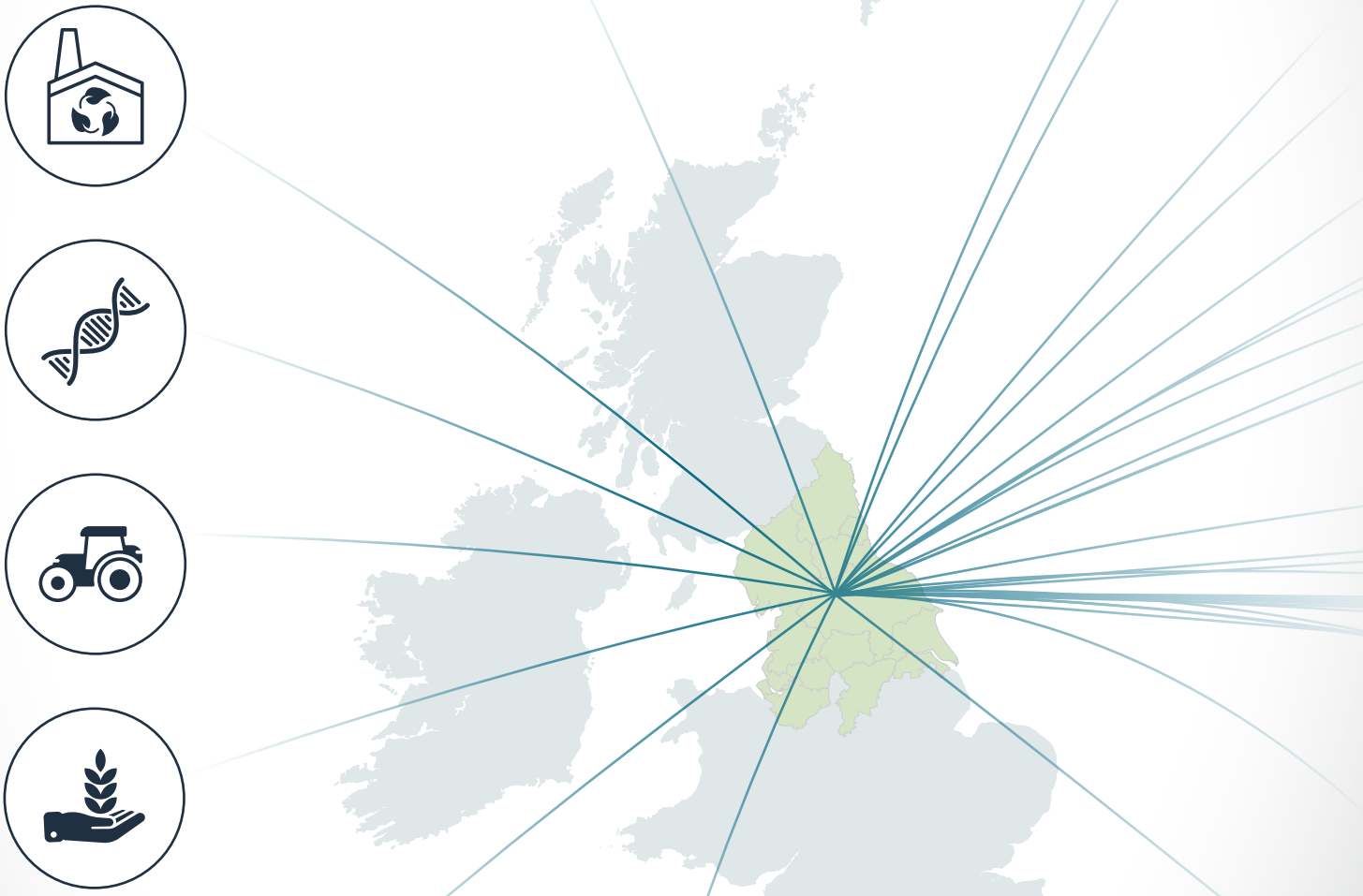
Full Report

August 2017

THE BIOECONOMY IN THE NORTH OF ENGLAND



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Writing and editorial team:
Jeff Eaves, University of York
Alison McQuilkin, University of York
Mark Mortimer, University of York
Richard Smith, University of York

Steering group:
Will Cannon, Croda
Joanna Counsell, Cogent Skills
James Davies, North East Local Enterprise Partnership
Lynn Frewer, University of Newcastle
Matt Goodwin, Centre for Process Innovation
Sarah Hosking, Unilever
Tony Lopez-Sanchez, University of Liverpool
Rick Mumford, Fera
Gesa Reiss, York, North Yorkshire & East Riding Local Enterprise Partnership
Joe Ross, BioVale
Deborah Smith, University of York (Chair)
Keith Wilson, Tees Valley Combined Authority

Other contributors and reviewers:
Ruth Alcock, Lancaster University
Rob Ashworth, University of Liverpool
Steve Bagshaw, FUJIFILM Diosynth Biotechnologies
Fabien Deswarte, Biorenewables Development Centre
Les Firbank, University of Leeds
Sam Gardner, University of York
Anna Grey, University of York
Mike Hartley and team, Kepier & Co.
Adrian Higson, NNFCC Ltd
Richard Hindle and team, SQW
Chris Holroyd, Lancaster University
Estefanía Ledesma Santiso, University of Leeds
Charles Martinez, Elsevier
Maggie McGowan, University of Hull
Paul McKenna, Lancaster University
Nicola Meenan, University of York
Jonathan Oxley, N8 AgriFood
Cristina Rosemberg, Technopolis
Paul Simmonds, Technopolis
Margaret Smallwood, BioVale
Jen Vanderhoven, CBMNet, a BBSRC Network in Industrial Biotechnology and Bioenergy, University of Sheffield
Bartek Wytrzyszczewski, University of York

Editing, design and layout: Green Ink (www.greenink.co.uk)

University of York
York
YO10 5DD
United Kingdom
www.york.ac.uk

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(available online at: www.york.ac.uk/research/the-bioeconomy-in-the-north-of-england-sia/)

Forewords

The bioeconomy is important. It encompasses the use we make of living things and their products as feedstocks into our society and economy. There has been no time in history when we have had a greater ability to use the natural capabilities of living organisms, and no time when we have had a greater need to do so responsibly and effectively.

Our nation is at the forefront of scientific developments that allow us to unlock the potential of different forms of biomass, be they microbes, plants, animals or 'waste products' from all three. Advanced agri-food technologies underpin the productivity and security of our food chain, and products we currently source from petrochemicals are becoming increasingly accessible through the creative exploitation of industrial biotechnology. In the North of England, where there are excellent universities, research organisations, and concentrations of food and drink, chemicals and pharmaceuticals production, we are particularly well organised to exploit scientific advances to grow the bioeconomy, and our region has the collective skills and determination to do so.

This science and innovation audit on the bioeconomy in the North of England comes at an important time as the government prepares its industrial strategy and we consider our future outside the European Union. Countries that can best exploit our rapidly expanding understanding of how living things produce complex and useful materials will win the race to clean, sustainable and profitable economies. This is the moment to invest in ensuring that the UK leads that race.

Steve Bagshaw CEng FIChemE
Chief Executive Officer, FUJIFILM Diosynth Biotechnologies
Chair, Industrial Biotechnology Leadership Forum

Strong economic growth in the North of England is essential for the continuing prosperity of the United Kingdom. To secure that growth, we must enhance productivity through innovation in sectors with the greatest potential. Our distinctive capabilities in the bioeconomy, as evidenced in this science and innovation audit, build on strong universities (including the N8 research-intensive institutions), colleges and research organisations, working in close and productive partnership with the powerful industrial presence in the region. Using the region's population of skilled workers to leverage these capabilities will offer us better use of our natural resources, greater prosperity and a low-carbon future.

This audit lays the foundations for accelerated action on the bioeconomy, understanding and exploiting our particular strengths through collaboration and strategic investment. The act of producing it has built common purpose across our regional organisations in every part of the innovation supply chain. Whether focusing on new technologies for agricultural application or the unique opportunities presented by innovation in industrial biotechnology, there has never been a more important time to harness our expertise for the benefit of all.

Professor Koen Lamberts
Vice-Chancellor, University of York
Chair, N8 Research Partnership

Executive summary

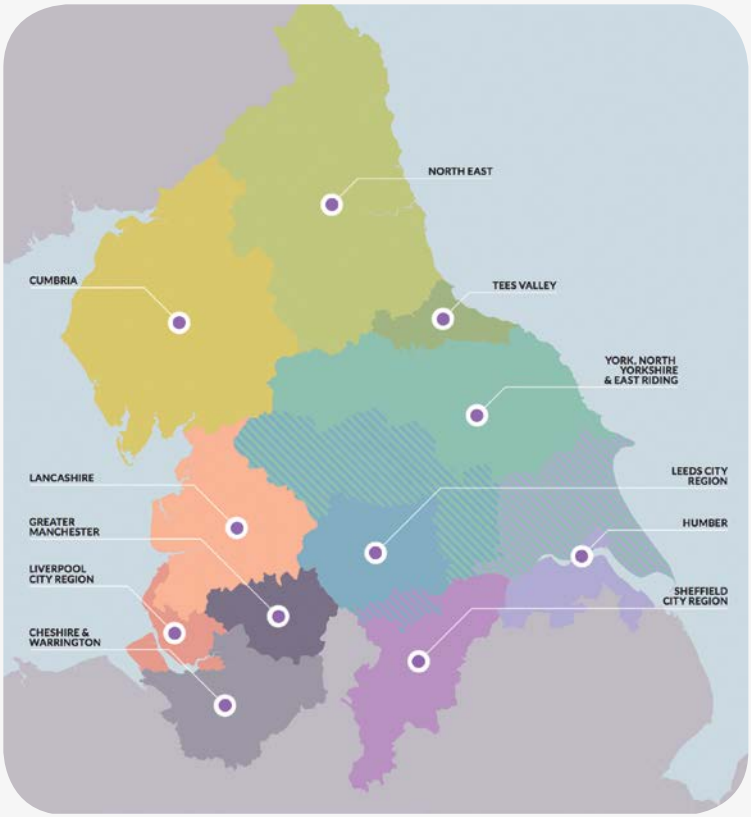
Introduction

In autumn 2015, the UK government announced regional science and innovation audits (SIAs) to catalyse a new approach to regional economic development. SIAs enable local consortia to focus on analysing regional strengths and identifying mechanisms to realise their potential. One such consortium in the North of England has assessed regional strengths and opportunities in the bioeconomy. This report presents the results, which include a broad-ranging analysis of the North of England's bioeconomy capabilities, and highlights the challenges and substantial opportunities for future economic growth.

We are pleased to have the opportunity to present the case to the UK government that the North of England has the facilities, specialised research and innovation capability, and industrial capacity to deliver a world-leading bioeconomy based on agri-science, agri-technology and industrial biotechnology, with the potential to alleviate pressing societal challenges. This is a substantial economic opportunity for the region, one that is rooted in its existing process industry infrastructure and skills, its research and innovation expertise (which includes world-class universities), its proven capability in technology translation, and its strong connectivity through good logistics, supply chains and networks.

The SIA consortium is led by the University of York and includes small and large companies, universities, agricultural colleges, the science skills body Cogent Skills, translational organisations working between research and industry, and Local Enterprise Partnerships (LEPs). The geography of the audit is covered by the 11 LEP areas shown in Figure 1.

FIGURE 1: THE 11 LEPS IN THE NORTH OF ENGLAND



National and international context

The challenge

Over the next 30 years, the world population will exceed 9 billion and the global economy will quadruple, with people becoming increasingly affluent. Almost 70 per cent of the population will live in urban areas. Food and energy demand will double, with renewable sources including biofuels and bioenergy accounting for 10 per cent of commercial supplies. Pressure on the environment and competition for land will intensify as demand for food and animal feed increases. Climate change mitigation will require the cultivation of crops for energy and the production of bio-based ingredients to displace petrochemicals. The bioeconomy will have a major part to play in the transformation of global systems to meet these challenges.

The opportunity

Agri-tech and industrial biotechnology provide technological tools to address these issues by improving agricultural resilience, securing food supplies and offering non-petrochemical routes to industrial feedstocks. Agri-tech involves bioscience and bioengineering approaches to improving agricultural productivity by reducing crop and livestock inputs and developing improved crop varieties. Industrial biotechnology harnesses plants and microbes to create novel foods, products and materials, as well as sustainable feedstocks for the agri-food and chemicals industries. It also adds value to waste streams.

The bioeconomy

This report adopts the following definition of the bioeconomy: "The bioeconomy is the production of biomass and the conversion of renewable biological resources into value-added products, such as food, bio-based products and bioenergy".[1] Healthcare and therapeutic applications of industrial biotechnology are considered beyond the scope of this report, but the authors note that the biomedical sector involves similar underpinning expertise and is an important adjacent economic sector in the region, with the potential for technology crossover.

It has been estimated that more than half of total agricultural output and 35 per cent of chemicals and related industrial output will depend on biotechnology by 2030.[2] In recognition of the importance of the bioeconomy, at least 26 nations have introduced specific strategies to address it,[3] and several countries have taken active steps to promote it. For example, since 2002, the US BioPreferred programme has required federal agencies to purchase bio-based products preferentially.

The combined bioeconomy of the UK, including upstream, downstream and induced components, is estimated to generate £220 billion in gross value added (GVA) (2014 figure) and to employ more than 5 million people.[4] Excluding agriculture, the UK's bioeconomy is the third-largest in the European Union after Germany and France. The UK is a leading country in the key areas of research and innovation that underpin the bioeconomy, and ranks first globally in terms of 'quality' of research, as measured by field-weighted citation.[5]

Vision for 2030

The consortium's vision is one of an integrated and innovation-driven product, process and service bioeconomy in the North of England. This will have the necessary critical mass to compete in the multi-trillion-pound global market for sustainable food, feed, chemicals, materials, consumer products and energy. Using advanced land management strategies and technology-enabled precision agriculture, the region's farms will cultivate diverse crops for food and non-food markets. Agricultural products, by-products and urban waste will be processed at regional biorefineries to produce foods, animal feeds and high-value chemicals

and materials, at the same time returning carbon and nutrients to the soil. Established chemicals clusters will have undergone a substantial transition to use locally produced and imported biomass feedstocks for the production of bulk bio-based chemicals. By 2030, the region will have gained global recognition for the production and conversion of biomass. Its international profile will attract inward investment into productive, knowledge-based businesses sustaining high-value jobs.

Key strengths

Science and innovation

The North of England has extensive research capability in the science that underpins the bioeconomy. It is comparable with the UK as a whole – a global frontrunner – and, in many regards, outperforms the rest of the country. The region is particularly distinctive for its success in winning funding for translational research, which is at a level well above the national average.

Assets and capabilities

There are over 16,000 companies providing absorptive capacity for innovation in the bioeconomy of the North of England. Collectively, they have an annual turnover of more than £91 billion and employ around 415,000 people. By turnover, food and drink represents around one-third of the regional bioeconomy and chemicals make up one-quarter. Large companies predominate in food and drink, chemicals and utilities.[6]

The close links between industrial biotechnology and the chemicals sector is particularly relevant to the region, where the process industries are a major employer. The bulk chemicals industry is located around the estuary ports where crude oil is imported, and biomass-processing companies are also starting to use seaborne logistics to import raw materials. The size of the opportunity can be gauged from a recent report that concluded 40 per cent of Italy's chemical industry could make the transition to bio-based production.[7]

The N8 Research Partnership[8] is one of the major science and innovation assets of the North of England, with proven collaborative skills in agri-food research. Other universities in the region have bioeconomy-relevant capabilities, including the consortium partners Sheffield Hallam University and the University of Hull.

Translational organisations are a major differentiator and unique strength for the North of England. These bodies have capital equipment and dedicated expertise with which to support business innovation. They include Fera Science Ltd in Yorkshire, which supports a range of aspects of agri-food innovation, including the safety and integrity of food supply chains 'from field to fork'. The Centre for Process Innovation on Teesside, home to the National Industrial Biotechnology Facility, and the Biorenewables Development Centre in York have both expertise in process development and the capability to scale up processes from the laboratory to full production. In addition, the Unilever–University of Liverpool Materials Innovation Factory brings high-throughput automation to the development of new, bio-derived consumer products.

The North of England has a distinctive set of bioeconomy assets, including world-class science, applied research excellence, translational expertise and industrial capacity. These can be mobilised to build economic value from agri-tech and industrial biotechnology, and achieve full exploitation of the bioeconomy to deliver jobs and economic growth.

Talent

Concentrations of skilled people working in the process and manufacturing industries are a strong basis for building a competitive advantage in bioprocessing. The region holds 38 per cent of the UK's chemicals industry workforce, 31 per cent of the polymers industry workforce,[9] and 36 per cent of apprenticeships[10] relevant to the bioeconomy. Six land-based colleges, including three of the five largest providers of land-based qualifications in England, are in our region and the universities in the North of England provide a quarter of UK science, technology, engineering and mathematics graduates.[11]

Growth opportunities

The products that will create future growth in the bioeconomy include: advanced biofuels and bio-based jet fuels; biochemical building blocks and bio-based plastics; novel foods; high-value chemicals from novel crops; functional foods and nutraceuticals; and novel crop varieties that are resistant to pests, diseases and climate-related stresses. It has been estimated that industrial biotechnology, biofuels and bioenergy could reduce global greenhouse gas emissions by 1.0–2.5 billion tonnes of carbon dioxide per year by 2030.[12]

The consortium's ambition is to double the size of the transformative bioeconomy in the North of England in GVA terms from £12.5 billion now to £25 billion in 2030. This will happen primarily through industry responding to economic drivers, but will be facilitated by specific interventions to catalyse growth and remove barriers.

The opportunities to achieve this include:

- making the transition in the chemicals industry to become significantly bio-based
- academic collaborations with major innovation-active companies, such as Croda and Unilever, and encouraging more large companies to pursue open innovation
- supporting disruptive innovators to thrive in the region and bring new products and services to market
- supporting the scale-efficient food- and feed-processing industries to establish competitive advantage in bioeconomy products (e.g. by producing protein from non-animal sources).

Gap analysis

As stated, the key ambition is to double the size of the transformative bioeconomy in the North of England by 2030. The SIA has identified the main strengths and weaknesses regarding this goal. Combining this analysis with the vision for 2030, feedback from consortium members, primary research with industry participants in the region, and an understanding of what has been critical for success in other regions around the world, gives a clear view of the gaps that need to be filled (see Table 1 overleaf).

