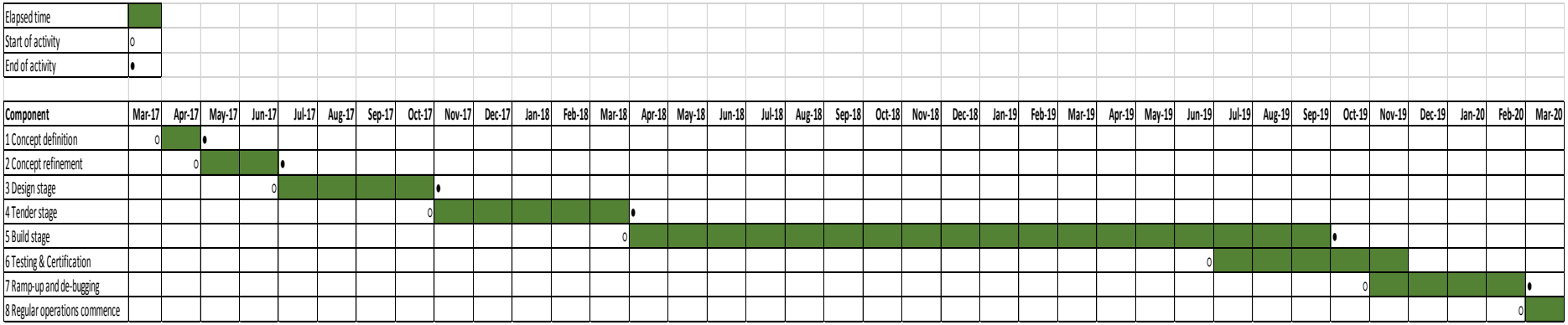
	• A technical characterisation of the economies of scale and speed in automated high-throughput rate materials chemistry discovery and applications experimentation (faster, cheaper and more precise activities); • A mapping of these technical characteristics across to key investment risk management parameters (allowing a demonstration of how MIF Nexus will generate more compelling investment opportunities based on financial considerations for start-ups, existing SMEs, major corporations and venture capital). This will include quantitative estimates of the extent to which the facility can reduce investment risk exposure for materials chemistry innovation; • Integration of these two model elements will allow expected benefits to be related to facility costs using conventional risk-based Net Present Value (NPV) estimates. The baseline data for this modelling will be provided by combining data from existing corporate experiences in pre-cursor facilities, e.g. MIF. In this context, the MIF project overall cost was of the region of £67m investment in the building and equipment, with contributions from Government (Research Partnership Innovation Scheme), the University of Liverpool and Unilever, the anchor industrial tenant.
Management Case	This project will be a partnership of the University of Liverpool with significant inputs from key industrial anchor tenants. MIF Nexus will replicate the successful MIF model, whereby an academic materials design engine is linked with industrial applications robotic testing to serve a wide range of local industries and facilitate spin-outs and other innovation ventures. There is significant experience of managing and delivering such projects within the University and the Liverpool City Region. The University of Liverpool and Unilever have established MIF together. The University of Liverpool, together with Liverpool John Moores University with support from the ERDF and BEIS have created sensor City, a global hub for the development of sensor technologies. The principle objectives of MIF II will be to: • Co-locate university expertise in materials chemistry with significant industry partners • Enable formulation and rapid testing of the outputs of the materials design engine to evaluate IP potential; • Provide device prototyping and testing; • Deliver not only new materials to industry but also insight and characterisation of existing materials; • Nurture spin-outs/joint ventures; • Enable global connectivity from the LCR region outwards; • Deliver possible remote access worldwide as a service for specialised equipment;

Materials Chemistry

- Build on core expertise in integrated computation-experiment approach;

Use the Liverpool model for innovation (Specialised space, differentiated equipment, differentiated methodologies and software platform, world-class academic leadership).