Table 1. Gap analysis

Current state We have…	2030 state We want to be…	Next steps
Strong sector-specific research and a differential strength in translating research into innovation, but this is not fully coordinated	Strategic and joined up in our approach to innovation, accelerating new products and processes to market	Establish a single-entity 'Northern Bioinnovation' to own the vision and coordinate innovation support for businesses in the regional bioeconomy
Used European Union economic development funding to accelerate innovation via short-term applied research projects with our open access innovation centres	Providing a comprehensive 'innovation to market' support service to industry through integrated, self-sufficient applied research and scale-up centres funded by large businesses, and providing public sector support for market access for small- and medium-sized enterprises	Provide a five-year innovation support programme managed by Northern Bioinnovation, including the following components: • innovation research projects • skills development • capital grants to support innovation
No real cluster of innovation activity based around commercial-scale processing of biomass	Driving economic activity and innovation through bioclusters, providing a focal point around which publicly funded support can be channelled to assist early-stage insurgent companies developing disruptive technologies	Establish the first biocluster as an 'advanced bio-manufacturing park' based around a central biomass process such as sugar production and providing demonstration facilities for new added-value processes using secondary product streams
Joined-up applied research capability in agri-food that combines the work of eight universities	World-leading in our connected industrial biotechnology and agri-food applied research, offering scale and single point of contact benefits to industry	Extend the collaborative 'N8 AgriFood' approach to industrial biotechnology and challenge universities to develop a pipeline of technologies that can be commercialised within the bioeconomy
Transport bottleneck east–west across the Pennines	Able to move substantial quantities of biomass around the region as part of a high-capacity transport network	Begin the process of planning the logistics implications of an economy using much larger quantities of biomass
Regional, non-sector-specific venture funds providing seed funding to emerging businesses	Allowing insurgent bioeconomy companies to access £10–30 million of capital to establish production facilities	Investigate the formation of a substantial (£100 million plus) bioeconomy venture fund for the region
An uncertain policy framework for biofuels and bioenergy, and no equivalent renewables incentives for using biomass for higher-value products	Operating under a policy regime that actively promotes the replacement of petroleum-derived with biomass-derived products and gives the process industries a reason to change their supply chains	Government review of the policy framework for biorenewables and adoption of an equivalent of the US BioPreferred programme

CHAPTER 1
INTRODUCTION

5 million

jobs directly and indirectly supported by the UK bioeconomy

1 Introduction

We are pleased to have the opportunity to present the case to the UK government that the North of England has the facilities, specialised research and innovation capability and industrial capacity to deliver a world-leading bioeconomy based on the region's strengths in the areas of agricultural technology (agri-tech), agri-science and industrial biotechnology.

The bioeconomy sits at the intersection of new technology with existing economic activity, where there is strong scope for creating new economic value through challenge-driven research and innovation. The bioeconomy can be understood as the application of advanced biotechnology to agriculture and industry, and has the potential to alleviate a series of pressing societal challenges globally. It constitutes a substantial opportunity for the region.

This science and innovation audit (SIA) consciously regards the bioeconomy as an integrated whole, rather than addressing different supply chains (e.g. food, industrial biotechnology, bioenergy) separately. Developments in the bioeconomy will tend to integrate the production of food with the manufacture of materials, chemicals and fuel through the 'biorefining' of biorenewable raw materials from agriculture, aquaculture and forestry. Commercial biorefining already exists in the UK. Examples include the Vivergo plant in Hull (which uses feed wheat to produce both biofuel and a protein-rich animal feed for the livestock industry) and the British Sugar plant at Wissington (which uses sugar beet to produce sugar, bioethanol, animal feed and biogas, as well as other products).

Biorefineries can choose to optimise the production of both food and chemicals. The success of the Brazilian sugar cane industry is partly based on its ability to switch between the production of sugar for food and feed markets and the manufacture of bioethanol, depending on the demand for these commodities. These facilities are emerging in Europe, for example the commercial-scale biorefinery at Bezancourt-Pomacle in northern France, a member of the larger regional Industry and Agro-Resources (IAR) cluster.[13] Many opportunities for innovation in the bioeconomy are characterised by the concept of the biorefinery, and will arise from technology transfer between adjacent and related sectors and from linking different supply chains to maximise total value.

This audit adopts the overall definition of the bioeconomy used in the 2016 report *Evidencing the Bioeconomy,* commissioned by the Biotechnology and Biological Sciences Research Council (BBSRC) and the Department of Business, Innovation and Skills: "The bioeconomy is the production of biomass and the conversion of renewable biological resources into value-added products, such as food, bio-based products and bioenergy". In that report, the size of the UK's 2014 bioeconomy, including upstream, transformative, downstream and induced components but largely excluding the biomedical sector, was calculated at £220 billion gross value added (GVA) and estimated to support 5.2 million jobs.[14,15]

Healthcare and therapeutic applications are considered to be beyond the scope of this audit,[16] and other SIAs within the North of England are looking at health-related sectors. For example, the Greater Manchester and Cheshire East SIA, published in 2016, looked at industrial biotechnology in healthcare applications. The Leeds City Region Wave 2 SIA focuses on medical technology, and the Liverpool City Region Wave 2 SIA has a strand on infection. The biomedical sector develops and deploys similar expertise and scientific resources, and biomedicine is therefore an adjacent sector with the potential for technology crossover. Advances and innovations in, for example, biologics, sensors and biopharmaceuticals – areas that are also considerable regional strengths – will be applicable across the range of sectors embraced by the bioeconomy, including agriculture, chemicals, food and drink, and others.

1.1 Vision for 2030

The consortium's vision is one of an integrated and innovation-driven product, process and service bioeconomy in the North of England, with the critical mass to compete in the multi-trillion-pound global market for sustainable food, feed, chemicals, materials, consumer products and energy. Vibrant networks will catalyse new cross-sectoral supply chains and partnerships that ensure biomass flows to the highest-value applications.

By 2030, the region will have gained global recognition for the production and conversion of biomass. Its international profile will attract inward investment into highly productive, knowledge-based businesses that offer sustainable, high-quality jobs.

The region's farms will use advanced land management strategies and technology-enabled precision agriculture to cultivate diverse crops that have been tailored using fast-track, genomics-based breeding for use in both food and non-food markets. Agricultural products, by-products and urban waste will be processed at flexible regional biorefineries that are able to handle and process a range of materials to produce foods, animal feeds, and high-value chemicals and materials, as well as returning carbon and nutrients to the soil. These biorefineries will be formed from clusters of companies benefiting from common logistics and utilities. The production of bulk bio-based precursors alongside petrochemical-based analogues in the region's established chemicals clusters will consume locally produced and imported feedstock. They will benefit from dedicated supply chains and use biotechnology and green chemistry to pre-treat and extract value from raw biomass, while regenerating their local communities by providing new, high-productivity jobs.

New skills will enter the workforce. Chemical engineers will be familiar with biological processes, high-viscosity fermentation broths and cell cultures. Farmers will understand the value and agronomy of new crop varieties and will be able to reduce agricultural inputs and preserve soil health. Horticulturalists will produce crops year-round using advanced lighting technology. Innovation chains will deploy agri-science and industrial biotechnology to support manufacturing sectors, drawing in skilled workers with prospects of high-value jobs and career progression.

An integrated network of industry support, linking universities, contract research organisations and specialist business services across the region, will deliver the help that innovative companies need to grow and ensure innovation crosses between the food and drink, pharmaceutical and chemicals industries. Further education colleges and universities will teach the new skills required to drive the bioeconomy. Financiers will have dedicated funds to support emerging clusters of biotechnology companies, funding both technology-based start-ups and new ventures for existing concerns.

1.2 The SIA process

This report is based on the hypothesis that the North of England has the assets, specialised research and innovation capability, and industrial capacity to deliver a world-leading bioeconomy based on agricultural technology, agri-science and industrial biotechnology.

The core foundations of this hypothesis are:

- **Capability to research and translate:** The bioeconomy requires fundamental research into relevant technical areas, and facilities and skills to translate research findings into market-ready products, processes and services.

- **A sound infrastructure base:** The bioeconomy will be developed from existing infrastructure and investment in process plant and logistic capability, able to produce and move large volumes of biomass-derived products.
- **Skilled people:** People with entrepreneurial capability and skills in science, technology, engineering and mathematics (STEM) – particularly in such areas as agri-tech, industrial biotechnology, chemical transformations and food processing – will build the bioeconomy.
- **Connectivity:** The bioeconomy requires new supply chains and effective networks to ensure that innovative products, processes and services are brought to market.

Analysis of these foundations has informed the conclusions and recommendations given in this report.

The consortium delivering this SIA is led by the University of York and comprises members that are actively engaged across the bioeconomy in research, innovation and/or economic delivery, as well as cross-cutting stakeholders in regional policy and skills provision. Consortium members are listed in Appendix A. The consortium builds on existing networks and established contacts, and reflects a consensus among members that the North of England, while incorporating established sub-regional groups and linked in many ways to national initiatives, is an appropriate and functioning geography in which to conduct collaborative activities in the bioeconomy.

In order to gain as comprehensive a view as possible of this hypothesis and its foundations, the consortium has called on the expertise of a wide range of industry, academic, research and public sector support (see Figure 2). The consortium includes all members of the N8 Research Partnership, which comprises the research-intensive universities in the North of England,[17] other regional universities with specialist capabilities, representatives of the region's agricultural colleges, and the science skills body Cogent Skills. Several technology translational organisations are participants, including Fera Science Ltd (Fera), the Biorenewables Development Centre (BDC) and the Centre for Process Innovation (CPI). Members also include a number of small and large companies, characterised by their open approach to innovation and, in many cases, providing an industry perspective to national and regional policy bodies. Finally, the region's Local Enterprise Partnerships (LEPs) are strongly represented.

The consortium achieves two distinctive synergies:

- **Innovation chain:** The consortium includes different perspectives on the bioeconomy, from scientific research through productivity innovation to consumer-driven replacement of non-renewables in bio-derived manufactured products. Consortium members in different parts of the region bring an appreciation of how related expertise and capability in such areas as life sciences, materials science and chemistry interface with our research and innovation focuses of agri-tech and industrial biotechnology.
- **Economic value chain:** The consortium links the main producers and manufacturers of the regional economy, from farmers producing commodity foodstuffs and biomass, to chemicals, materials and energy suppliers processing bio-transformed raw materials, to companies making food, drink and other consumer products, thereby integrating industrial absorptive capacity across the productive sectors.

The consortium has also commissioned research from the Department for Business, Energy & Industrial Strategy (via its data contractor Technopolis Group), Cogent Skills, Kepier and Co. and SQW Consulting. A full list of writers and reviewers is given in the acknowledgements.

FIGURE 2: MEMBERS OF THE CONSORTIUM

CHAPTER 2
WHY THE BIOECONOMY? TRENDS AND DRIVERS

9 billion
world population by 2050

100%
increase in energy and food demand by 2050

>50%
of agricultural output will depend on biotechnology by 2030

13.6%
of UK GVA is underpinned by the bioeconomy

3-7%
reduction in global carbon emissions through industrial biotechnology and bioenergy by 2030

€13 billion
global sales of bio-based polymers in 2016

219 billion
litres of biofuel will be consumed per annum by 2020

2 Why the bioeconomy? Trends and drivers

The bioeconomy (see Figure 3) draws together economic activities undergoing considerable growth. The bioeconomy integrates the production of food with the manufacture of materials, chemicals and fuel through the biorefining of biorenewable raw materials from agriculture, aquaculture and forestry. Demand for agriculture, forestry and fishery products is growing globally, and the market for sustainable and naturally sourced products is seeing particular expansion in developed economies.[18] At the same time, ecosystems continue to be overexploited. Climate change mitigation requires a reduced dependence on fossil fuels, while agricultural productivity needs to increase. Achieving sustainable lifestyles requires changes in food production and consumer behaviour and, ultimately, the adoption of a circular economy.[19]

Against this backdrop, innovations in physical, biological and chemical processes that transform biomass – the 'transformative bioeconomy'[20] – are being developed. Advances in one sector, feed for livestock for example, can be applied in others. Thus, fast-track crop breeding techniques can produce varieties of grain with a straw that cattle can digest more easily. This would result in novel applications of the new straw as an animal feed, and as a feedstock for biofuel or chemicals production. Such innovation is being driven by both sizeable incumbent companies adopting new technologies and insurgent companies developing disruptive technologies.[21] The bioeconomy is developing rapidly across the world and represents a major opportunity for the UK to both drive and derive economic benefit.

2.1 Global and national drivers of the bioeconomy

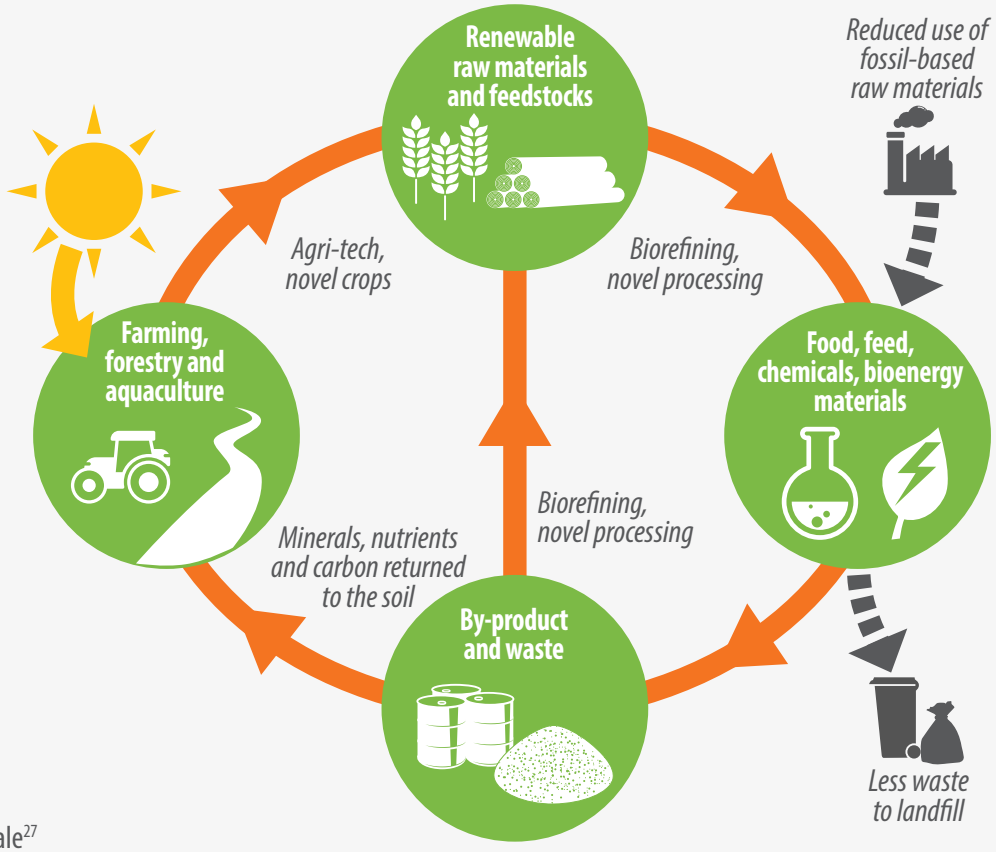
According to the Organisation for Economic Co-operation and Development (OECD), the world population will grow to more than 9 billion over the next 30 years.[22] Over the same time period, the global economy is forecast to quadruple, with people becoming increasingly affluent and almost 70 percent living in urban areas. Food and energy demands are expected to double, with renewable sources including biofuels and bioenergy accounting for 10 per cent of commercial supplies. Pressure on the natural environment and competition for agricultural land will intensify as a larger, more prosperous population requires more food and animal feed. Policies designed to combat climate change will encourage the cultivation of crops for energy and bio-based ingredients to displace petrochemicals.

The resource demands implied in these projections require new technological solutions. Agri-tech (the adoption of modern technology in the agri-food supply chain) and industrial biotechnology are cross-cutting technologies that contribute to improving agricultural resilience, securing food supplies and industrial production, and mitigating climate change. Agri-tech will deliver the sustainable intensification of agriculture by allowing greater productivity with lower inputs. Industrial biotechnology harnesses the production powers of plants and microbes to create novel products and materials, produces sustainable feedstocks for the chemical and food industries, and adds value to waste streams. Microbial processes can convert simple molecules, such as carbon monoxide, carbon dioxide (CO_2) and methane, into more complex molecules and, therefore, into more valuable food and chemical products.

2.1.1 A large, growing and actively supported bioeconomy

A 2014 report published in *Nature* estimated that bioeconomy products accounted for 13 per cent of global exports with a value of about $2 trillion, representing a 10 per cent increase from 2007.[23] The OECD estimates that more than half of agricultural output and 35 per cent of chemicals[24] and related industrial output will depend on biotechnology by 2030.[25] In 2011, the European Union (EU) bioeconomy had a turnover of more than €2 trillion, with around 25 per cent derived from non-food products. EU employment in the biotechnology sector is estimated at 17 million people (8.5 per cent of the EU workforce) with the majority of jobs in agriculture.[26]

FIGURE 3: THE BIOECONOMY



Source: BioVale[27]

The consortium has identified at least 26 nations with published bioeconomy strategies and some level of active support for the sector.[28] Since 2002, federal agencies in the USA have been required to purchase bio-based products preferentially under the BioPreferred programme. In 2014, the bio-based products industry in the USA had grown to generate $393 billion GVA and more than 4 million jobs.[29] That same year, bio-based feedstocks displaced 1 trillion litres (6.8 million barrels) of petroleum, reducing CO_2 emissions by 10 million tonnes. The ongoing growth of bio-based products continues despite a 50 per cent decline in the price of oil during 2014. In the EU, the Renewable Energy Directive, which mandated a 10 per cent share of renewable energy in transport by 2020, has been instrumental in driving the consumption of biofuels.[30]

2.1.2 Expanding use of biofuels and bioenergy

The International Energy Agency (IEA) has estimated that the global use of bioenergy for power will increase from approximately 475 terawatt hours (TWh) in 2016 to approximately 586 TWh in 2020, a compound annual growth rate (CAGR) of 5.4 per cent.[31] The IEA also estimates that global biofuels production will increase from 139 billion litres in 2016 to 144 billion litres in 2020, a CAGR of 1 per cent. Little growth in biofuels is expected in the USA, which currently represents approximately 43 per cent of worldwide demand, but growth is expected in Europe and especially in Asia.[32] An alternative view from Global Industry Analysts is that biofuel consumption will grow to approximately 219 billion litres by 2020, driven by increased fuel efficiency from biofuels coupled with government support.[33]

Bioethanol is the largest-volume biofuel currently produced. It is made from corn starch in the USA and from sugar cane and wheat in the UK, prompting competition for agricultural land between food and

fuel. Commercial quantities of 'second-generation' bioethanol are now becoming available.[34] Second-generation bioethanol uses cellulosic material (wood, grass and agricultural waste)[35] to produce ethanol from biochemically or hydrothermally treated biomass through fermentation or the action of enzymes. Optimisation requires robust microbial strains and enzymes, as well as new, more digestible lignocellulosic feedstock that may find applications in animal feed as well as biofuel production.