Timeline and milestones	Planning and scoping of the project will begin in late 2017. An indicative Gantt chart is provided below:



High Performance & Cognitive Computing

Project Title	'Deep Change' Programme
Lead Organisation	The Hartree Centre
Partner Organisations	• Atos Bull (Atos) • Digital Innovation Factory (DIF) • IBM Research UK (IBM) • Liverpool John Moores University (LJMU) • Liverpool Local Enterprise Partnership (LEP) • Liverpool School of Tropical Medicine (LSTM) • Materials Innovation Factory (MIF) • Sensor City (SC) • University of Liverpool (UoL) • Virtual Engineering Centre (VEC).
Project Description	The World Economic Forum performed a comprehensive study which found that digital transformation, applied to business and government, has the potential to unlock $100 Trillion in value to business and society between 2015 and 2025.[60] Liverpool City Region (LCR) has long recognised the potential of digital transformation for its place, and has focussed strategically resources to build a unique combination of digital facilities and capabilities which already deliver significant competitive advantage to organisations (see tabulated examples below). Typically, these capabilities are focused on a specific technology or have a remit to assist types of business, for example: • Digital Innovation Factory - focus on robotics and autonomy • Hartree Centre - focus on high performance and cognitive computing • LCR 4.0 - focus on digital transformation (nut SMEs only) • Materials Innovation Factory - focus on materials discovery • Sensor City - focus on internet of things and sensors • Virtual Engineering Centre - focus on virtual reality technology and techniques.

[60] http://reports.weforum.org/digital-transformation/

High Performance & Cognitive Computing

The World Economic Forum performed a comprehensive study which found that digital transformation, applied to business and government, has the potential to unlock $100 trillion in value to business and society between 2015 and 2025.[61]

Individually, these programmes make significant contributions to beneficiary organisations, and there are knock-on impacts for the City Region. However, by harnessing these combined capabilities in collaboration with the world-class knowledge in LCR's universities, and exposing the potential of public sector and societal needs, LCR has the right combination of assets, skills, and knowledge to make a 'Deep Change' and seize its share of the $100 trillion digital transformation dividend.

The success of collaborations to achieve project outcomes are determined by the people and place of the collaboration. Anselin et al. (1997) find that spillover benefits from universities and public sector research for organisations extends around 50 miles from the research-intensive institution. LCR has the unique position of benefiting from all these digital assets mentioned and the skilled individuals running and operating these facilities in close proximity.

'Deep Change' will combine and integrate these digital assets and take LCR organisations, private and public, on a journey of digital transformation through three core components; Discovery, Accelerator, and Rising Stars. These components are described in detail in the following section.

Key Components

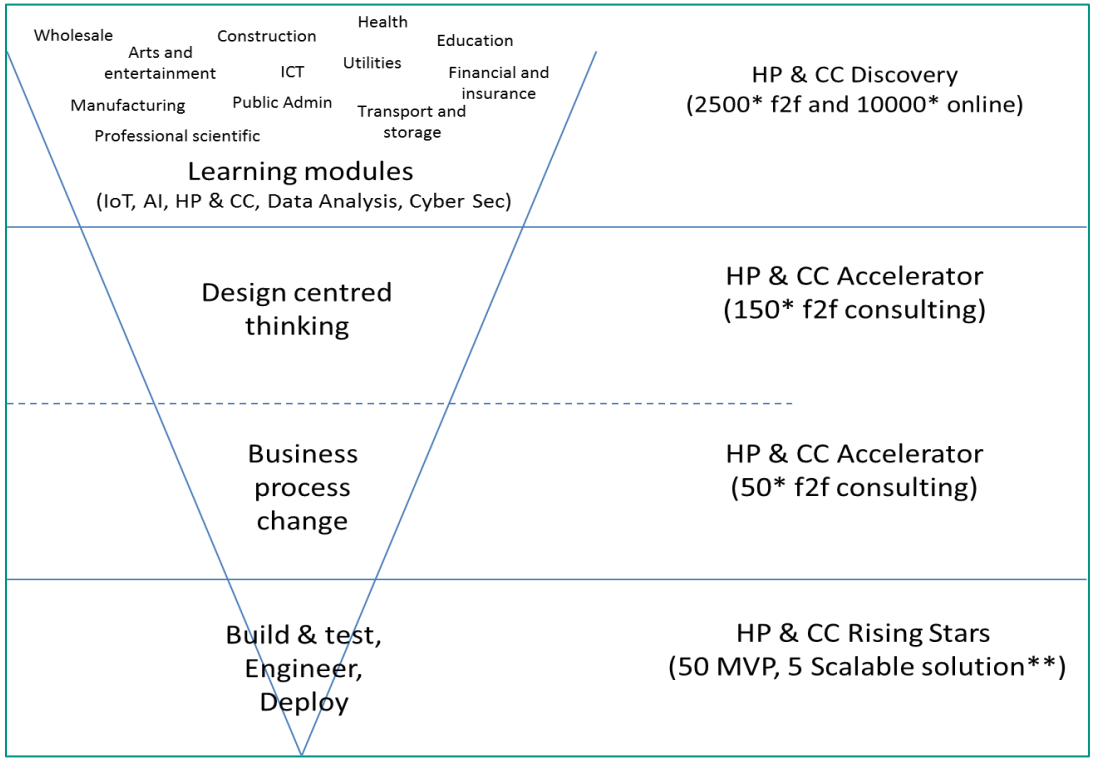
The programme components, showing volumes and types of engagement, can be seen in **Error! Reference source not found.**, with further detailed description below.