Exploitation of by-products such as lignin, co-products such as animal feed, and production side-streams of high-value chemicals will ensure that biomass is used and reused (returning nutrients and carbon to the soil) before finally being burnt for energy.[36] The World Wide Fund for Nature estimates that industrial biotechnology and bioenergy have the potential to reduce global greenhouse gas emissions by between 1 billion and 2.5 billion tonnes of CO_2 per year by 2030 (3–7 per cent of total global emissions in 2013).[37]

2.1.3 Bio-based feedstocks to replace oil

A recent report estimates that 40 per cent of Italy's chemical industry can make the transition to bio-based production.[38] In the North of England, this would equate to approximately £2 billion in GVA. Worldwide production of bio-based products, including biofuels, renewable chemicals and bio-based polymers, is projected to grow from approximately $203 billion in 2015 to $400 billion by 2020 and $487 billion by 2024.[39]

Bio-based polymers are important products in the emerging bioeconomy. Although many biopolymers are similar to synthetic plastics, others biodegrade more readily or deliver novel benefits. Production costs can be reduced by using more resilient bacterial strains that break down cheaper feedstocks, such as food processing by-products and municipal waste.[40] In 2016, global sales of bio-based polymers were €13 billion, with partly bio-based 'drop-in' replacement polymers dominating the market. Production of novel 100 per cent bio-based biopolymers also increased.[41] Despite low oil prices, global production capacity is forecast to grow from 6.6 million tonnes in 2016 to 8.5 million tonnes in 2021; this represents a 2 per cent share of the polymer market as a whole. Due to better access to feedstock and a favourable political framework, much of the capacity growth will be in Asia, although demand is strongest in Europe.[42]

2.1.4 Innovation to secure UK and global food supply chains

Globally, demand for food is projected to increase by 50 per cent by 2030 and to double by 2050, but this must be produced from the same area of land with lower inputs. The UK imports nearly 50 per cent of its food,[43] with around 30 per cent coming from the EU. The country needs to produce sufficient food to secure supplies if, for example, climate change compromises productivity abroad. It also needs access to a range of imported sources of food to mitigate against potential shocks to the food chain within the UK.

The UK's livestock industry has become increasingly dependent on imported protein-rich feeds, such as soya beans, reflecting a European protein deficit of 70 per cent for animal feed.[44] However, protein is seldom recovered from existing UK agricultural products. For example, sugar beet produces more protein per hectare than soybean but this is distributed over 80 tonnes of roots and 40 tonnes of foliage and currently cannot be recovered cost-effectively.[45] By 2030, 62 per cent of fish consumed will be derived from aquaculture[46] and new sources of fish feed are needed. The development of innovative vegetable or insect protein for human consumption or for animal feed could satisfy increased demand while reducing the environmental impact of its production.

2.1.5 Future markets

Future technical and market developments in the bioeconomy will arise from demands by both food and chemicals:

- advanced biofuels (cellulosic bioethanol and bio-based jet fuels – potential global markets of €14.4 billion and €1.4 billion respectively by 2030)[47]
- biochemical building blocks and bio-based plastics (the EU market could reach €5.2 billion in 2030)[48]
- novel foods with alternative protein (in Europe, protein was a €33.4 billion market in 2013)[49]
- biosurfactants (the EU market could reach €3.1 million in 2030)[50]
- high-value chemicals from novel agricultural crops (including plant-derived drugs, which in 2010 represented 5.5 per cent of the total pharmaceutical industry with sales revenue of £18 billion)[51]
- oils and fats derived from oil crops (2010 global market: £500 million–£1 billion)[52]
- functional foods and nutraceuticals (2010 global market: £45 billion)[53]
- novel crop varieties that are resistant to pests, diseases and climate-related stresses (a rapidly growing global market that will dominate sales of crop seeds, currently estimated at $50 billion),[54] which will be used as feedstocks for both food and chemical production.

2.2 The power of the UK bioeconomy

The UK bioeconomy is one of the largest in the EU and is underpinned by strong research and development (R&D). A report commissioned by BBSRC estimated the primary or transformative part of the bioeconomy to be valued at £56 billion.[55] Food and drink manufacturing accounted for almost 40 per cent of that total, with industrial biotechnology and bioenergy contributing 13 per cent. Almost half the employment in the transformative bioeconomy was in agriculture and fisheries (see Figure 4). Excluding agriculture, the UK's bioeconomy is the largest in the EU after Germany and France.

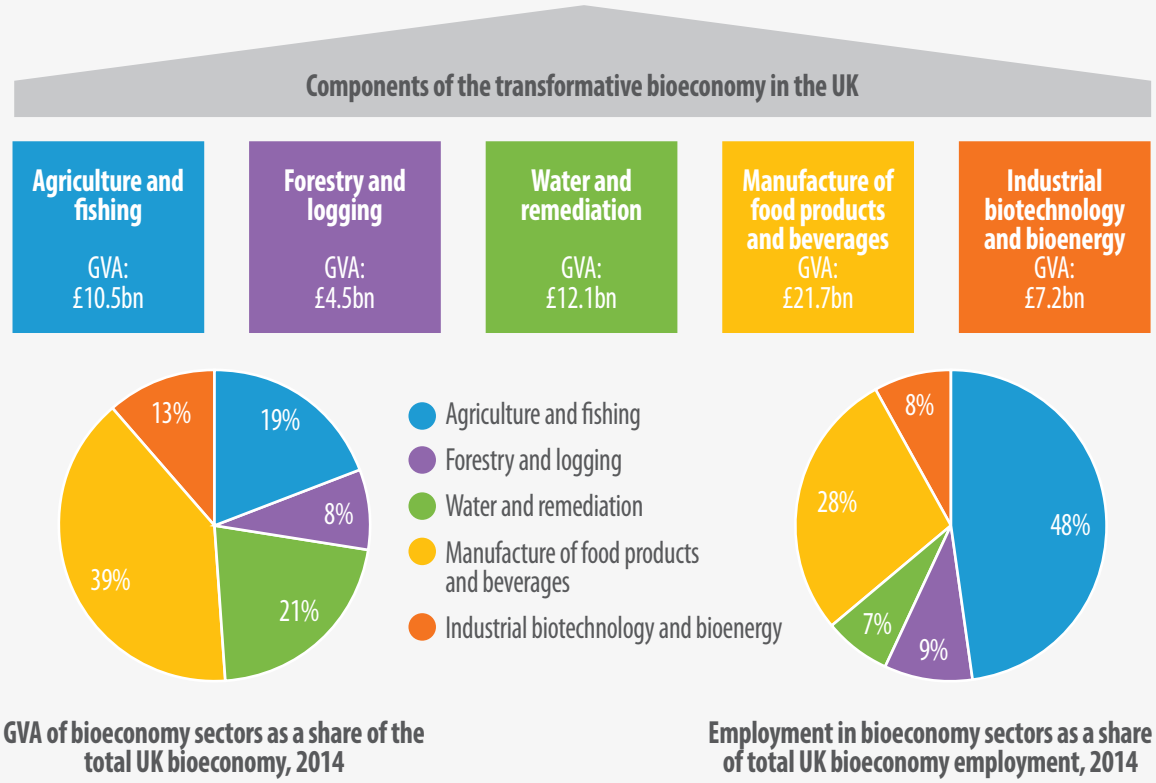
A 2015 report by Capital Economics[56] quotes OECD statistics showing UK investment in biotechnology R&D to be the fourth largest in the world, even when considering only the UK's expenditure on industrial biotechnology and bioenergy (i.e. excluding medical applications). OECD figures quoted in the same report place the UK seventh globally in terms of industrial biotechnology patent output (4 per cent of patents filed between 2010 and 2012) and third behind the USA and Canada in the ranking of biotechnology 'revealed technological advantage', a measure of the relative importance of biotechnology in total patent output.

Despite clear evidence of business investment in the area, relatively little venture capital investment has been made in the UK bioeconomy. Lux Research estimated that venture capital investment of $5.8 billion was made in bio-based materials and chemicals start-ups internationally in the period 2010–2016.[57] By contrast, the British Venture Capital Association estimates that between 2010 and 2015 (the most recent year for which data are available) only £121 million was invested in biotechnology, representing approximately 2 per cent of the total venture capital invested in the UK.[58] The growth of new insurgent biotechnology firms and regionally focused venture capital investment can be considered a measure of the vitality of a biotechnology industry.[59] Access to, and take up of, venture capital is therefore a concern and suggests that most innovation in the industry is being carried out by incumbent industries.

2.3 Bioeconomy sectors and opportunities

The consortium identified agri-science, agri-tech and industrial biotechnology as areas where research and innovation have strong potential to grow the bioeconomy. These underpinning capabilities support a range of established industrial sectors. Such industries share technological toolkits, including advanced genetics, synthetic biology and green chemistry, serving not only the diverse market sectors of the bioeconomy as defined in this audit, but also the pharmaceutical sector. Sharing innovation more effectively across sectors

FIGURE 4: THE UK BIOECONOMY



Source: Bauen et al. (2016)[60]

provides opportunities to accelerate growth and productivity. A recent EU project observed: "… currently there is not enough cooperation and knowledge exchange between different players in the value chain. The lack of cooperation between the different stakeholders horizontally and vertically along the value chain is slowing down the R&D and innovation process".[61]

Table 2 provides a (non-exhaustive) sample of trends and opportunities within these sectors to illustrate the range of business-led challenges that can be addressed by research and innovation.

The UK's science and technology sector can adopt a strong position in the global bioeconomy. Meeting the growing demand for energy, food and manufactured goods creates new market opportunities and inspires novel solutions. Other countries and regions are investing in their bioeconomies and legislating to encourage the uptake of bio-based products. The UK is in a fortunate position, having strong technology leadership and a substantial existing bioeconomy.

Table 2. Industrial sectors, trends and opportunities aligned to the bioeconomy[62]

Sector	Trends and drivers	Bioeconomy opportunities
Agriculture	Increased population and economic pressure on natural resources Environmental threats including climate change, soil degradation and biodiversity loss Reduced resilience due to restrictions on agri-chemical and antibiotic use and resistance to pesticides and herbicides Livestock-to-human disease transfer Emerging non-food markets for agriculture, including energy, fibre and biologicals	Productivity improvements from precise, efficient application of inputs, including fertilisers and pesticides Increased yield, quality, sustainability, resilience and profitability of crops and livestock from genetics and breeding Better soil preservation and soil–crop/soil–livestock interaction management for sustainability Integrated weed, pest and crop/livestock disease management for reduced impact Incorporating ecosystem service delivery into decision making
Food and drink	Relatively high costs of production and low food prices; impact of Brexit on workforce Globalisation reducing confidence in food quality, safety and authenticity Increased risk and rapid spread of new threats to food chain integrity Adverse weather and natural events affecting food production Public health, including obesity, diabetes and food allergies Better labelling Local sourcing	Alternative and novel foods, including genetically modified New approaches to ensuring food supply chain efficiency and integrity, including traceability and monitoring Crops and livestock with improved nutritional value Novel crops for new foods, energy crops and plant-derived high-value chemicals Processed food reformulation and better labelling for public health Biodegradable packaging
Animal feed	Improving livestock housing Wellbeing with reduced antibiotic usage Competition with energy crops Reliance on imported raw materials, including soya and palm oil High energy inputs during production Growing consumer demand for meat and other protein-rich foods	Additives for better productivity and disease control, including amino acids, trace minerals, antioxidants and enzymes Increased nutritional value Alternative protein sources

Table 2 (continued)

Sector	Trends and drivers	Bioeconomy opportunities
Chemicals	Increased raw materials and energy prices Greater regulation of chemical production and use Maintaining environmental water and air quality during production Sustainable supplies of raw materials and energy Consumer preference for 'natural' products Incremental innovation Diversification of input raw materials, including biomass and food, industrial and municipal waste	New, flexible, low-impact bioprocessing production methods in distributed biorefineries Novel biocatalysts and enzymes for processing biomass More bio-derived/natural ingredients in consumer goods New actives and better formulations for agri-chemicals Biodegradable and functional packaging for food, drink and consumer goods
Consumer goods	Use and sourcing of 'natural' products Sustainable resourcing/production Rising input costs driven by competition for resources New functionality Ethical and environmental policies from fast-moving consumer goods companies diffusing throughout their supply chains Traceability and animal welfare Potential impacts of changing regulation through trade deals	Biodegradable and functional packaging Sustainable sourcing of ingredients, packaging Low energy, clean bio-derived processes More bio-derived/'natural' ingredients in consumer goods New benefits from bio-derived ingredients
Fuel and energy	Competition for agricultural products between food, feed, fibre and fuel Climate change driving low-carbon alternatives Reduced dependency on fossil fuels Interaction between food, energy and environment Land use Need to return carbon and nutrients to soil	Better ways of hydrolysing diversified biomass and lignocellulose Second- and third-generation bioethanol Increased demand for biofuels and biopower Biofuels for aviation By-products from biofuel production/ biopower generation Energy from food, industrial and municipal waste Fuel crops for marginal and degraded land Strategic land-use management
Materials	Demand for energy-efficient (light, cost-effective, low-carbon) materials in automotive, aerospace, construction, etc. Increased demand for bio-based polymers, films and plastics Increased demand for bio-based and renewable raw materials Eco-friendly packaging preferred Government procurement policies	Smart coatings for strength and resilience Biodegradable functional packaging High-performance bio-based construction boards and insulation Smart (e.g. self-healing or self-cleaning) bio-based materials

2.4 Conclusions

Surveying overall trends reveals that the bioeconomy:

- has a key part to play in addressing the major global sustainability challenges
- touches on several major economic sectors, each of which has challenges and opportunities
- offers the potential for increased integration of supply chains across such sectors as food and drink and chemicals production that are conventionally treated separately, notably through the adoption of biorefineries producing multiple products
- requires a high degree of technological innovation to realise the opportunities presented
- involves both 'incumbent' players with a high capacity for absorbing innovation in their established sectors, and growing 'insurgent' companies that will take the next steps in developing radically new products and processes
- is growing across the world and receives explicit policy support from governments in some of the world's largest economies, thereby contributing to that growth
- is part of the supply chain for a range of production, service and manufacturing sectors that are key to the UK's economic wellbeing
- is an area in which the UK holds a strong innovation position
- permits the integration of agriculture with industrial processes supported by innovative technologies.

In the context of a UK industrial strategy, the bioeconomy is too large and too important for the country to rely on market forces alone to ensure that new research and discoveries develop into economic growth. The technological challenges are substantial and, like the chemicals industry, industrial biotechnology concerns the production of bulk chemicals in significant volumes and with a consequently high requirement for capital investment.

Recommendation: The UK should take a strategic interest in the development of its bioeconomy, setting in place appropriate policy and fiscal support to promote innovation for both economic and sustainability purposes. In considering where to direct public sector investment, and recognising the role of place in the economy, the UK government should take into account evidence of regional strengths, where incumbent businesses have infrastructure and skills relevant to the bioeconomy, and where research and innovation capability exists to support insurgent new businesses.

CHAPTER 3
INTRODUCTION TO THE NORTH OF ENGLAND

47%

of UK GVA in chemicals produced by the North of England

£6.5 billion

GVA produced by North of England food and drink sector

522,000

regional students in higher education

£1.2 billion

annual research income to the N8 universities

3 Introduction to the North of England

The North of England is a distinct, cohesive region of the UK with a strong cultural identity. It has a long heritage of manufacturing, which has bequeathed a legacy of science and engineering expertise and infrastructure assets to industry, academia and the public realm. Despite transport challenges regarding links between the major conurbations, the region has substantial logistical advantages, including three of the UK's major port complexes (located on the Humber, Mersey and Tees rivers). Major motorway north–south routes on each side of the country (M1 and M6) provide effective road transportation, but east–west road and rail links remain a major shortcoming.

The evolution of the UK economy towards service industries, accompanied by the concentration of these in London and the South East, has left the region with a substantial economic and productivity gap compared with the UK as a whole. The North of England, however, retains process and agri-food industries, as well as research and innovation expertise, making it a fertile environment for a growing manufacturing and innovation-led bioeconomy. Place is central to the bio-based economy. Often the feedstocks are sourced locally and, when they are imported, waste and by-products must be processed locally. Therefore, linking businesses at a geographical scale that is relevant to their activities is crucial to development of the bioeconomy.

3.1 Geography of the North of England

The North of England is a geographically and socioeconomically interdependent part of the UK, which lies between the Wirral peninsula and the Humber estuary in the south and the Scottish border in the north. The region boasts iconic cities, beautiful landscapes, world-class universities, nationally leading manufacturing capabilities and much of the UK's best, and most varied, agricultural land. It is economically and socially diverse, containing areas of high population density and large rural areas, and zones of significant prosperity as well as economic deprivation. The North of England hosts five of England's eight 'city regions',[63] four of its national parks, a population of nearly 16 million people, a workforce of 7.5 million, and generates more than one-fifth of the UK's economic output.[64] With varied scenic, tourist and sporting assets easily accessible from major urban centres, relatively low population density and low housing prices compared with the South East, the region enjoys a good quality of life and features some of the UK's most desirable places to live.

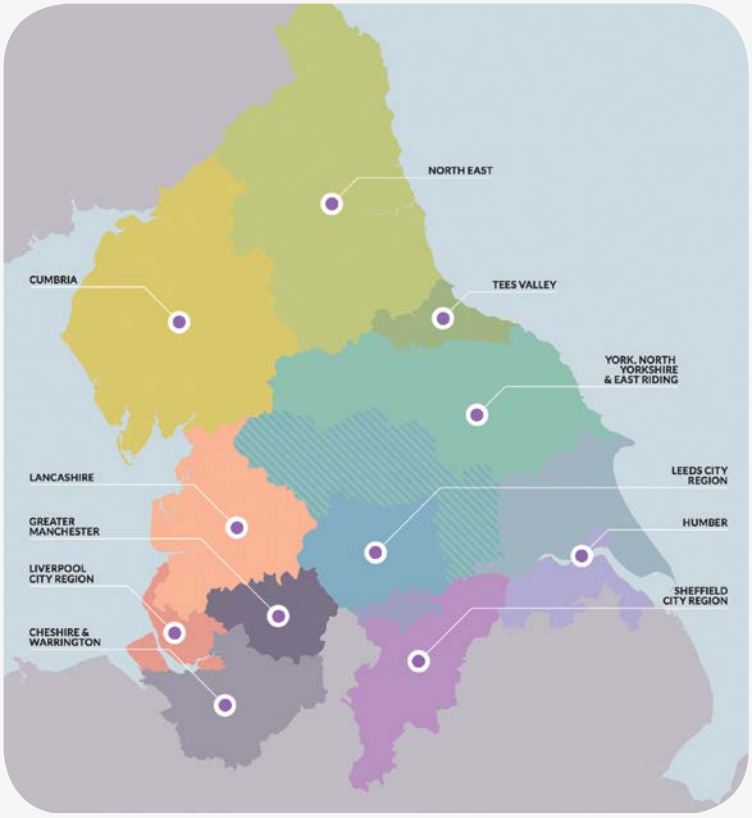
Priorities for economic development are set by 11 LEPs (see Figure 5), which between them cover with some overlap the three Nomenclature of Territorial Units for Statistics 1 (NUTS 1, major socioeconomic units) regions of North West (England), North East (England), and Yorkshire and the Humber.[65] The Sheffield City Region LEP also includes five Derbyshire and North Nottinghamshire local authorities outside these NUTS 1 regions.[66] These 11 LEP areas[67] represent the geography of this audit.

3.2 Economic performance of the region

The North of England economy was recently surveyed in the 2016 *Northern Powerhouse Independent Economic Review*.[68] This identified four 'prime' capabilities, of which two (advanced manufacturing and energy) are rooted in the region's traditional strengths of manufacturing and production, while the other two (digital and health innovation) have emerged more recently. Three 'enabling' capabilities (financial and professional services, logistics and education – particularly higher education) are also identified.

The review highlights the economic gap between the North of England and the rest of the UK. Figures sourced by the audit consortium (Table 3) confirm this analysis. As a benchmark for this report, the North

FIGURE 5: THE 11 LEPS IN THE NORTH OF ENGLAND



of England accounts for one-fifth to one-quarter of the UK's population and economy, and this gives a reference comparison for other figures provided throughout. Furthermore, the SIA region represents 21 per cent of total UK GVA, 24 per cent of the UK population and 22.4 per cent of all UK jobs. The region's chemicals and chemical products industry, and food and drink manufacture are disproportionate contributors to the UK economy, but productivity, wages, qualifications and investment in R&D generally lag behind the rest of the UK.

Bearing the economic gap in mind, the *Northern Powerhouse Independent Economic Review* contrasts 'business as usual' and 'transformational' scenarios to 2050 for the region. The transformational scenario identifies the need for action to raise the level of basic skills, retain and attract graduates, improve innovation performance, increase inward investment and improve transport connectivity to facilitate the movement of people between major urban centres. While the bioeconomy requires some attention in these areas, it also provides an excellent platform from which to contribute to achieving them with its potential to transform already high productivity sectors and established regional strengths.

3.3 Higher education

The *Northern Powerhouse Independent Economic Review* highlights the region's higher education provision as a key enabling capability for transformation of its economy. The North of England is home to 32 higher education institutions (listed in Appendix B), and 52 further education institutions, of which six are specialist land-based colleges. The 32 higher education providers are distributed throughout the region and collectively have 522,000 students,[69] the equivalent of 23 per cent of the UK total.[70] While the region

Table 3. Economic indicators for the audit area (2015)[71]

Measure	Region	UK
Economic output GVA	£338.78 billion	21% of UK total
Chemicals and chemical products GVA[72]	£5.2 billion	47% of UK total
Food and drink GVA[73]	£6.5 billion	24% of UK total
Agriculture, forestry and fishing GVA[74]	£2.0 billion	19% of UK total
Productivity (GVA per job filled per year)	£43,328	£49,814
Productivity (GVA per hour worked)	£27.39	£30.97
Population	15.656 million	24% of UK total
Population (aged 16–64 years)	9.864 million	24% of UK total
Population (jobs)	7.501 million	24% of UK total
Gross full-time earnings per annum	£25,546	£28,213
Workforce in STEM and research	4.4%	5.4%
Qualifications at national vocational qualification (NVQ) level 3+	52.6%	55.8%
Qualifications at NVQ level 4+	32.2%	37.1%
Total R&D expenditure[75]	£4,975 million	16% of UK
Business R&D	£3,198 million	15% of UK
Higher education R&D	£1,429 million	18% of UK
Business births[76]	North West 14.1% Yorkshire and Humber 13.8% North East 13.6%	14.3%
Innovation active companies[77]	Yorkshire and Humber 65% North East 53% North West 52%	53%

underperforms relative to the UK in terms of school-leaver qualifications, it produces significant numbers of graduates and postgraduates, especially in STEM subjects (see Chapter 6). Ten of the higher education institutions are members of this audit consortium. Eight constitute the N8 group of North of England research-intensive universities,[78] among the UK's top 30 universities measured by research power.

The major contributions made by the N8 universities to the regional economy are described in the 2016 report *The Power of Eight* [79] and include:

- £1.2 billion annual research income
- £12.2 billion annual regional economic impact
- 190,000 registered students
- 119,000 full-time equivalent direct, indirect and induced jobs.

3.4 Regional opportunities in the bioeconomy

The *Northern Powerhouse Independent Economic Review* assesses specialisation and productivity in a number of industry sectors relevant to the bioeconomy (see Table 4). These indicate both the potential to build from successful sectors and the opportunity to improve less strong ones.

The close link between industrial biotechnology and the chemicals sector is particularly relevant in the region, where the process industries represent a major employer. In the UK, the production of chemicals is a major component of the manufacturing industries and their biggest manufacturing exporter. In 2011, the sector had a turnover of £60 billion, sustaining 500,000 jobs and a £5 billion trade surplus.[80]

An industry priority is to secure key feedstocks, which includes using biofuels and exploiting renewable supplies and waste.[81] Bio-based chemicals can be used to make key ingredients from renewable carbon sources that are similar to those produced from fossil fuels, as well as producing new bio-based ingredients that are classified as natural, or have novel functionality, delivering benefits that are not possible with petrochemical-based alternatives. Such opportunities have been estimated to be worth around £10 billion to the UK formulated products industry.[82] The interaction between food and drink production and industrial biotechnology is similarly important. The integration of food and drink processing with bioenergy production, for example, is already happening (see Box 1).[83]

3.5 Sub-regional absorptive capacity for innovation

This audit hypothesises that the region has the industrial capacity to deliver a world-leading bioeconomy, with its industry base providing the absorptive capacity for innovation. Specialisation in industrial sectors

Table 4. *Northern Powerhouse Independent Economic Review:* bioeconomy-relevant sectors

Clearly specialised and high-productivity sectors	Mixed picture	Poor performers
Chemicals	Textiles (some specialisation, productivity close to sector average)	Wood and paper (specialised, productivity below sector benchmarks)
Food, drink and tobacco		
Electricity and gas	Water, sewage, waste (no specialisation, high productivity)	Agriculture (not specialised, productivity below sector benchmarks)

BOX 1

Yorkshire Greens is a partnership between d'Arta UK, a frozen food producer; Swaythorpe Growers, a farmer cooperative; and GWE Biogas, a bio-energy firm. The partners plan to build the UK's first carbon-neutral food-processing facility in Driffield, East Yorkshire. Peas grown by Swaythorpe will be processed in a facility powered by the anaerobic digestion of unavoidable food waste, including vegetable waste produced by the plant.

linked to the bioeconomy also implies that the region holds assets and skills within those industries. These specialisations are not evenly spread across the region, and the audit consortium has therefore mapped specialisations to indicate where clusters of employment, and hence assets and skills, lie.

Figures 6, 7 and 8 map employment location quotients (LQs)[84] at the local authority level in the chemicals, food and drink, and agriculture sectors, using the Business Register and Employment Survey and this audit's UK Standard Industrial Classification (SIC)[85]code definition (see Appendix C).[86] These figures illustrate the large concentration of chemicals industries located in the North of England. This includes Teesside, the Humber estuary and Runcorn, as well as speciality chemicals companies in West Yorkshire and life sciences companies in and around Manchester, Teesside and the North East.[87] Also notable is specialisation in the food and drink sector in North Yorkshire along the M62 corridor and the south bank of the Humber. Unsurprisingly, the more rural areas of the region show some specialisation in agriculture, which is balanced by low specialisation in urban areas. The low productivity of agriculture across the whole of the North of England noted in the *Northern Powerhouse Independent Economic Review*[88] is explained by the predominance of this sector in the mountains and moorlands of Cumbria, the Pennines and Northumberland, which masks much higher productivity in lowland areas of Yorkshire, Lincolnshire and Cheshire.

3.6 Conclusions

The North of England has a rich manufacturing heritage and leads the UK in the process industries, contributing almost half the UK chemicals sector's GVA. It is particularly specialised in chemicals and in food and drink employment, and represents a significant, although non-specialised, part of the UK's agricultural base. Although in need of modernisation and upgrading, the North of England benefits from good, and in places excellent, transport links by rail, road and sea, around which its primary businesses are clustered.

As a large and diverse part of the UK, the North of England has areas of economic growth and opportunity as well as areas of deprivation. Economic indicators for the region as a whole are lower than those for the rest of the UK and there is a well-recorded economic and skills performance gap. Factors affecting the regional economy overall have been analysed elsewhere and present a case for investment in the North of England to raise performance and close the gap compared with the rest of the UK.[89] The region has a strong education sector, which encompasses technical training as well as higher and further education (see Chapter 6), and a research capability that is at least comparable with that of the UK as a whole.

These factors make the region particularly well suited to developing its bioeconomy. Industrial biotechnology is a process technology and shares many requirements with the chemicals sector. Industrial biotechnology, biofuels and bioenergy are bulk businesses requiring substantial logistics and utilities infrastructure, which has been built over decades in the North of England. The agri-food supply chain is

FIGURE 6: CHEMICALS LQ MAP BY LOCAL AUTHORITY REGION

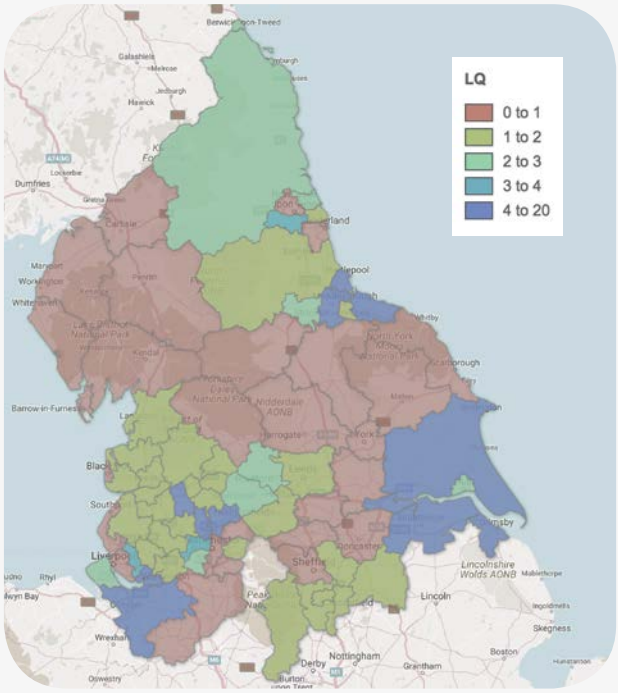


FIGURE 7: FOOD AND DRINK LQ MAP BY LOCAL AUTHORITY REGION

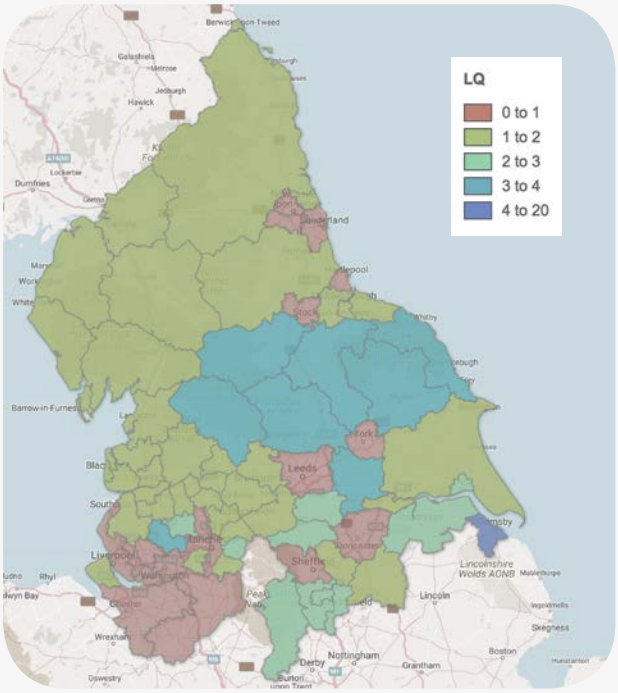
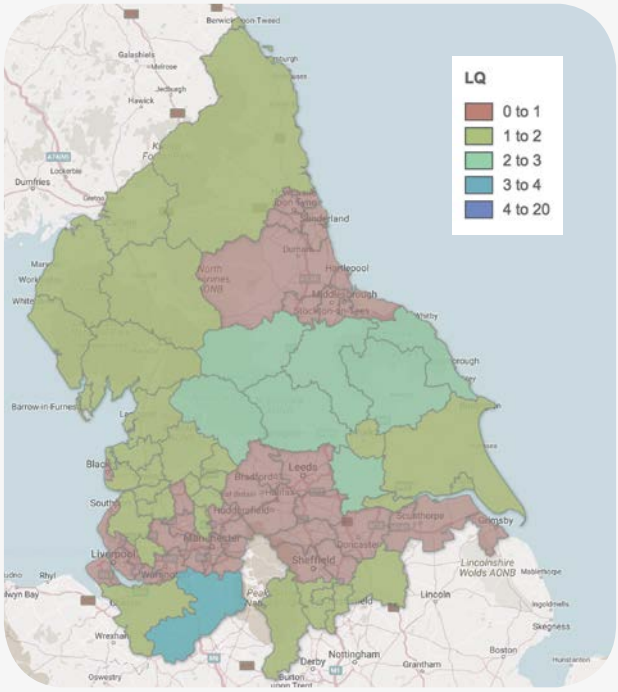


FIGURE 8: AGRICULTURE LQ MAP BY LOCAL AUTHORITY REGION



strong here. The higher education sector provides a robust research base from which to build innovation and provide higher-level skills. The bioeconomy has the potential to provide a well-targeted boost to the North of England and to contribute to rebalancing the UK economy overall.

Recommendation: The North of England should build on its industrial strengths and regional specialisation in the chemicals and agri-food supply chains, together with its logistics infrastructure and its strong base in higher-level skills and research to develop its regional bioeconomy. This will focus strategy and resources on highly productive sectors of the regional economy and assist in closing the economic and productivity gap with the rest of the UK.

CHAPTER 4
REGIONAL STRENGTHS IN SCIENCE AND INNOVATION

29%

of UK bioeconomy research funding won by North of England

78%

growth in value of bioeconomy projects in the region over the past decade

£254 million

invested in industrial biotechnology and agri-tech by Innovate UK in the past 14 years

30%

of EU bioeconomy research funds won in the UK come to the North

25%

of Industrial Biotechnology Catalyst grants won by the universities of York and Manchester

4 Regional strengths in science and innovation

The consortium's vision for the bioeconomy of the North of England calls for an innovation supply chain that provides access, for both incumbent and insurgent stakeholders in the bioeconomy, to cutting-edge research and industrially relevant experimental facilities. Crucially, the region must excel at translating research and accelerating the progress of new commercial concepts through the technology readiness scale.

4.1 Translation of research for societal and economic benefit

Effective innovation requires universities that are willing to work with collaborators inside and outside the academic sector, companies with an open innovation mindset, and intermediary organisations with an explicit remit to help bring new technologies to market. The North of England is fortunate in having all three of these prerequisites.

Since 2007, the world-class research, innovation and skills of the region's research-intensive universities have been brought together in the N8 Research Partnership,[90] which has a strong track record of collaboration. In addition to internal collaboration, the N8 works with institutions within the SIA region and further afield[91](see Box 2). A full list of university centres supporting the bioeconomy is given in Appendix D.

Given that a successful economic sector based on science and research depends heavily on translation to industry, the audit consortium looked for measures indicating the strength of this capability in the region. Substantial public investment is dedicated to improving the commercialisation of research conducted by businesses and universities, and to helping universities conduct knowledge exchange activities that assist open innovation programmes in individual firms and companies working together. The consortium investigated various data sources to evaluate the extent to which the bioeconomy innovation system is functioning, and the degree to which it provides a competitive advantage to the companies located within the region. Unilever's open innovation approach (Box 3) provides an example of close and substantial collaboration between industry and academia.

4.1.1 Dedicated innovation funding

Innovate UK provides funding and active assistance to companies, universities and other organisations to identify and exploit science and technology innovations that will deliver economic growth and create jobs nationally. Industrial biotechnology and agri-tech are important technology platforms for Innovate

BOX 2

N8 AgriFood, also known as the N8 Agri-Food Resilience Programme, pools the N8 universities' collective capabilities to establish a world-leading research position on methods to improve resilience across the global agri-food supply chain. With a combined N8–Higher Education Funding Council for England investment of £16 million in start-up funding for five years, the universities are building a long-term translational research platform that will address food chain issues at local, national and international scales.

"The N8 partnership is a real step change in how universities work together, greatly expanding what a single university can achieve. N8 AgriFood provides a single forum for industry to access academic research across these eight northern universities, and will drive the formation of productive partnerships across the public and private sectors," said Professor Katherine Denby, Director of N8 AgriFood.

BOX 3

Unilever uses open innovation extensively to achieve sustainable growth and meet consumer expectations of its products.[92] The company's home and personal care R&D facilities are based at Port Sunlight on the Wirral peninsula. Unilever has strategic relationships with the University of Liverpool and University of Manchester, and has made a large investment in the £68 million Materials Innovation Factory (MIF) at the University of Liverpool. MIF houses open-access robotic platforms and a 'Research Hotel', where industry teams can co-locate with researchers and specialist technical staff.

UK[93] and, between 2004 and 2017, these disciplines received almost £254 million in agency funding (see Box 4 for examples).[94] Catalyst funds have tightly defined technological focuses and aim to support projects from research to commercial viability. Funding calls have included the £52 million Industrial Biotechnology Catalyst, funded jointly with the Engineering and Physical Sciences Research Council (EPSRC) and BBSRC, and the £70 million Agri-Tech Catalyst funded by BBSRC and the UK Department for International Development.

Organisations in the North of England are well represented in competitions such as the Industrial Biotechnology and Agri-Tech Catalysts, and in other Innovate UK funding competitions relevant to the bioeconomy. Between 2014 and 2017, projects with North of England partners won 35 per cent of Agri-Tech and 29 per cent of Industrial Biotechnology Catalyst grants.[95] The University of York and University of Manchester collectively won more than 25 per cent of the Industrial Biotechnology Catalyst funds provided to academic institutions. In total, a review of Innovate UK funding between 2004 and 2017 revealed that one-third of their investment in the bioeconomy has gone to the North of England.[96]

The Sustainable Agriculture Research and Innovation Club (SARIC), supported by three Research Councils and 12 industry partners, addresses the industry-led challenges of resilient and robust crop and livestock production systems, and predictive capabilities for sustainable agriculture. Over half of the projects supported by SARIC are led from the North of England.[97] Furthermore, one-third of projects funded by the Bioprocessing Research Industry Club, which is a partnership between BBSRC, EPSRC and a consortium of leading companies to support innovative bioprocess-related research, are based in the North of England.[98]

BOX 4

Biome Technologies led a Catalyst project, partnering with CPI and the University of York and University of Liverpool to examine the feasibility of converting polyester precursors derived from lignocellulose into biopolyesters and to map their properties. Another project led by **Velcourt** with the University of York, BDC and Limagrain, was funded to study the development and agronomy of new oil seed rape strains to produce oil with higher thermal stability for food-processing and industrial applications such as biolubricants.

Precision Decisions and Newcastle University are collaborating on a Knowledge Transfer Partnership funded by Innovate UK. This project is developing improved applications and web-based tools to convert raw data into coherent spatial agronomic information, enabling precise visualisation of where fertilisers, pesticides and other crop inputs need to be applied.

4.1.2 Quantitative measures of the impact of university research

In 2014, universities across the UK participated in a comprehensive evaluation of the impact of their research as part of the Research Excellence Framework (REF) 2014. A total of 153 institutions submitted 6,637 selected case studies to demonstrate research impact across 36 subject areas.[99] Overall, the ten universities in the SIA consortium submitted 14.3 per cent of the case studies across the full spectrum of disciplines. Of those submitted in the three subject areas most relevant to the bioeconomy (chemistry; biological sciences; and agriculture, veterinary and food science), 17.5 per cent were submitted by consortium members and indicate translational specialisation in these institutions.[100]

Specifically looking at research relevant to the bioeconomy, Durham University ranked first in chemistry and the University of Liverpool was third, with the University of Manchester and University of Leeds featuring in the upper quartile. The University of York was the UK's top-ranked institution for impact in biological sciences, while Newcastle University ranked second and Lancaster University came third in earth systems and environmental sciences (see Box 5).