Pilot Phase

- Building on the successes and lessons of the LCR Fourth Industrial Revolution programme (LCR 4.0), the Pilot Phase will broaden its scope beyond current limitations of SME-only engagements to include public sector organisations and larger industrial clients. As shown in the Wider Context section below, LCR 4.0 already brings together many of the existing digital exemplar facilities and people to deliver specific digital transformation projects for LCR's SME community. This provides much of the process, platform, organisation and personal networks required ready to launch and underpin 'Deep Change'.

[61] http://reports.weforum.org/digital-transformation/

Figure 8-1: Components of the 'Deep Change' programme



Discovery

- With the lessons of piloting understood and applied, the Discovery component will be targeted at both public and private sector organisations to build knowledge and awareness of the benefits, opportunities and disruptive thinking behind digital HP&CC technologies. Targeted at professional individuals, learning modules will be developed in key digital transformational technologies and principles. These will include Internet of Things (IoT), Artificial Intelligence (AI), HP&CC methods, data analysis, cyber security and disruptive business models. Modules will be delivered in digital interactive online media to provide maximum reach and impact, allowing individuals to work through materials in a flexible way, in their own time. Additional face-to-face surgery sessions will be delivered in the City Region's digital exemplar institutes such as Sensor City, VEC, Hartree and DIF, helping to bring the community together.

High Performance & Cognitive Computing

- UoL is already partnered with the world-leading online education provider, Laureate Online Education (LOE). There are currently 27 online Masters programmes and two Doctorate programmes offered through the partnership between UoL and LOE. The focus is on providing professional development across subject areas including Education, Business, Law, Health, Psychology and Computer Science, aimed predominantly at working professionals who therefore benefit from the flexibility of online delivery.
- Hartree is partnering currently with UoL in delivering their Big Data MSc and will host a summit in July 2017 with the aim of increasing the focus on digitally relevant, online professional qualifications. By extending this relationship with the other digital facilities, wider technical content can be created and can be brought to life with real world case studies.
- The Discovery component will initiate and drive the community discussion across organisational boundaries, professional qualifications will be achieved, and innovative ideas discovered and seeded ready to be carried forward into the Accelerator component.

Accelerator

- Organisations committed to undertaking digital transformation will apply, via a lightweight process, to the Accelerator programme. This will be a consultative process to identify how digital technologies can deliver value to the organisation concerned. A detailed business analysis and process design will give the organisation a roadmap for change, with a value proposition making clear the business benefits.
- Hartree, working in collaboration with IBM UK, operates currently a Cognitive Accelerator Programme which has helped create the UK's first 'Cognitive Hospital' project. Working with Alder Hey, a consultative approach was taken to identify a roadmap for the introduction of cognitive technology across different operational processes in the hospital. This collaboration has evolved in to the development of a 'minimum viable product' (MPV) which has brought innovation awards and additional funding of £10m to the hospital as it has demonstrated thought-leading innovative digital practice. The MPV is currently being engineered to scale out to all NHS Trusts in the UK.
- Consulting activity under the Accelerator component will to draw on the talents of digitally focused firms and organisations identified in the LCR 4.0 programme, acting as a reinforcing community of expert resource in our City Region. This will kick-start the supply side of the market, bringing together suppliers with complementary skills and digital transformation technologies to focus on business and (for public sector organisations) service delivery challenges.
- Collaborations will be formed, with detailed project planning and the development of minimum viable products taking place in digital exemplar partners' facilities across LCR, including for Infection (in the Knowledge Quarter), Materials Chemistry in the Materials Innovation Factory, Robotics in the DIF, IoT in Sensor City, virtual reality in the VEC, and HP&CC at Hartree. MVPs with potential for significant growth and commerciality will lead onto the next component, Rising Stars.