BOX 5

Lancaster University's research into plant–herbivore interactions led to the development of seed treatments that enable crops to respond more rapidly when attacked by insects. The use of the natural plant-signalling molecule jasmonic acid has been patented by Lancaster University and commercially licensed to BASF for global products that help to protect a range of major crops. The technology has been applied to more than 2.5 million hectares of soybean crops in the USA, where it has resulted in increased yields and raised yield value by around $60 million per annum.[101]

4.1.3 Regional patent activity in the bioeconomy

The review team analysed World Intellectual Property Organisation data based on international patent classifications, which divide patents into 35 groups.[102] Overall, inventors with home addresses in the North of England were responsible for 14.7 per cent of UK-based patents filed worldwide.[103] A striking regional specialisation emerged in areas relevant to the bioeconomy and this was particularly notable in chemicals and related products, where the North of England dominates the UK (see Table 5 and Box 6).

BOX 6

Plaxica, a North East-based technology licensing company, has filed worldwide patents for processes that take low-value waste from the pulp and paper industries and convert this feedstock into fermentable mixed sugars. Originally created as a spin-off from Imperial College London, Plaxica has chosen to locate its development arm at the Wilton Centre in Tees Valley (since 2010) due to the region's combination of specialist skills, facilities and networks, particularly in the process industries. Plaxica has extensive interactions with the National Industrial Biotechnology Facility at CPI and also collaborates with the Durham University and Newcastle University.

Table 5. International patent classifications relevant to the bioeconomy

International patent classification	Percentage of UK patents filed by inventors living in the North of England
Basic materials chemistry	45.5
Macromolecular chemistry, polymers	31.7
Textile and paper machines	26.2
Materials, metallurgy	23.9
Chemical engineering	22.2
Organic fine chemistry	18.1
Environmental technology	17.4

4.2 Share of the UK science base

The consortium evaluated the region's share of the UK science base by assessing various quantitative measures of science output relevant to the bioeconomy.

4.2.1 Number of bioeconomy publications

In the 2013 report *Encouraging a British Invention Revolution*, Sir Andrew Witty assessed the academic output of British universities in areas critical to the nation's prosperity.[104] Two areas reviewed using keyword searching of the *Scopus* publications database were found to be of fundamental importance to the bioeconomy: agri-science and agri-tech. Universities in the North of England figured prominently.

- Agri-science: one in four of all agri-science publications[105] came from universities in the SIA region (1,925 out of 7,552). Two of the top three publishers were from the North of England[106] (Sheffield and York).
- Agri-tech: almost one-third (31 per cent) of the total publications[107] in agri-tech were from universities in the SIA region (745 out of 2,428). Two in the top four publishers were from the North of England[108] (Sheffield and York).

The consortium also analysed the *Scopus* publications database using journal codes to define bioeconomy research disciplines. The team analysed the publication output of research organisations across the UK from 2011 to 2017 in agricultural and biological sciences, biochemistry, genetics and molecular biology, chemistry and chemical engineering.[109] Publications of the ten universities[110] in the SIA consortium account for 15.7 per cent of all publications in the UK for all subjects. It was found that these ten institutions published a similar proportion in agricultural and biological sciences (15 per cent of all UK publications), were stronger publishers in biochemistry, genetics and molecular biology (16.2 per cent), and were responsible for a disproportionate number of UK publications in chemistry (20.8 per cent) and chemical engineering (21.5 per cent).

4.2.2 Regional share of bioeconomy research funding

Over the past ten years, the North of England has received 29 per cent of UK project funding relevant to the bioeconomy, leading or participating in one-quarter of all projects.[111] Similarly, more than one in five of the EU's Horizon 2020[112] and Framework Programme 7 (FP7)[113] bioeconomy projects in the UK involved northern universities, representing 30 per cent by value.[114]

A review of all projects relevant to the bioeconomy in the ten years to 2016 captured on Gateway to Research[115] revealed that northern universities are strong in research relevant to the bioeconomy. Research sectors included waste applications, where projects led by regional institutions accounted for 26 per cent of UK funds in this area, agriculture (25 per cent), food (24 per cent) and the environment (19 per cent). Moreover, the region's scientific contribution to bioeconomy research is growing rapidly. Funding for bioeconomy-related projects in the UK rose by 25 per cent in the ten years from 2006, whereas the value of projects led from the North of England grew by 78 per cent over the same period.[116]

4.3 Quality of science

The consortium reviewed available data sources to assess the quality of the region's research output relevant to the bioeconomy.

4.3.1 Citation rate analysis

In the previously mentioned 2013 report by Sir Andrew Witty,[117] the quality of agri-tech and agri-science research published by North of England universities plays a prominent role.

- **Agri-science**: 25 per cent of all agri-science publications[118] originated in the North of England; of these, 27 per cent were in the top 1 per cent[119] of cited academic journals from across the world.
- **Agri-tech**: 31 per cent of agri-tech publications[120] originated in the North of England; of these, 33 per cent were in the top 1 per cent[121] of cited journals.

The consortium's own analysis of the *Scopus* database by journal types shows that in agricultural and biological sciences, three universities in the region[122] were in the UK's top ten by field-weighted citation index (FWCI), a measure of the quality of research, and the ten universities in the SIA consortium[123] had an FWCI 0.16 higher than all UK publications in that field,[124] implying their papers were cited 16 per cent more than the UK average. Chemistry and chemical engineering papers from those ten universities were cited 3 per cent more than the UK average for those subjects.

In collaboration with Elsevier, the consortium conducted an analysis of the *Scopus* database between 2011 and 2016 using keyword methodologies similar to those used in the Witty review. In the fields of industrial biotechnology, agri-science and agri-tech, the very high FWCIs of UK publications, with values over 2.00 for agri-science and agri-tech and 1.61 for industrial biotechnology (Table 6), support the observation in the Capital Economics, TBR and E4tech 2016 report *Evidencing the Bioeconomy* that the UK "is one of the leading countries in a number of key areas of research and innovation that underpin the bioeconomy [and in] respect of field-weighted citation impact [...] in first place globally."[125] The ten universities in the consortium performed better than the UK norm, with average FWCIs of 10 per cent, 9 per cent and 21 per cent higher than the UK figures respectively.

Table 6. Citation indices for the bioeconomy

FWCI	UK average	Consortium universities
Industrial biotechnology	1.61	1.71
Agri-science	2.09	2.18
Agri-tech	2.11	2.32

4.3.2 REF research quality measures

In addition to assessing research impact in universities, the REF 2014[126] exercise measured the quality of research outputs. All the N8 universities were in the UK's top 30 universities for research power, a combined metric of the quality and volume of research.[127] In areas particularly relevant to the bioeconomy, Newcastle University, the University of Sheffield and the University of York were in the upper quartile for the quality of biological sciences (out of 42 REF submissions),[128] the University of Liverpool and Durham University were in the chemistry upper quartile (37 REF submissions), and the University of Liverpool was in the upper quartile for agriculture, veterinary and food science (29 REF submissions).

4.4 Conclusions

The will and capability of researchers to translate science into economic and societal benefit is evident. The region is particularly distinctive for its success in winning funding for translational activity. This funding is not restricted to the university sector and many of the region's companies and translational centres are leaders and collaborators in projects. The concentration of translational funding in the region, and growth in its share of funding over the past ten years, provides a powerful endorsement of the audit's hypotheses that research and innovation are strong in the North of England, and that connectivity in the innovation system is comparatively good and an asset to the region.

This evidence accords with the audit consortium's perception that the various stakeholders in the regional bioeconomy work well together, and that some have highly developed open innovation platforms. Several regional companies provide leadership in national science and innovation networks.

Qualitative information drawn from stakeholders, including one-to-one interviews with companies by consultants SQW (see Appendix E), however, suggests there is room for improvement in connectivity and effectiveness in providing support to industry. Many companies, especially small- and medium-sized enterprises (SMEs), find the interface with universities to be challenging. The translational groups and centres are well equipped, but struggle to secure funding to maintain their expertise and provide longitudinal support for companies through the full technology development pathway. Handover of companies from one innovation support organisation to another is frequently poor, and knowledge of the support available across the region is by no means universal.

Based on both qualitative and quantitative measures, this audit indicates that the North of England has research capability in the underpinning science of the bioeconomy that in many regards outperforms the rest of the country, which is already a frontrunner at the global level.

Recommendation: The fundamental strength of the North of England bioeconomy research base requires support to ensure it continues to produce globally leading new science, particularly in agri-food and industrial biotechnology, from which commercial innovations can be created. In order to convert this into commercial success, the translational capacity of major facilities in the North of England should receive targeted investment. Building from the proven networking capability of the N8 universities, research and innovation providers across the region should collaborate to develop their collective capability to translate research into growth in the bioeconomy by developing projects, programmes and infrastructures that deliver the commonly held vision outlined in this report.

CHAPTER 5
BIOECONOMY ASSETS IN THE REGION

16%

of UK renewable energy produced by Drax in 2016

>1,000

companies worked with the Centre for Process Innovation

340

industry projects completed by the Biorenewables Development Centre since 2012

16,454

regional companies active in the bioeconomy

4,500

clients worldwide use Fera's proficiency-testing service

£130 million

invested in the Immingham Renewable Fuels Terminal

5 Bioeconomy assets in the region

The consortium's vision for the bioeconomy of the North of England is built firmly on the assets of the region. These fall into three categories: (1) the industrial base and its logistics infrastructure; (2) the research base; and (3) the specialised translational organisations that can support science and innovation from laboratory to commercial realisation through the spectrum of technology readiness levels.[129]

The industry base will deliver innovation in the bioeconomy. As a key regional asset, this audit has therefore reviewed the current bioeconomy business base of the North of England. Determining the innovative capacity of business in detail is beyond the scope of this report, other than identifying regional levels of business investment in R&D (see Table 3). However, numbers and sizes of companies in the bioeconomy are important indicators. While only a proportion of companies will be innovation suppliers, potentially all companies will be innovation customers.

5.1 The industrial base

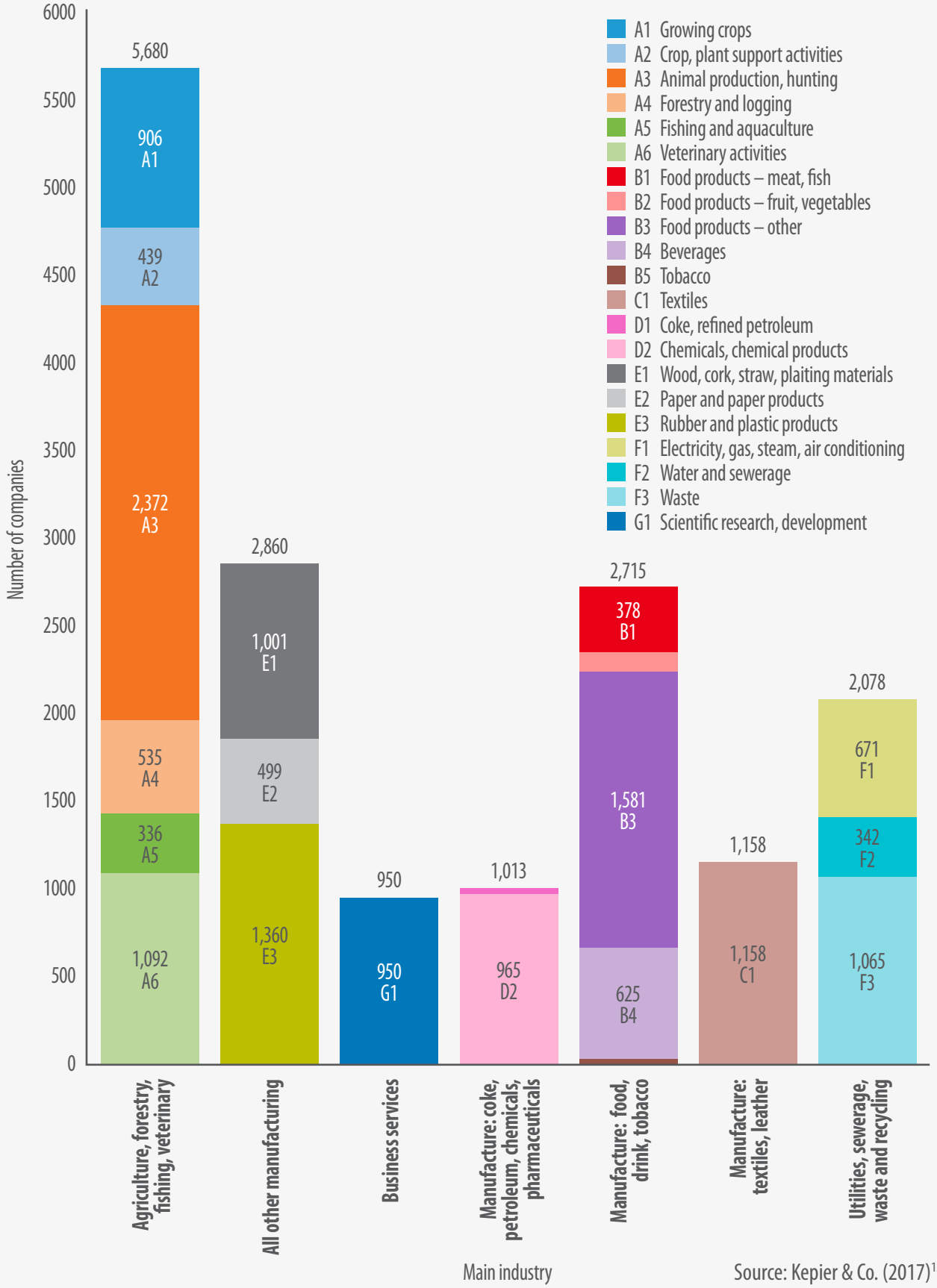
The consortium engaged consultants Kepier & Co. to map companies that are active in the bioeconomy across the North of England and provide an estimate of the extent to which their business activities (employment and turnover) form part of the bioeconomy. The methodology is described in Appendix F. This information supplements the data on employment LQs given in Chapter 3, and is a key resource for consortium members wanting to connect with the industry base of the regional bioeconomy. Figure 9 charts the 16,454 bioeconomy companies identified with a location in the North of England. These companies represent an estimated annual turnover of more than £91 billion and employ 415,000 staff.

Information on the industry structure of the regional bioeconomy is provided in Table 7. Large companies predominate in sectors that include food and drink, chemicals and utilities. Implied productivity per employee is high in the capital-intensive chemicals sector and in utilities, waste and recycling, and it is expected to remain so when further enabled through the adoption of industrial biotechnology. In other words, we expect these sectors of the advanced bioeconomy to sustain and create high-productivity jobs.

Filtering out companies with an annual turnover of less than £10 million reveals concentrations of activity (see Figures 10, 11 and 12); this supplements information gained from employment LQs (see Figures 6, 7 and 8). The bulk chemicals industry has built up around the estuary ports close to sources of imported crude oil, and large process companies in the bioeconomy gain the same advantage concerning seaborne logistics for movement of biomass. There are significant clusters of fine and speciality chemicals around Manchester and West Yorkshire. Larger food and drink companies are predominantly located along the M62 corridor. Utilities and waste companies and other manufacturing businesses are mostly associated with the region's large conurbations.

While this clustering of activity has happened naturally through market factors, regions of Europe that have had a longer-term strategic focus on the bioeconomy have emphasised the conscious development of bioclusters using public–private partnerships between government, academia and enterprise. These are typically centred on one or more commercial biomass-processing operations (e.g. sugar, oil seed, etc.) that provide opportunities to create value from secondary or co-products through the application of bioeconomy technologies (industrial biotechnology and agri-tech). An example is the Flanders Biobased Valley;[130] there is no similar such asset in the North of England.

FIGURE 9: BIOECONOMY COMPANIES IN THE NORTH OF ENGLAND: NUMBER OF COMPANIES BY MAIN INDUSTRY AND MAIN ACTIVITY IN SIA AREA



Source: Kepier & Co. (2017)[131]

Table 7. Industry structure of the North of England bioeconomy

Sector by 2-digit SIC code classification	Percentage of regional bioeconomy by turnover	Annual turnover within region (£billion)	Employment in region	Turnover per employee (£)	% of turnover delivered by companies whose turnover is > £50 million
Manufacture: food, drink, tobacco	33.65	30.82	144,764	212,885	61
Manufacture: coke, petroleum, chemicals, pharmaceuticals	23.89	21.88	54,493	401,440	68
Utilities, sewerage, waste and recycling	16.62	15.22	41,658	365,426	76
All other manufacturing	13.68	12.53	86,771	144,403	37
Agriculture, forestry, fishing, veterinary	7.50	6.86	50,662	135,515	19
Manufacture: textiles, leather	3.87	3.55	24,192	146,745	22
Business services	0.77	0.71	12,487	56,648	33

5.2 The research base

Within the 32 higher education providers in the North of England, approximately 90 per cent of funded academic research in the region is carried out in the N8 research-intensive universities,[132] but several of the other higher education institutions have particular strengths in working with the regional industry base. For example, the bioeconomy is one of Northumbria University's multidisciplinary research themes[133] and the University of Chester has established NoWFOOD, a centre of excellence for food science and technology.

The N8 consortium is one of the major science and innovation strengths of the North of England, due to its proven ability to catalyse collaboration across the majority of the region's research base. The £16 million N8 Agri-Food (see Box 2) is one of the N8's flagship collaborative projects, integrating a wide range of research groups and specialist institutes across the partnership. N8 AgriFood focuses on research with a strong translational element that will bring a step change in the resilience of global agri-food systems. N8 universities and their partners in agriculture and industry work to ensure the stability and integrity of global agri-food systems in the face of the global challenges of climate change, declining resources and rapid socio-political transformations.