Rising Stars

- Globally, the market potential for digitally focused businesses is significant. The Rising Stars component will aim to take digitally focused LCR companies with potential, and provide significant technical support to enhance their capability and enable them to scale.
- With Hartree's partnerships already including Intel, Atos and IBM UK, Rising Star candidates for the City Region will gain the engineering excellence to develop highly scalable solutions and the potential for global reach to achieve the ambition of 'Unicorn' businesses operating and remaining in our City Region.

The Wider Existing Context

'Deep Change' allows partner organisations in our emerging HP&CC cluster to co-ordinate their digital resources, assets, and expertise across the City Region to broaden the reach of existing work and collaborate to unlock the potential benefits of digital transformation for large or small business and public sector organisations. Already mentioned in the introduction, existing facilities, capabilities and programmes will be leveraged and newly-proposed initiatives will be included in to the 'Deep Change' plan.

The breadth of outline ideas generated through LCR consultation and existing programmes which tackle digital transformation is evidenced below and strengthens the case for 'Deep Change' to continue and extend the current work already underway.

Table 3: Examples of existing 'Digital Transformation' success flowing from HP&CC cluster activity in LCR

Project	LCR 4.0 (Liverpool City Region 4th Industrial Revolution)
Challenge	Transform Liverpool City Region businesses in the manufacturing space through digital innovation.
Partners	Virtual Engineering Centre, University of Liverpool, Hartree Centre, Liverpool John Moores University (LJMU), Sensor City Limited, ERDF
Outcome	By exploring the challenges and opportunities of Industry 4.0 together, LCR 4.0 helps SMEs to increase productivity and de-risk innovation.

PROJECT	Functional Material and Formulation of FMCG
Challenge	Shortening the time for Idea to idea to innovation

High Performance & Cognitive Computing

Partners	University of Liverpool, Materials Innovation Factory, Hartree, SCD, Unilever
Outcome	Unilever using existing collaborations with Hartree and Materials Innovation Factory can use a combination of Computer Aided Formulation and High Throughput Automation design and test new formulation of Home and Personal Care.

PROJECT	**Digitally Transforming the Nuclear Industry**
Challenge	Preventing corrosion in New Nuclear
Partners	University of Liverpool, National Nuclear Laboratory, STFC- Scientific Computing Department, Hartree Centre.
Outcome	Numerical model for coupling CFD and neutron kinetics that can examine the impact of nuclear reactions in the core region and at the walls. Effective training of Scientist to use the model

PROJECT	**STRIVE (Simulation Tools for Rapid Innovation in Vehicle Engineering)**
Challenge	Create a new 'digital' supply chain for the UK automotive sector.
Partners	Virtual Engineering Centre (University of Liverpool and Hartree), Bentley Motors Ltd, Northwest Automotive Alliance, OPTIS, Icona Solutions Ltd, DNA Agile, Advanced Manufacturing Supply Chain Initiative (AMSCI).
Outcome	The result is significantly reduced timescales for the development of new vehicles and enhanced build quality.

PROJECT	**The Living Hospital**
Challenge	Create a smart, cognitive hospital improving efficiency and quality of care
Partners	Hartree Centre, IBM, Alder Hey Hospital, Alder Hey Trust
Outcome	Creation of a cognitive application to improve patient engagement and experience being engineered for UK NHS roll out and additional £10m innovation funding for Alder Hey

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Strategic Case	The motivation for selecting our HP&CC Theme and developing the 'Deep Change' programme stems from an analysis of the significant opportunity for digital transformation, the need to provide addition expertise for automation particularly in manufacturing jobs (a significant employer in the City Region) and the potential and strengths of the City Region's existing partners in computational science engineering and digital transformation. The UK hosts four vendor-funded 'centres of excellence' for HP&CC in the UK. Of these, two are based at Daresbury (IBM UK Research) and (Atos Bull), in association with Hartree, with the other two (Cray Research and SGI) associated with the UK's other major HPC centre at Edinburgh. The centres at Daresbury are primarily focused on industry-relevant challenges and have the additional benefit of economies of scale and scope in the range of industrial engagements. This, and the other digitally-focused assets and skills in the City Region, are both nationally and internationally recognisable, and genuinely unique in their proximity. Throughout the SIA process, key regional partners have been consulted to help define and shape the programme proposed. 'Deep Change' carries forward existing relationships and projects in the City Region, which are demonstrating potential but are isolated and limited in scope. Initial HP&CC Theme ideas considered Skills and SME development as core foci; however, these were considered again limiting in their scope. Against this background, 'Deep Change' addresses previous limitations by leveraging the three key underpinnings to our emerging HP&CC cluster: • Physical assets and facilities e.g. Hartree, VEC, Sensor City, DIF, and MIF. • Knowledge excellence in the academic institutions e.g. the University of Liverpool (Big Data MSc and research in uncertainty quantification, robotics and autonomy, growing professional online education), and LJMU (applied computational science and research in sensors and networks). • Complementary City Regional programmes e.g. LCR 4.0 (providing digital transformation for SMEs combining Virtual Engineering Centre, University of Liverpool, Hartree Centre, Liverpool John Moores University, Sensor City Limited, ERDF), and the Hartree/IBM Cognitive Accelerator (providing cognitive transformational projects to Healthcare, industry and government). **Rationale for public sector intervention** Accelerated global competition and disruption • Businesses globally are entering a period of unprecedented technological change where internet of things and the application of machine learning and data analytics is accelerating productivity gains and innovation at a pace previously not seen leading to intense competition. The risk of not starting on the journey is that competition can enter global markets overnight, leaving laggards behind.

- "The democratization of technology (driven by its plummeting cost), increased access to funds and a rising entrepreneurial culture means that there are now hundreds of start-ups attacking traditional markets. Uber, Twitch, Tesla, Hired, Clinkle, Beyond Verbal, Vayable, GitHub, WhatsApp, Airbnb, Matternet, Snapchat, Homejoy, Waze and the list goes on. These start-ups are achieving scale far quicker than analog companies ever did. Whereas the average Fortune 500 company took 20 years to reach a market capitalization of $1 billion, Google managed it in eight years, and the likes of Uber, Snapchat and Xiaomi in three years or less."62
- Continuing market uncertainties, exacerbated by BREXIT, mean that industry is ripe for local partnerships which enable them to drive down operating costs by improving operational efficiency.

Challenges of Technology Transfer

Tech transfer challenges and cultural differences compound these issues e.g. inadequate technical infrastructure to use novel technology effectively and insufficient financial/staffing resource to benefit from technology transfer or training opportunities.

The gulf in maximising the outcome for UK industry from technology transfer between the world class research and science base has most recently been highlighted in the Dowling review (Dowling 2015).

- Public support for the innovation system is too complex.
- People are central to successful collaborations.
- Effective brokerage is crucial particularly for SMEs and continued support is needed for activities that help seed collaborations.
- Pump prime funding would stimulate the development of high quality research collaborations with critical mass and sustainability.
- Technology transfer offices need to prioritise knowledge exchange over short term income generation, and further work is required to improve approaches to contracts and IP agreements.
- Government strategy on innovation needs to be better coordinated and have greater visibility.

Societal impacts

Digital technologies are considered widely as a means to deliver business-as-usual, rather than consider the potential for digital transformation to drive and inform policy decisions. At a national level, the UK leads globally at becoming an 'open data society', however this transformation has typically been adopted by external entrepreneurial organisations rather than providing internal business improvements which drive firm/organisational-level societal benefits, such as employability, sustainability and trust.

[62] http://reports.weforum.org/digital-transformation/wp-content/blogs.dir/94/mp/files/pages/files/digital-enterprise-narrative-final-january-2016.pdf