FIGURE 10: LOCATIONS OF CHEMICAL COMPANIES WITH TURNOVER > £10 MILLION

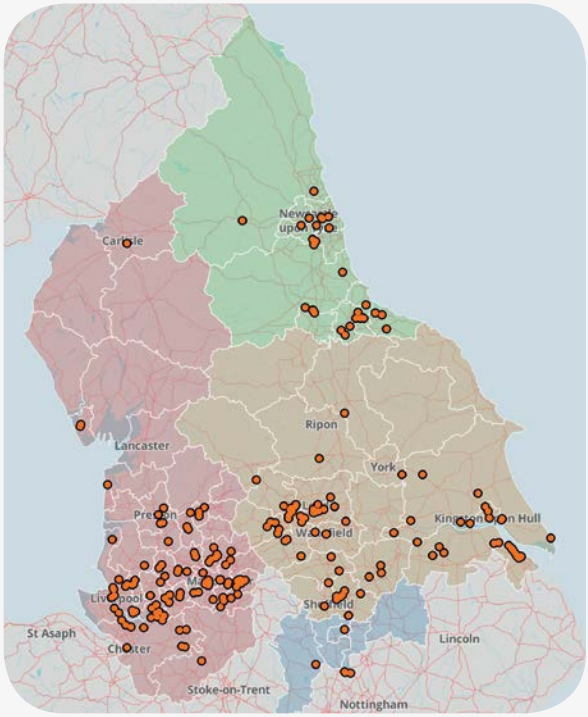


FIGURE 11: LOCATIONS OF FOOD AND DRINK COMPANIES WITH TURNOVER > £10 MILLION

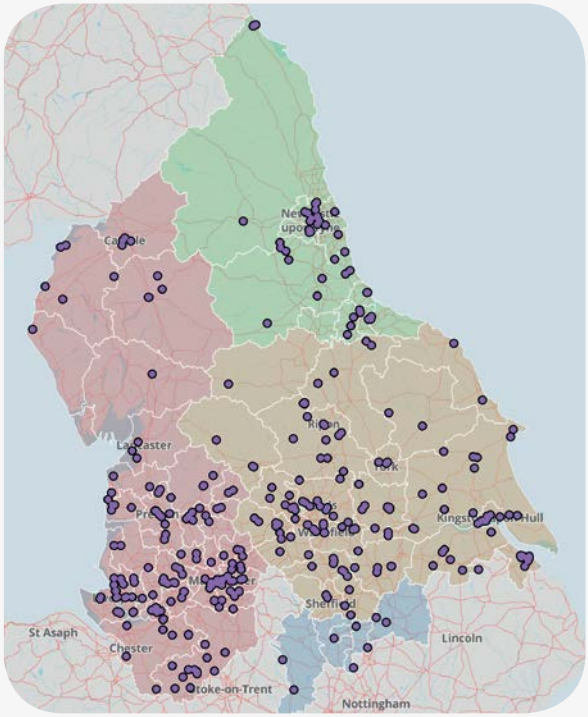
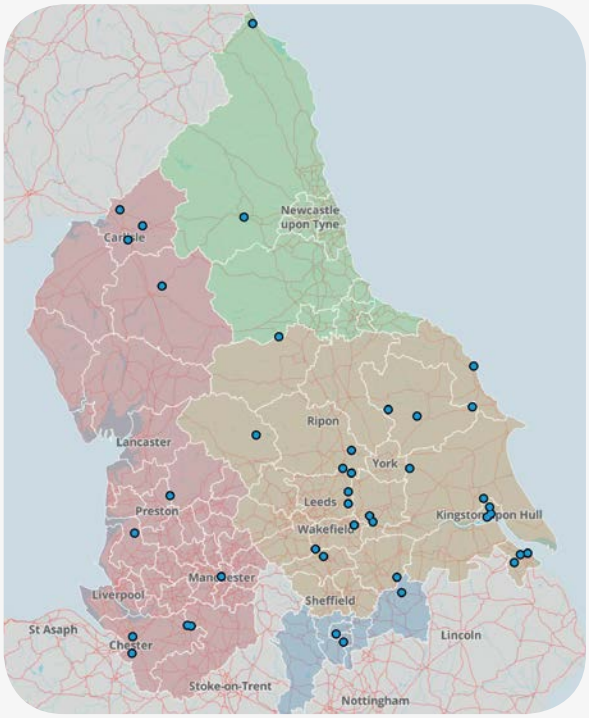


FIGURE 12: LOCATIONS OF AGRICULTURE COMPANIES WITH TURNOVER > £10 MILLION



Source: Kepier & Co. (2017)[134]

N8 Agrifood capability covers a broad range of technical and social sciences. Expertise in robotics and autonomous systems will underpin the development of automated sensing systems alongside suitable control structures. Precision engineering holds the potential to revolutionise farming through the automated detection of weeds and insects, and the targeted deployment of suitable counter measures. N8's 'big data' and data science abilities and facilities will be exploited to promote sustainable farming through networks of field-based sensors, the bioinformatics of plant and animal genomic data, and the exploitation of novel combinations of such existing data sets as climate information and plant disease records. The University of Leeds and Newcastle University have significant livestock expertise that complements that of the University of Liverpool, with its renowned veterinary school and the Tesco Dairy Centre of Excellence, and Lancaster University's research into productivity and environmental impacts. A distinctive feature of N8 AgriFood is its commitment to understand consumption at all levels – individual, collective and institutional – alongside the field of practice. Consumer practice research will include the ethnographic observation of consumption habits at the household level and beyond, together with survey- and diary-based analysis of long-term trends.

Outcomes of the programme include horizon scanning; new tools, techniques and technologies for sustainable food production; resilient supply chains and smarter consumption; and the identification and mitigation of risks across the agri-food supply chain. In forming the collaboration, the programme has identified more than 650 researchers across the N8 universities engaged in agri-food projects relevant to the bioeconomy, collectively holding a portfolio of £269 million in research funding over the previous six years. Box 7 provides an example of such collaboration.

In total, the consortium has identified more than 30 explicitly translational research centres related to the bioeconomy within the universities of the North of England (around half of which are associated with N8 AgriFood). These collectively represent a huge investment in expertise, capital equipment and research output (information is provided in Appendix G). Notable centres outside the N8 include the University of Hull Logistics Institute, which has expertise in supply chain management, and the National Centre of Excellence for Food Engineering at Sheffield Hallam University.

N8 AgriFood brings together the majority of the academic research capability in the region associated with agri-science and agri-tech. 'Industrial Biotechnology for the Bioeconomy' is a growing research community within the N8.[135] Academic groups across the region are working on the full range of biotechnological processes for the conversion of varied wastes and cultivated feedstocks into higher-value ingredients for consumer products, construction, food and drink, and other sectors. These include the use of microbes and enzymes in fermentation and anaerobic digestion, catalytic and biocatalytic conversion of biomass, and microwave and hydrothermal treatment of lignocellulosic materials.

BOX 7

The Advanced Biotechnology Centre at the University of Sheffield conducts research and development at the interface between (bio)chemical engineering and biomolecular science, delivering innovative and disruptive bio-manufacturing technologies for translation. It is steered by businesses including Albumedix, CPI, Croda, FUJIFILM Diosynth, Glaxo SmithKline, MedImmune, PALL, Syngenta and Technopath, and connects bio-based industries with Sheffield's academics across the bioeconomy. Through partnerships with international companies, the centre acts as a portal for knowledge dissemination to support the development, transfer and implementation of new bioprocess technologies.

5.3 From laboratory to market

The consortium has identified the region's concentration of large bioeconomy translational organisations as a major differential strength. These organisations are the engines of innovation uptake, providing services, open-access facilities and links with the research base for companies across the North of England and, in most cases, at national and international levels. They are distinguished from university applied research facilities by their core mission to provide innovation services promoting economic growth. Without the support of these organisations, the gulf between commercial ideas and realisation is beyond the reach of most insurgent innovators. Further information on innovation providers in the SIA region is given in Appendix H.

The two largest bioeconomy innovation support facilities in the North of England are CPI on Teesside, which is dedicated to supporting the commercialisation of new products and processes by the UK's manufacturing sectors, and Fera, which supports a wide range of agri-food innovations, including the safety and integrity of food supply chains 'from field to fork'.

CPI is a major UK technology translation centre and the process industries division of the High Value Manufacturing Catapult. Based in the North East, CPI has helped over 1,000 companies to develop new products and processes (see Box 8), has completed over 800 projects with a value of more than £380 million, and has worked with 66 universities. Its facilities include the National Industrial Biotechnology Facility, the National Biologics Manufacturing Centre and the National Formulation Centre. CPI's approach to the establishment of biotechnology-based industrial processes and facilities is based upon its experience of designing, building and operating the National Industrial Biotechnology Facility, and exploiting current advances in synthetic biology, computational modelling and high-volume data generation and processing.[136]

As a commercial business employing 350 scientists and with more than 100 years' experience of regulatory science, Fera sits between industry and government, and is uniquely placed to support agri-food innovation. From plant health and crop protection through food and feed safety and authenticity to novel biotechnologies, Fera provides world-class expertise in risk evaluation and assurance in support of the development of new technologies and agri-food products, including novel crops, foods and animal feeds and new crop protection agents. Fera's customer base includes UK and foreign governments; 650 individual growers, agronomy businesses, seed houses and agro-chemical firms; 800 food sector businesses including the UK's top ten supermarkets; and 4,500 worldwide users of its proficiency testing service.[137] Based at the

BOX 8

Calysta has identified a market for a high-protein, sustainable aquaculture food source and has developed a microbe-based production process fermenting methane gas into fish food. Calysta complemented its core expertise in DNA synthesis and directed evolution with CPI's expertise in running gas-based fermentations. Using CPI's open-access National Industrial Biotechnology Facility[138] helped reduce the time and costs of development. Calysta and Cargill are now building a production facility in Tennessee, USA, which is expected to come on line in 2019. Calysta is also establishing a £30 million market-introduction facility at CPI to produce samples and support customer testing, product registration, new product development and up-scaling, which is expected to employ up to 40 people.[139]

National Agri-Food Innovation Campus (NAFIC), Fera forms part of a concentration of agri-food translational organisations located near York.

Also at NAFIC are two of the UK's four centres for agricultural innovation: the Centre for Innovation Excellence in Livestock and the Crop Health and Protection centre. The four centres were established in a major £90 million government initiative to improve technology uptake by UK companies in the agri-tech supply chain and constitute a significant regional asset. NAFIC is home to the Food Innovation Network, launched in 2016 to drive innovation, productivity and growth in UK agri-food businesses. The Stockbridge Technology Centre, located a few miles from NAFIC, provides horticultural expertise, training and experimental crop development to industry.

BDC is another important translational organisation in the region. Alongside CPI, it is one of the five members of the BioPilots UK alliance of open-access biorefining centres. BDC helps businesses to develop ways to convert plants, microbes and biowastes into profitable biorenewable products. Established through a collaboration between the Green Chemistry Centre of Excellence and the Centre for Novel Agricultural Products at the University of York, its expertise spans process development, genetic analysis and microbiology. With equipment to produce kilogram quantities of biorenewable materials, BDC staff have completed over 340 projects with external partners since the centre was established in 2012.[140]

The Unilever–University of Liverpool MIF collaboration is one of the region's main examples of industry–academia shared investment in facilities. MIF specialises in computer-aided materials science and automated high-throughput screening, and aims to accelerate the translation of new and sustainable chemicals, materials and formulations into consumer-driven products.[141]

5.4 Logistics

Logistics infrastructure in the North of England is of mixed quality. The M62 corridor is a vital artery for the region and is currently being upgraded through a £250 million programme. Both road and rail links across the Pennines are widely held to be in need of improvement.[142] Many companies interviewed by the consortium, however, especially those in the east of the region, cited excellent sea, road and rail logistics as a reason to be based there (see Appendix E).[143] The importance of the ports for the large-scale movement of materials is evident in the concentration of bioeconomy-related business nearby. Box 9 gives examples of companies that have invested in and benefit from the regional infrastructure.

5.5 Finance

The bioeconomy primarily encompasses manufacturing sectors. The financial requirements of research and bringing new products and processes on stream will be significant and carry a high capital demand. Section 2.2 notes the limited level of venture capital invested so far in the UK bioeconomy and the implication that incumbent companies with available resources are driving growth.

A disruptive, innovative bioeconomy requires insurgents to access high-risk finance. This is not yet available at the scale needed in the North of England. Overseas-based bioeconomy insurgent companies, such as Ginkgo Bioworks, Avantium and Rennovia, have all received venture capital funding rounds valued in the tens of millions of dollars. Ginkgo received $100 million in a single, Series C investment round.[144] The Northern Powerhouse Investment Fund has a maximum limit of £2 million and does not currently specialise in bioeconomy opportunities.

BOX 9

Drax is a major national player in the bioeconomy, exemplifying the contribution that can be made by bio-based energy to UK sustainability targets. In 2016, following 50 per cent conversion from coal to biomass, the Drax power station in North Yorkshire produced 16 per cent of the UK's renewable energy. Drax has invested £700 million in the logistics supply chain for internationally sourced forest waste raw material, and Associated British Ports has spent £130 million creating the new Immingham Renewable Fuels Terminal, which is now the world's largest dedicated biomass-handling facility.[144] To improve its supply chain resilience, Drax also imports biomass through the new £100 million biomass-handling facility in the Port of Liverpool. The international supply chain developed by Drax via these seaports has proven that the large-scale import of biomass into the North of England is economically viable.

Croda stated that an advantage in continuing its operations in the North of England is proximity to the "world's best woody biomass transport infrastructure" based at the Drax development.

Greenergy, with production plants at Immingham on the Humber estuary and Seal Sands on Teesside, is the UK's largest producer of biodiesel and is a Fortune Global 500 company with a rapidly growing business exporting to Brazil and Canada. Greenergy is the UK's leading supplier of road fuel, has the lowest delivered cost of supply and is growing internationally. Greenergy achieves efficiency at scale in its global supply chain, further validating the business model of importing biomass for processing.

Creating the capability to generate such investments in the region is likely to require a combination of public and private funds, reasons for investors to believe that the North of England is the right place to invest in the bioeconomy, and an economic development strategy that encourages companies to build production facilities in the region rather than elsewhere.

5.6 Conclusions

The North of England's asset base is central to the hypothesis that the region is the right place to invest in the bioeconomy. The North of England has a distinctive set of bioeconomy assets, including world-class science, applied research excellence, translational expertise and industrial capacity. These can be mobilised to build economic value from agri-tech and industrial biotechnology and achieve full exploitation of the bioeconomy to deliver jobs and economic growth.

The region is large and this brings advantages of scale and diversity, but its various research, translation and industry assets are distributed unevenly. Different areas within the region have varying bioeconomy specialities and translational focuses. These include bioenergy and biofuels around the Humber estuary and Teesside, bio-based consumer products around Merseyside, large-scale bioprocess industries in the North East and agri-food in North Yorkshire. As a result of this distribution, the whole of the North of England has greater potential than that of its parts separately, but risks failing to benefit from synergies and common capabilities across adjacent industry sectors.

Supply chains that encourage innovation within the bioeconomy are distributed rather than integrated. The small insurgent businesses that will transform the regional bioeconomy tend to gravitate to the larger concentrations of activity, where business and innovation support and skilled workforces already exist. Currently, these bioclusters tend to be found around the existing chemicals clusters, although some are specifically choosing to locate close to translational centres such as CPI and Fera. In the future, new types of biocluster are likely to form around large biomass industries producing fuel, energy or major food and drink materials, where there is the opportunity to utilise secondary product streams and share logistics and utilities. Such biorefinery complexes would provide a locus for investment and translational support, and generate industry-led challenges for further applied research in academia.

Insurgent companies developing new products and processes will need access to substantial funds to bring them to market. This provides opportunities for the established incumbents in the region to invest in the innovation pipeline at an appropriate stage, but there is currently a gap in high-risk venture capital ready to invest in disruptive technologies.

Recommendation: Learning from the success of bioeconomy cluster organisations in mainland Europe, including the IAR cluster in France, the region should develop a coordinated approach to catalyse and nurture the formation of biocluster locations where companies can integrate their supply chains and access shared utilities, logistics, innovation facilities, applied research capability and investment capital.

CHAPTER 6
SCIENCE AND INNOVATION TALENT TO DRIVE THE BIOECONOMY

24%

of food and drink industry workforce employed in the North of England

30%

of UK process operators employed in the region

31,000

bioeconomy-relevant apprenticeships started in the region in 2015/16

26%

of UK land-based apprenticeships delivered by the region's colleges

25%

of UK STEM graduates and postgraduates qualify in the region

6 Science and innovation talent to drive the bioeconomy

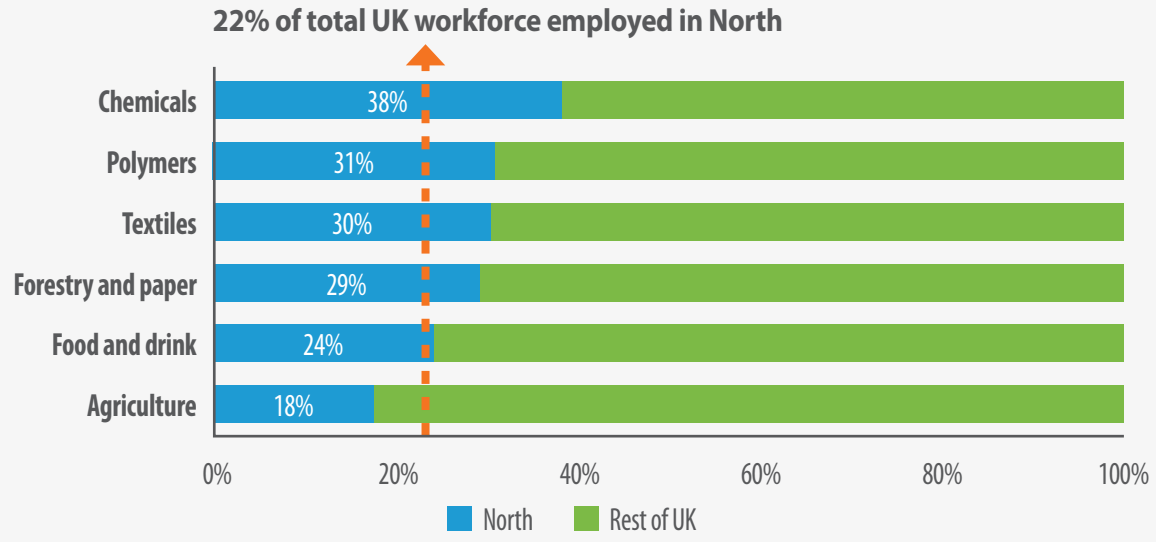
Delivering the consortium's vision for the bioeconomy depends on having key technical skills within the workforce. Researchers will use knowledge of microbiology and synthetic biology to create new biochemical pathways for processing biomass. Biochemical engineers will design new processes and production plants, and process operators and technicians will run them. Experts in agronomy, animal and plant health, agri-engineering and precision agriculture will provide innovation in crop and livestock production. The food and drink industry will require nutrition, food science and processing skills. The bioeconomy overlaps existing disciplines and calls for unusual combinations of technical expertise. Equally important are skills to drive commercial innovation, including entrepreneurship, leadership, business management and partnering. Many of these skills exist already in the workforce, some will be grown through the regional education system, and others will need to be imported. Establishing a sustainable skills base is a prerequisite for the North of England to become a global bioeconomy leader.

6.1 The northern bioeconomy workforce

As quoted in Chapter 3, 22 per cent of the total UK workforce is based in the North of England. The consortium used the same bespoke SIC code definition of the bioeconomy for workforce analysis as that adopted to investigate LQs (Chapter 3) and to conduct the business audit in Chapter 5. According to this definition, Office for National Statistics Labour Force Survey data shows that 1.66 million people in the UK are employed in the bioeconomy.

Of these, 24 per cent (just under 400,000) are employed in the North of England. The region is a disproportionate employer in certain bioeconomy-related sectors, accounting for 38 per cent of the UK's chemicals industry and 31 per cent of the polymers industry workforce. This compares with 22 per cent of the UK workforce employed in the region across all sectors. These concentrations of skilled people, currently employed in aligned process manufacturing industries, provide the bedrock of workforce capacity that will support growth in new bioprocessing initiatives (Figure 13).

FIGURE 13: BIOECONOMY WORKFORCE IN THE NORTH OF ENGLAND BY SECTOR



Source: Office for National Statistics (2017)[146]

6.2 Supply of process skills

In the process industries, technicians and plant operators form a key component of the skills mix. The national shortage of skilled technicians is well documented.[147] The Science Industry Partnership forecasts a need for up to 73,000 technicians across the science industries alone over the next ten years.[148] Technicians working in the bioeconomy need to possess chemical, biological and engineering knowledge, and to be able to run processes using a range of complex equipment while collecting and analysing data. Twenty-five per cent of the UK's science, engineering and production technicians and 30 per cent of its process operators and plant and machine operators are employed in the North of England.[149] This critical mass of technical-level workers, essential to the commercialisation of new technology, is a comparative advantage to the North of England's bioeconomy but requires both a continuing flow of new entrants and further up-skilling in the workplace.