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	The OECD have published Recommendation on Digital Government Strategies63 under three headings: • Set strategic digital government objective • Ensure the coherent use of technology across policy areas and levels of government. • Strengthen capacities to support better implementation of digital government strategies. • Centrally, the UK is clear about these strategic objectives. However, support to deliver operational improvements is limited. • The 'Deep Change' programme has been designed to address each of the business, technology science interaction and wider government and societal opportunities but these will not take rise unless intervention happens.
Economic Case	As our SIA analysis shows, we have significant strengths and huge potential to embed the application of HP&CC technology throughout all our innovative and globally-significant sectors, which employ over 175,000 in Advanced Manufacturing, Digital and Creative, Financial and Professional Services, Health and Life Sciences, Low Carbon Energy, Maritime and Logistics. Sci Tech Daresbury currently has a growing cluster of data-centric companies with almost 400 people working in over 20 organisations in data-intensive computing. They form a community of over 100 science and technology businesses generating an estimated gross GVA impact of almost £100m pa. Now home to technology giant IBM's Research base, with a £200 million investment in IP and a package of technology and onsite expertise, IBM Research capability at Hartree is a UK first. The main outcome of Deep Change will see firms – small, medium and large – and public-sector organisations tackling the root causes and barriers to adopting new technologies, and supporting the creation of new markets for disruptive technology, leading to a supply of new tech companies and service delivery organisations to meet rising market demand. The Tech City UK and Nesta Tech nation survey 2016 found that many UK tech firms are being held back by a weak economic climate. The UK Small Business Survey shows that 37% of businesses in the ICT industry feel they are weak in entering new markets, and 24% report they have difficult in introducing new products and services. The estimated benefits arising from funding 'Deep Change' is dependent on increased awareness adoption of software tools for digital transformation. The World Economic Forum found that digital transformation applied to business and government has the potential to unlock $100 trillion in value to business and society between 2015 and 2025. This said, the effect on employment is challenging with, for example, retail sector digital transformation expected potentially to reduce employed staff. For the cost of £18.5 million to deliver 'Deep Change', the total GVA created for a 5-year period following the project would be £60 – 150 million net contribution. This wide range takes into account outcomes depending on the success of the Rising Star component of our programme in embedded

[63] http://www.oecd.org/gov/digital-government/recommendation-on-digital-government-strategies.htm

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the HP&CC into organisations.

Financial Case

The table below sets out the likely costs for the programme of work which 'Deep Change' comprises. Our proposed pilot stage will test and reduce risk in the full -blown programme which will follow.

Phase	*Participant*	*Contribution*	*Costs per project (k)*	*Total Programme*	*Output*
Pilot Study	Hartree	Resource, systems and background IP	150	450	3 x MVP
	SME	Resource			
	LMU	Resource			
	UoL	Resource			
	DIF	Resource and facilities			
	Sensor City	Resource and facilities			
	ATOS	Background IP			
	IBM	Background IP			
Discovery	Hartree	Resource and systems	2,500	2,500	Online training (10,000 individuals) f2f training (2500 individuals)
	UoL	Resource			
	LMU	Resource			
	DIF	Resource and facilities			
	VEC	Resource and facilities			
	Sensor City	Resource and facilities			
Accelerator	Hartree	Resource	25	5,000	Digital Tranformation Roadmap (200 organisations)
	SME	Resource			
	UoL	Resource			
	LMU	Resource			
	VEC	Resource			
	DIF	Resource			
	Sensor City	Resource			
	Client	Resource			
Build and Test	Hartree	Resource, infrastructure and background IP	100	5,000	MVP (50 solutions)
	ATOS	Resource, infrastructure and background IP			
	IBM	Resource, infrastructure and background IP			
	SME	Resource and background IP			
	UoL	Resource and background IP			
	LMU	Resource and background IP			
	Client	Resource and background IP			
Solution Engineering	Hartree	Resource and background IP	600	3,000	Hardened solution ready for scale (5 solutions)
	ATOS	Resource and background IP			
	IBM	Resource and background IP			
	SME	Resource and background IP			
	Client	Resource and background IP			
Deployment	Hartree	Resource, infrastructure and background IP	500	2500	Embedded transformational capability (5 solutions)
	SME	Resource, infrastructure and background IP			
	ATOS / IBM	Resource, infrastructure and background IP			
	Client	Resource, infrastructure and background IP			
			Total	18,450	

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Management Case	We highlight two key projects in our existing digital transformation programme which shaped the approach that 'Deep Change' will take. • Computer-Aided Formulation with Unilever. Production of a computer aided formulation tool that enabled virtualisation of product formulation (shampoo, fabric softener) stability tests reducing the process down from 8-12 weeks' wet lab time to 45 mins of simulation time. Hartree also developed an 'app' to enable the computation to be run from an iPad interface thus increasing the technology's usability by allowing remote access from any location. This project provides the springboard for Unilever to accelerate product discovery and testing and improve the efficiency of its operations through the adoption of digital technologies and tools, making substantial savings in time and money. • Hartree/IBM UK's Cognitive Accelerator. This has generated a roadmap for Alder Hey Children's Hospital on how to adopt IBM Watson Cognitive Computing technologies to meet its mission to provide research excellence, the best quality of care and an enhanced patient experience. An initial application was developed which allows patients to learn about their procedure and the hospital and ask questions that concern them. There are many benefits, including more efficient use of the clinician's time during appointments via reduction of administrative burden. Akin to aims of 'Deep Change' Programme, a digital solution was developed from a technology partner that solved a specific challenge within an organisation – in this case allowing doctors to spend more time with patients and less time doing paperwork, whilst enhancing the efficiency of service provided to the patient. 'Deep Change' is therefore based on Hartree's and its partner's existing capabilities in driving adoption of disruptive technologies. Standard project and programme management principals will underpin delivery with over-arching governance managed by regular programme review boards. Key milestones are in the Gantt chart. below. Opportunities for major private-public partnerships exist throughout the programme.
Timeline and milestones	The timeline for 'Deep Change's' piloting and full-blown delivery is given in the Gantt chart below.

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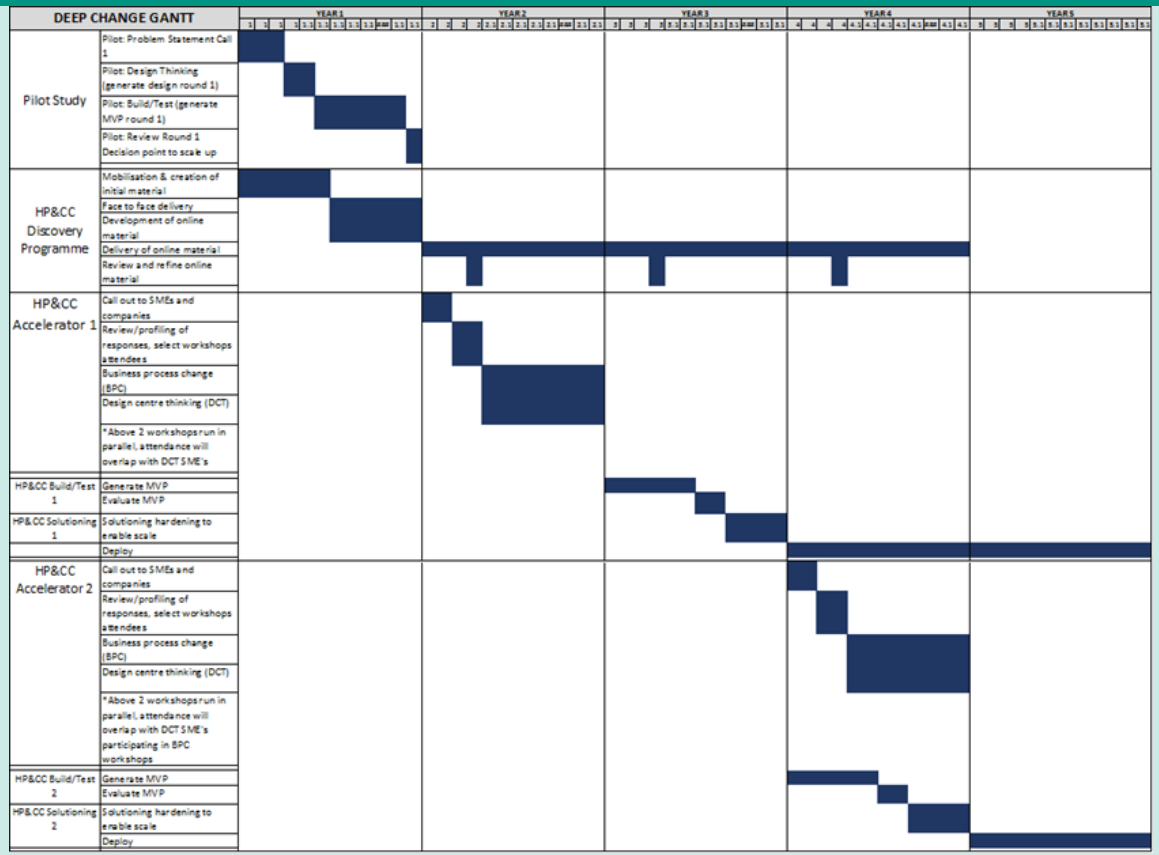

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- You can contact us via lcrsia@liverpoollep.org
- This SIA report, the summary report and further information can be accessed via our website www.liverpoollep.org/lcrsia