Apprenticeships are an increasingly important route into these types of jobs (see Box 10). They are less likely than research or managerial roles to attract talent from outside the region, and so a healthy home-grown supply is particularly important. The North of England already provides a large part of this supply nationally and therefore has a relative advantage in this respect. In 2015/16, 86,000 apprenticeships were started in sectors of relevance to the bioeconomy nationally[150] and 36 per cent of these (30,810) were located in the North of England.

BOX 10

For Teesside chemical manufacturer **Lucite**, apprenticeships are crucial to ensure a workforce with the right skills. Lucite has played an active role in the development of the new apprentice standards as part of the national 'trailblazer' team. Faith Hambley, Lucite's Learning and Development Officer, said: "The structure of trailblazers means that, once complete, individuals can be working effectively in their chosen specialism within weeks. In our case, this will be either as a production technician or an electrical and instrumentation technician."

6.3 Skills provision to the agri-food supply chain

The universities in the North of England provide a range of degree-level and postgraduate skills to support the agri-food sector, such as those offered by Newcastle University's School of Agriculture, Food and Rural Development. A large proportion of high-level skills entering the sector, however, come through the further education sector. The North of England's land-based colleges are national assets. Six of the 52 regional further education institutions are designated specialist land-based colleges,[151] focusing on applied research and knowledge transfer, specialist continuing professional development activities and high-level skills, alongside technical training. More than half of the degrees offered in land-based subject areas are currently delivered in colleges of further education.[152]

During 2014/15, the six land-based colleges delivered more than 28 per cent of available land-based further and higher education qualifications, and 26 per cent of all land-based apprenticeships nationally. Three of the five largest providers of land-based qualifications in the country (Askham Bryan, Myerscough and Reaseheath, see Box 11) are based in the North of England. The region's land-based colleges attract students from across the country; in 2014/15 students were recruited from 38 of the UK's 39 LEP areas.[153] These colleges will play a major role in agreeing suitable apprenticeship standards for the land-based industries, which currently lag behind agreed standards in the process industries due to the prevalence of small and micro-businesses in the agriculture industry.

BOX 11

Askham Bryan College will open their new £2.4 million agri-tech innovation centre and land-based engineering workshop in 2017.[154] Made possible with funding from the York, North Yorkshire and East Riding LEP, its land-based engineering workshop features a large open area with modern, specialist equipment. The Agri-tech Innovation Centre offers high-quality teaching and office facilities. Students can now access the latest farm management techniques and technologies, and the facilities also enable local partners, such as Fera, BDC and the University of York, to demonstrate how their developments can be applied to a modern farm setting.

Myerscough College is investing £20 million in facilities to integrate its courses with agri-business training, including an agriculture and countryside rural skills centre and the £3 million Food and Farming Innovation Technology Centre. This showcases innovation and technology in farming and food production, focusing particularly on grazing livestock and grassland management, an agri-engineering centre and horticultural glasshouse facilities.[155]

Reaseheath College's £8 million industry standard Food Centre[156] includes operational areas for dairy production, bakery, butchery and food trials. It is the only education institution in Britain to receive British Retail Consortium 'Grade A' certification, and the first to be selected as a Centre of Excellence for Dairy by the National Skills Academy for Food & Drink.

6.4 High-level technical skills

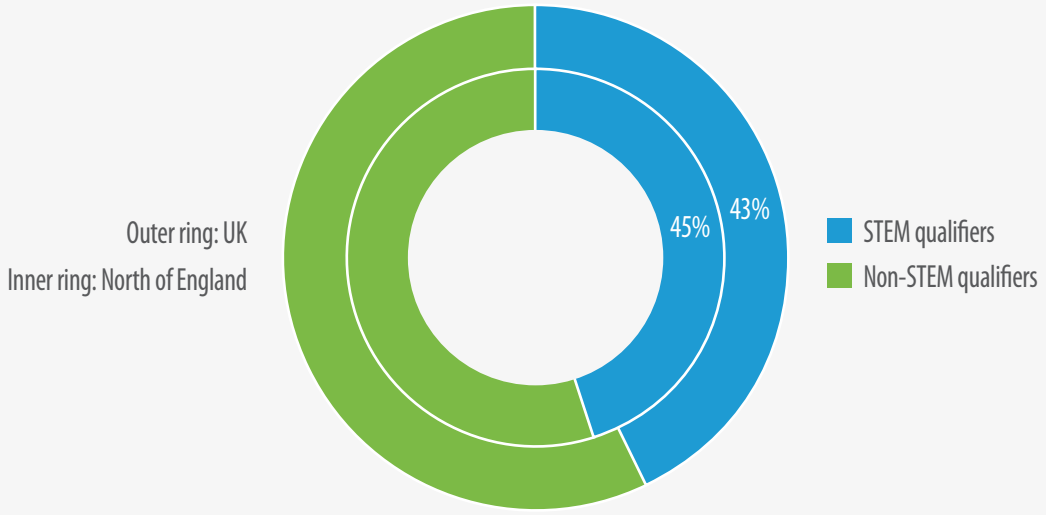
New entrants in the bioeconomy workforce require skills in STEM subjects, with 61 per cent of degree holders in the bioeconomy having a STEM degree compared with 38 per cent in the workforce as a whole. Research conducted by the Science Industry Partnership[157] indicates that the national supply of STEM graduates is, overall, currently sufficient to meet forecast science industry demand.

The region's universities produce more than their share of graduates in STEM subject areas equipped to research, scale up and commercialise new technologies in the bioeconomy. In 2014/15, almost 44,000 first-degree students and just over 20,000 postgraduates qualified from universities in the North of England in STEM subjects, a quarter of the UK total. Of all graduates, 45 per cent qualify in STEM subjects in the North of England, compared with 43 per cent nationally (Figure 14). The region therefore supplies enough highly skilled STEM entrants to the workforce to sustain current bioeconomy requirements and has some capacity to supply growth in the sector.

New UK graduates in the bioeconomy tend to be quite mobile. According to Destination of Leavers from Higher Education survey data,[158] in 2015, 40 per cent of postgraduates and 42 per cent of graduates entering employment in the bioeconomy (as defined by this report's SIC code definition of the bioeconomy given in Appendix C) in the North of England gained their qualification from a university outside the region. This implies a healthy movement of new talent into the region at high skills levels and is strongly influenced by the regional concentration of jobs in the major chemicals clusters.

The ability to attract talent at the highest skills levels is crucial to the bioeconomy, since some of the specialised research skills required for innovation may be in short supply within the region. Bioprocess or agri-tech companies clustering in a similar way to that of the chemicals industry, for example around major logistics hubs and primary biorefining sites, will help attract talent to the regional bioeconomy by providing a range of employment opportunities in specific locations.

FIGURE 14: FIRST DEGREE STEM QUALIFIERS 2014/15



Source: Higher Education Statistics Agency Student Record 2014/15[159]

6.5 Commercial and entrepreneurial skills

Alongside technical skills, commercial awareness and entrepreneurial capability among the high-level workforce is vital for realising innovation in the bioeconomy. Research carried out by the Science Industry Partnership with food and drink employers[160] and companies using industrial biotechnology[161] suggests that new graduates' commercial and practical skills often do not meet employers' expectations. This conclusion was supported by the consortium's survey of regional companies. The same source reports some innovation skills gaps at senior levels in companies, including the ability to identify funding sources, appraise the benefits of new technologies and understand potential applications. The region already has a slightly lower than UK average rate of business births[162] (see Table 3) and these skills gaps represent a potential barrier to the development of the bioeconomy. Box 12 provides an example of an initiative designed to boost entrepreneurship.

BOX 12

BioVale, the Yorkshire-based bioeconomy cluster organisation, will deliver a three-year Interreg-funded project to provide entrepreneurship 'boot camps' to bioeconomy SMEs as part of an international project to raise capability in the sector. The intensive, week-long courses offer €7,000-worth of fully funded, specialist training for new, high-growth, bio-based businesses from across North West Europe. They are designed to give start-up companies in the bioeconomy the tools they need to commercialise and grow.

6.6 Developing future leaders

Doctoral Training Centres (DTCs) have been highlighted by industry as an excellent route to developing researchers with the commercial awareness and entrepreneurial skills needed to increase the scale of inventions to production levels in the bioeconomy.[163] In DTCs, postgraduate students undergo a

programme of study alongside their PhD projects to improve their employability, often involving industrial placements. There are 14 bioeconomy-relevant DTCs funded (2013/14) by EPSRC and the Natural Environment Research Council (NERC) in the North of England, which account for a substantial proportion (11 per cent) of DTCs awarded by these Research Councils nationally.[164] In addition, for 2015–2019, BBSRC has awarded funding for 295 Doctoral Training Partnerships (DTPs) and 81 collaborative training partnerships (CTPs) to North of England institutions. This accounts for 17 per cent of BBSRC-awarded DTPs and 43 per cent of CTPs nationally.[165]

6.7 Up-skilling the bioeconomy workforce

Many people working in the UK bioeconomy have already left full-time education. The uptake of new skills is therefore critical to the success of the consortium's vision. This requires translational organisations to incorporate the delivery of new skills into their services, as part of an organised training provision in bioeconomy-relevant skills. Box 13 illustrates some examples. The chemicals clusters in the region have already catalysed specialised training capabilities to provide services that are appropriate to their needs. The Humber chemicals cluster organisation, CATCH, makes workforce training a central part of its membership services.

Translational organisations such as CPI and Fera also provide training relevant to their activities. As in the chemicals industry, a growing, technology-enabled bioeconomy will drive a requirement for improved workforce skills. This will be provided by expanding the services offered by organisations like CATCH and Britest, which are already serving adjacent sectors, by translation organisations serving the bioeconomy and by regional colleges and universities delivering continuing professional development programmes.

BOX 13

Stockbridge Technology Centre is running the Tru-Nject research project, which combines sensors and satellite image data with unique application technology to optimise agricultural fertiliser use. With encouraging results gathered to date in field trials, the project also delivers free precision agriculture training events for farmers at the institution site and Manterra to improve farm productivity.

Britest uses chemical engineering tools developed at the University of Manchester to improve process efficiencies in the chemicals and pharmaceuticals industries, and supports its innovation projects with professional training, mentoring and facilitation.

CATCH operates a world-renowned training facility in northeast Lincolnshire. Using a full-scale demonstration process plant, the facility provides skills, training and competency solutions for the process industries across the UK and internationally. CATCH also manages engineering and supply chain schemes, capital and business support programmes, network groups, skills programmes, conferences, events and publications aimed at encouraging best practice, knowledge exchange and business excellence.

6.8 Conclusions

The consortium identified skills provision as an essential enabler of its vision for the region to become a global leader in the bioeconomy. This audit shows that the region has, in most respects, sufficient infrastructure and capacity to provide a skills pipeline for the bioeconomy at all levels, and that the

availability of employment attracts external talent, at least at the graduate level. There is evidence, both anecdotal and through rates of business formation, that despite relatively high levels of business innovation, the region is less entrepreneurial than other parts of the UK.[166] This may have consequences on the growth rate of the bioeconomy.

In order to grow the bioeconomy within the envisaged timescale, companies must broaden the skills base of their existing workforce. Within its training and translational organisations, the region has or can generate most of the specialist skills needed by industry in the bioeconomy, but the capability to deliver these skills to the frontline workforce needs to be expanded. The region will inevitably need to attract certain types of talent, and the North of England covers a large area. Researchers, innovators and entrepreneurs will want to identify clusters of activity in the bioeconomy that provide varied employment opportunities, good quality of life and effective business support.

Recommendation: Colleges and universities in the North of England should provide courses that deliver the range and overlap of skills needed to service an innovative bioeconomy. Building on the DTC model, formal training in technical skills should be coupled with opportunities to learn commercial and entrepreneurial skills before taking up industry employment. Our translational centres should incorporate skills provision and knowledge exchange into their services, where appropriate, in collaboration with the higher and further education system. Where there are emerging cross-sectoral training requirements (similar to those provided by CATCH), investment will be needed to create regional and national facilities. Employers must invest in their current workforce to transfer skills from adjacent sectors across traditional boundaries. Skills provision should be 'joined up' across the region in the same way as research and innovation, making it easy for companies to access.

CHAPTER 7
NATIONAL AND INTERNATIONAL ENGAGEMENT

26%

of N8 university revenues are generated from international sources

47

country partners collaborated in EU Framework Programme projects with Fera

>£4 billion

recent investment in the bioeconomy of Yorkshire and the Tees Valley

2,450

companies in the three major chemical estuaries of the North of England

7 National and international engagement

For the UK bioeconomy to effectively exploit its recognised technological expertise to create international markets for its products, processes and services, it must have networked, global supply chains for materials and innovation. The North of England already has strong national and international connections in the bioeconomy and is well placed to capitalise on these existing relationships, as well as building new ones.

7.1 International science and applied research collaborations

As major UK academic institutions, the region's research-intensive universities are committed members of the international research and teaching community. Approximately 26 per cent of the revenues of the N8 network come from international sources.[167] The importance placed on international relations is embodied in membership of mission groups, such as the Worldwide Universities Network, and the establishment of overseas campuses. These include Xi'an Jiaotong–Liverpool University, the Southwest Jiaotong University–Leeds Joint School, Lancaster University College at Beijing Jiaotong University, Lancaster University Ghana and Newcastle University Singapore.

One of the reasons that the UK has one of the most creative, productive and highly rated research sectors in the world is because its research output is comparatively international.[168] According to Elsevier's *Scopus* database, almost half of the UK's research publications feature international co-authors.[169] This is especially the case in research related to the bioeconomy. The consortium found that the UK's international co-publication rate is 66.8 per cent for agri-science, 65.4 per cent for agri-tech, and 52.4 per cent for industrial biotechnology. Aggregated international co-publication rates from consortium universities (the N8 group plus Hull and Sheffield Hallam) in these subjects are almost identical to those of the UK as a whole.

The consortium reviewed where its partner universities are co-publishing, and found a global spread of collaborators (Figure 15). The largest numbers of regional academic collaborations are with European partners, but Australia, Brazil and the USA also have strong academic links with the North of England. Co-publication with industry partners is also global, although it is notably led by collaboration with the USA, reflecting the USA's current leading position in the global bioeconomy. Data from the European Framework Programmes (Horizon 2020 and FP7) provide further confirmation of the international nature of the region's bioeconomy research. In the ten years to 2016, the North of England secured £5 billion in funding for bioeconomy projects, representing 16 per cent of all EU research and innovation funding to the UK in the previous and current programme.[170] Box 14 provides two examples of international collaboration.

BOX 14

Working in collaboration with the University of York, the University of Cambridge and the University of Copenhagen, and the Centre National de Référence Marseille, Danish bioinnovation company, **Novozymes** has introduced novel enzyme cocktails for the breakdown of cellulose into sugars. It has developed these into an industrial pathway for generating biofuels from cellulosic waste. To date, several biorefineries worldwide are using this breakthrough technology.

Between 2007 and 2017, **Fera** collaborated with more than 500 partners from research and industry from 47 countries in FP7 and Horizon 2020 projects. Fera was ranked first in the UK and fourth in the EU for the number of FP7 knowledge-based bioeconomy projects it coordinated.[171]

FIGURE 15: NUMBERS OF INTERNATIONAL RESEARCH COLLABORATIONS

Note: Data compiled from the top ten countries where each of the consortium universities (N8 universities plus the University of Hull and Sheffield Hallam University) have international joint publications. Source: *Scopus* database

In addition to the region's universities, the major national facilities at Fera and CPI promote active participation in national and international research and innovation projects. These facilities represent the UK's world-leading capability in their respective areas of expertise.

7.2 National innovation networks

Agri-science and industrial biotechnology research and innovation are conducted across the UK, with notable concentrations of expertise in East Anglia, Wales and Scotland. The North of England is a full contributor to national networks and innovation programmes.

7.2.1 Networks in industrial biotechnology and bioenergy

With support from EPSRC, BBSRC has committed £18 million to fund 13 separate collaborative national networks in industrial biotechnology and bioenergy (NIBBs). These include 1,125 members from academia and 801 from companies, ranging from microbusinesses to multinational conglomerates. These multidisciplinary networks drive and fund joint industry–academia collaborations to harness the potential of biological resources for producing and processing materials, biopharmaceuticals, chemicals and energy. The quote in Box 15 summarises some of the benefits.

NIBB leadership, membership and competitively distributed funding is based disproportionately in the North of England. Nine of the 13 networks are led or co-led by universities in the region, 40 per cent of academic members are based in the region, and 27 per cent of company members are from the North of England. Of competitively distributed funding, 30 per cent has been secured by regional institutions.

BOX 15

"We at **Lucite** have always been aware that a key issue for us, as we strive to develop new technology for the sustainable production of methacrylates, is the transport of substrates and products across the membranes of the microbial hosts. The issue was identifying the key expertise with which we could collaborate to solve our product-specific problems. CBMNet [a NIBB led by the University of Sheffield] has been instrumental in bringing together the UK and European expertise in membrane science."
Graham Eastham, Lucite International

7.2.2 BioPilots UK

BioPilots UK is a recently established collaboration among five established biorefining open-access centres across England, Scotland and Wales. The aim is to develop UK-wide bio-based value chains. Together, the centres de-risk the commercialisation of bio-based products and processes by trialling new technologies to ensure their partners are investing in the right technologies for their businesses. By acting in concert, the centres streamline the provision of support to clients, with the necessary expertise available from across the network at each stage of the development process. The North of England members are CPI and BDC.

7.2.3 The Food Innovation Network

Established in October 2016, the primary objective of the York-based Food Innovation Network is to tackle the main obstacles to innovation, productivity and growth in UK agri-food and drink businesses. The network facilitates access to information, research, skills, expertise and funding to increase competitiveness and profitability, thereby contributing to the UK government's long-term plan for food and farming, which is to make the UK one of the world's leading food-producing nations.

7.3 Regional science and innovation networks

Individual bioeconomy-relevant networks within the North of England each have their own set of national and international links, and represent significant assets needed for the transfer of knowledge within and outside the region.

7.3.1 The chemicals and process clusters

The regional chemicals clusters each have well-established industry groups that provide networking and business services for their members and act as a collective voice for their interests at the national level.

The North East Process Industry Cluster works with regional chemical industries, including petrochemicals, polymers and materials, fine and speciality chemicals, pharmaceuticals, biotechnology and renewables. CATCH is an industry-led partnership supporting the process engineering, energy, engineering and renewable sectors in the Humber region. It has members from across the associated supply chains, regional and national government agencies, and all four Humber local authorities. Chemicals Northwest is the industry-led, chemical cluster support organisation for the North West chemical sector, the largest in the UK.[172]

7.3.2 BioNow

BioNow is an industry membership organisation supporting business growth, competitiveness and innovation in the North of England life sciences and biomedical sectors. Although these sectors are outside the scope of this audit, there is an element of membership crossover between companies in the biomedical sector and those active in industrial biotechnology, and a strong common interest in underpinning research and technology such as genomics and proteomics, synthetic biology, data management and bioprocessing.[173]

7.3.3 BioVale

BioVale is a free membership network supported by EU and national funds, and is the closest thing to a regional membership organisation for the bioeconomy. BioVale links businesses primarily in the Yorkshire and Humber region with each other, with universities and other innovation facilities, and with organisations and networks in Europe. It facilitates access to bioeconomy research and expertise, and to specialised training, facilities and funding. BioVale supports networking and partnerships between the region's bio-based innovators and their supply chains, and promotes the Yorkshire and Humber bioeconomy to export markets, investors, policymakers and funders. It has links to established bioeconomy networks in Belgium, France and Germany, and offers access to opportunities that individual companies, particularly SMEs, would otherwise find hard to source. The BioVale project, led by BDC, has undertaken over 200 projects with regional SMEs, catalysing 42 R&D projects involving 39 companies with a total value of £27.4 million that has resulted in investment of £9.8 million in the region.[174]

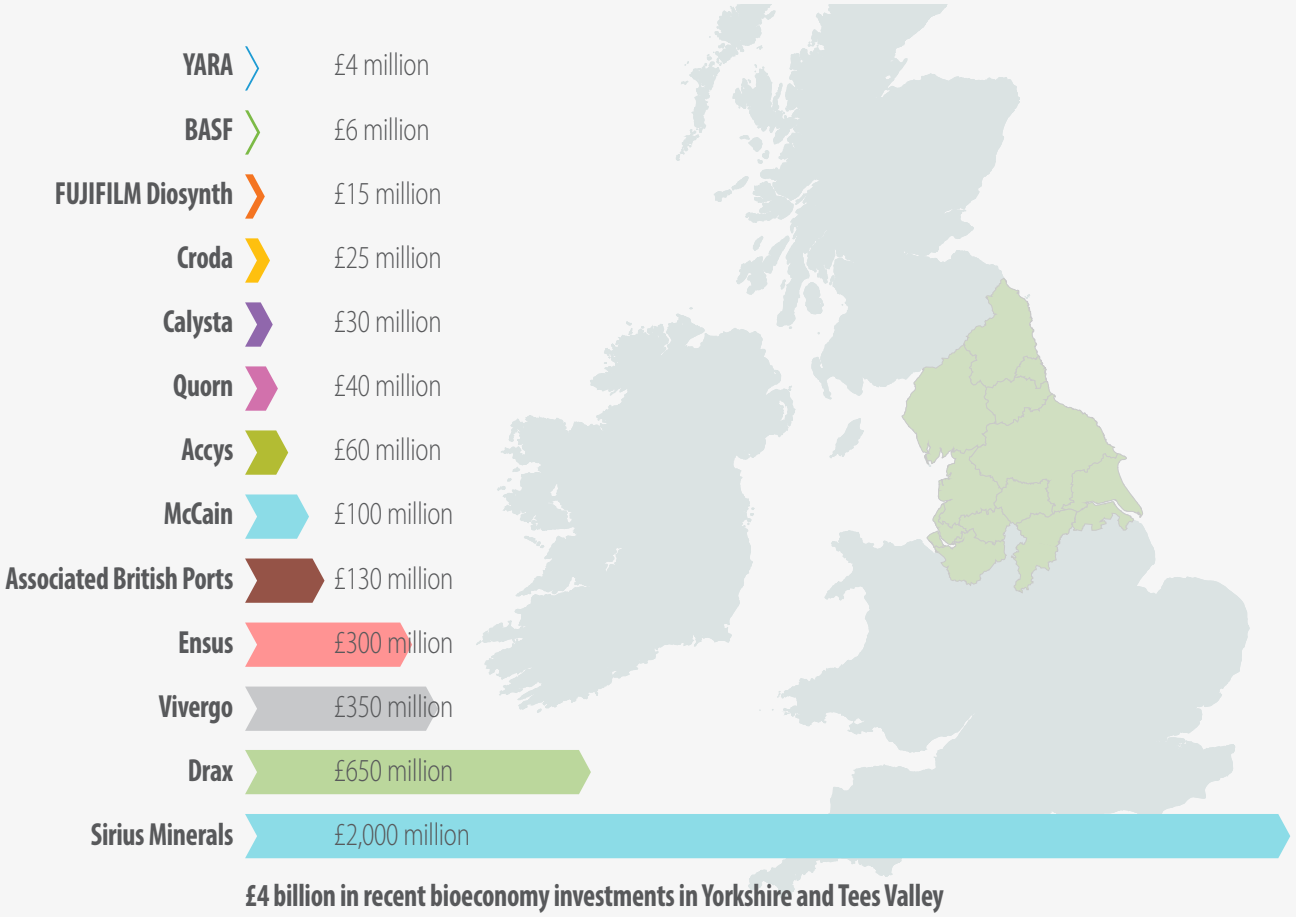
7.4 Globalising the bioeconomy: Exports and inward investment

The bioeconomy overlaps several recognised business sectors, including agriculture, food and drink, animal feed, chemicals, consumer goods, fuel, energy, medicine and materials (Table 2). Because data is not currently collected on this sector, it was difficult to quantify the volume of export sales and foreign direct investment in the regional bioeconomy through official statistics. Information provided by sector networks, LEPs and consortium members, however, reveals substantial inward investment in areas associated with the bioeconomy across the North of England. More than £4 billion has been announced or invested recently in Yorkshire and the Tees Valley alone (Figure 16).

Humber and Teesside house many of the North of England's largest biotechnology and biofuel manufacturers, including Vivergo (see Box 16), Greenergy and Ensus. These are obvious locations for significant bioeconomy investment due to their exceptional national and international logistical links, excellent regional networks and existing expertise and infrastructure.

As already noted, the North of England bioeconomy has a high degree of synergy with the regional chemicals industry. The chemicals sector is the most important UK manufacturing exporter, contributing £60 million a day to the national economy. The Department for International Trade estimates that the UK chemicals industry is responsible for £26 billion in overseas trade,[175] and the SIA region produces 47 per cent of the UK chemicals industry GVA. The three chemicals clusters of the Humber, Tees and

FIGURE 16: EXAMPLES OF RECENT INVESTMENT IN THE NORTH OF ENGLAND BIOECONOMY



Note: Sirius Minerals will be extracting polyhalites primarily for fertiliser, forming part of the agri-food chain.

Mersey estuaries, which collectively host 2,450 companies with sales of £41 billion and provide 95,000 jobs, produce the majority of UK exports in this sector.[176] Investment in the chemicals industries is evident outside these clusters, however. In 2016, German chemicals manufacturer BASF commissioned a new bioacrylamide facility operating a process developed in collaboration with the University of Huddersfield.[177] The facility is based at its Bradford site, one of the UK's largest single-site chemicals plants with an annual output of more than 250,000 tonnes, of which 84 per cent is exported.

The region's food and drink producers are also networked globally. Several UK supermarket chains, including Asda and Morrisons, are headquartered in the North of England and have international supply

BOX 16

Vivergo Fuels, based at Saltend on the Humber estuary, was founded as a £350 million joint venture between AB Sugar, British Petroleum and DuPont, representing expertise in agriculture, animal feed, fuel, energy and biotechnology. Using locally grown feed-grade wheat (a key factor in its choice of location), it is the UK's largest producer of both ethanol and single-source animal feed.

chains. Canadian food producer McCain Foods, one of the world's largest suppliers of potato products, announced in March 2017 its intention to invest £100 million in its Scarborough facility.[178]

7.5 Conclusions

Within the consortium hypothesis that the North of England has the assets, specialised research and innovation capability, and industrial capacity to deliver a world-leading bioeconomy based on agricultural technology, agri-science and industrial biotechnology, the audit team identified the key role of connectivity across the region. One of the foundations of the hypothesis is that the bioeconomy requires new supply chains and effective networks to ensure that innovative products, processes and services are brought to market.

This report demonstrates that the North of England has a well-developed research and innovation infrastructure based on strong national and international networks, a collaborative science and innovation culture, excellent import and export logistics, and a strong global industry base. The region is exceptionally well placed to internationalise the regional bioeconomy further and make a significant contribution to regional prosperity and UK exports.

While this audit found evidence of strong networks and 'networks of networks' operating at levels from regional to international, it also highlights the lack of a pan-North of England network with the stated purpose of developing and promoting innovation in the bioeconomy. Without capacity to connect assets and capabilities across the region and set strategy at the appropriate regional level, there is the risk that investment in bioeconomy innovation will be made in a piecemeal fashion and poorly directed. There is a sub-regional example of a body with these ambitions in the Yorkshire and Humber region (BioVale).

Recommendation: A regional body is needed to coordinate the innovation supply chain of the North of England bioeconomy, which is currently fragmented. Such a body would take ownership on behalf of its stakeholders for developing the inter-sectoral links that are essential for the development of new bioeconomy value chains. It would identify and work up collaborative proposals for investment in innovation infrastructure, reinforce existing relationships and build new ones between those involved in science, applied research and innovation across the region, and ensure the skills critical to all stakeholders are deployed effectively throughout the innovation supply chain. It would promote the North of England internationally as a key player in the emerging bio-based economy, and act as a voice for the regional bioeconomy in dealing with government, ensuring the assets and needs of the North of England are taken into account when developing a bioeconomy strategy for the UK.

CHAPTER 8
DEVELOPMENTS IN THE WIDER LANDSCAPE: POLICY, STRATEGY AND FUNDING

26

countries have national strategies for the bioeconomy

11

LEPs include aspects of the bioeconomy in their strategic economic plans

8 Developments in the wider landscape: Policy, strategy and funding

The UK government recognises the potential of the bioeconomy to drive future economic growth, and the Research Councils and Innovate UK have invested significant resources in stimulating innovation. The North of England has a well-networked community of stakeholders capable of identifying barriers to success and formulating solutions that deliver a connected, productive bioeconomy.

8.1 UK government science strategy

The science underlying the bioeconomy is supported strategically in the UK by BBSRC. Its core narrative[179] begins by stating that the bioeconomy is large and growing, and it is the UK's excellent basic bioscience that underpins this growth. Two of BBSRC's three strategic research priorities are agriculture and food security, and industrial biotechnology and bioenergy. These strategic priorities have a 2015/16 collective science budget of £175 million,[180] and together represent 37 per cent of BBRSC's total £473 million budget for the year. A further £136 million budget for biosciences underpins all three strategic priorities.[181]

8.2 UK government industrial strategy

In 2016, the UK government announced its intention to develop an industrial strategy for the nation to address long-term challenges, improve living standards and promote economic growth by increasing productivity and rebalancing the economy across the whole country. This strategy has been the subject of consultation during this audit.[182] As part of its overall industrial strategy, the UK government has also announced £4.7 billion investment in science and technology to 2021.

The UK government's industrial strategy emphasises innovation, place and driving economic growth for regions as well as the nation as a whole. The proposed ten pillars of the strategy[183] resonate with the vision and opportunities for, and findings of, this audit (Table 8).

Table 8. The ten pillars of the UK industrial strategy

Pillar	Connection to the bioeconomy in the North of England
Investing in science, research and innovation	The North of England is strong in research and innovation in disciplines that drive the advanced bioeconomy (industrial biotechnology, agri-science and agri-tech). Its differentiating factors are its industry assets and technical capabilities for translating research into innovation.
Developing skills	The region has a notably strong higher education infrastructure. It has world-class universities producing a disproportionate share of the UK STEM graduates, excellent land-based colleges and a strong pipeline of apprentices with which to supply a growing bioeconomy.
Upgrading infrastructure	Much of the region's bioeconomy is based around the UK's major ports in the Tees, Mersey and Humber estuaries. There is good north–south road and rail connectivity. Better east–west connections within the North of England would drive the overall economy, including the bioeconomy.

Table 8 (continued)

Pillar	Connection to the bioeconomy in the North of England
Supporting businesses to start and grow	The North of England has excellent open-access facilities and innovation services. More could be done in the region to provide funding for early-stage businesses, however. The Northern Powerhouse Investment Fund provides opportunities in terms of financial support, but the scale of ambition, the need for specialist sector knowledge and the level of risk require significantly higher venture capital than is proposed, for both the region and the bioeconomy.
Improving procurement	The US federal government's BioPreferred programme[184] has had success in stimulating the growth of an advanced bioeconomy in the USA. A similar programme in the UK has every opportunity to yield equivalent benefits.
Encouraging trade and inward investment	There is strength in bioeconomy innovation in the North of England. Some of these innovations are commercially exploited overseas, thus depriving the UK of the resulting skilled jobs and economic growth. Policies to promote the anchoring of innovation exploitation at home would help to correct this leakage of value. Visible promotion of the North of England's bioeconomy capabilities would attract inward investment in R&D.
Delivering affordable energy and clean growth	Bioenergy and biofuels are the spearhead for new, large-scale bioeconomy enterprises. These businesses invested when government policy was favourable, but are uncertain about whether future UK policy will provide an environment in which they can grow. A stable, supportive biorenewables policy is a prerequisite for growth in these sectors.
Cultivating world-leading sectors	The UK is at the forefront of bioeconomy research. There is, however, a disparity between investment in commercial development between the UK and the USA and Europe. This is most evident in the lack of UK start-up technology companies that have grown to a large scale, while the USA (e.g. Amyris, Rennovia) and Europe (e.g. Avantium) demonstrate major investment in new bio-based technology. We need to promote the growth of insurgent businesses and maximise their synergy with the asset base of incumbents.
Driving growth across the whole country	There is strength in the North of England and, with the right interventions, the region can deliver a thriving bioeconomy that includes disruptively innovative insurgents.
Creating the right institutions to align sectors and places	The North of England is well represented in networks that inform policy for the bioeconomy. It has 11 LEPs that recognise the potential of the bioeconomy. The region does not lack for numbers of institutions, but does lack a single, strong voice for the development of its bioeconomy.

8.3 LEPs and industry sector growth strategies

The North of England is represented by 11 LEPs (see Figure 5 in Chapter 3). Aspects of the bioeconomy feature in the strategic economic plans (SEPs) of all 11, particularly in the chemicals and the food and drink sectors. Although medical biotechnology is not within the scope of this audit, it shares underpinning technologies and is highlighted as an important sector within several of the SEPs. A report on the bioeconomy by LEP area, compiled during the conduct of this audit, is included as Appendix I.

8.3.1 Chemicals

The North of England's three chemical industry clusters are located in the Tees Valley, Humber, and Cheshire and Warrington LEPs. Tees Valley is home to the second-largest integrated chemicals complex in Western Europe, with manufacturing spread across the three main sites of Wilton International, Billingham and Seal Sands. Together, these sites span approximately 12 miles from east to west along both sides of the River Tees. Tees Valley is home to CPI, headquartered at Wilton International and with facilities at Wilton, Darlington and NETPark (Sedgefield). Together these facilities represent the UK's foremost capability in the commercial development and scaling up of industrial biotechnology.

The Humber chemicals cluster is supported by the ports of the Humber, which carry one-quarter of the nation's seaborne trade. Chemicals companies active locally include Air Products, BASF, BOC (LINDE), BP Chemicals, Cristal, Croda, Kemira, Knauf, Nippon Gohsei, Novartis, Phillips66, Syngenta, Synthomer and Total. The Humber LEP recognises the importance of bioenergy and biofuels within its renewable energy strategy. The Cheshire and Warrington SEP shows that the chemicals sector has the second-highest LQ for the region, with a focus on the opportunities for innovation in industrial and medical biotechnology.

8.3.2 Food and drink

The Northern Powerhouse Investment Fund review of the North of England economy[185] notes that participation in business sectors in the region broadly mirrors that of the UK as a whole, but it points out that food and drink are over-represented. The highest regional LQs for food production are within York, North Yorkshire and East Riding (YNYER), Lancashire and Greater Manchester LEP areas. YNYER LEP hosts both Nestlé and McCain Foods. Nestlé is the world's leading nutrition, health and wellness company. McCain Foods is one of the world's largest manufacturers of frozen French fries and potato specialities. McCain Foods has been active in seeking to use co-products as inputs for other bioeconomy processes and the company works with Soltens in Yorkshire to add value to potato by-products.

Greater Manchester LEP has a number of major food-producing companies located within its boundary, including Kellogg's, Kraft Heinz and Warburtons. Kraft Heinz's main UK and Ireland manufacturing facility at Kitt Green near Wigan is the largest food-processing factory in Europe, employing 1,200 people. Lancashire LEP is home to many food and drink companies, including Dr Oetker in Leyland and Pepsico in Skelmersdale, as well as a large number of brewers.

8.3.3 Absence of a pan-regional bioeconomy strategy

Although all LEPs have identified aspects of the bioeconomy in their strategic plans, only YNYER recognises the bioeconomy specifically as a strategic sector, including having established a £10 million investment fund to support bioeconomy business growth. There is no overall strategic plan for building the bioeconomy at the North of England scale. Different sectors within the bioeconomy have limited connections, and no single LEP area incorporates all features of research expertise, translational capability and industry absorptive capacity to deliver or fund an innovation-led bioeconomy programme. This is the principal reason why the audit consortium believes the North of England to be the appropriate geographic scale for strategic leadership of the regional bioeconomy.

8.4 Policy

Many of the companies interviewed during this research highlighted inconsistencies in government policy as a restraining force on the development of the bioeconomy. Some noted that incentives have been available for the production and sales of bioenergy and biofuel products, but not for the production and sale of higher-value-

added chemicals that could be made from the same feedstocks. This acts as a barrier to the development of the bio-derived chemicals sector. Box 17 gives some examples of company feedback in this area.

8.5 Support for industrial advisory groups

The Industrial Biotechnology Leadership Forum (IBLF) and the Chemistry Growth Partnership are two of the UK government's industry advisory bodies. Both advocate the role of the bioeconomy in the UK industrial strategy, and the IBLF has proposed a target for a transformative technology-driven UK bioeconomy that, by 2030, will be twice the size of that envisaged in the Capital Economics 2016 report *Evidencing the Bioeconomy*.[186] Both groups are chaired by chief executive officers from the SIA region (Steve Bagshaw, FUJIFIM Diosynth and Steve Foots, Croda; both of whom contributed to this audit). It is notable that member companies that are either based in the North of England or have significant operational assets in the region are well represented in both groups.

8.6 European bioeconomy cluster networks

Across Europe there is widespread private and public sector support for 'triple helix' cluster organisations focused on the bioeconomy. These bring together stakeholders from industry, academia and policy to promote innovation and develop sustainable bio-based value chains using funds from both the private and the public sectors. They have a particular focus on supporting SMEs; for example, they represent their SME members in the design of the Bio-based Industries Initiative, a multi-million euro EU innovation programme. They also help develop industry-led, trans-sectoral investments in innovation assets, such as open-access scale-up centres and new bio-parks where industries use circular bioeconomy principles, adding value to each other's by-products and wastes.

These cluster organisations are focused on particular geographical areas; for example, the French IAR cluster connects stakeholders in northeast France. They also play an important role in promoting their regions and companies internationally, especially their SMEs. Europe's Bioeconomy Intercluster, 3Bi, is a consortium of four European clusters (IAR in France, BioVale in the UK, the Bioeconomy Cluster in Germany and the Biobased Delta in the Netherlands). It connects more than 400 innovative bio-based SMEs across Europe, and has facilitated involvement of several UK SMEs in European research collaborations. For example, BioVale is a partner in a research and innovation programme funded by the German government

BOX 17

Drax (bioenergy) cited uncertainty in the policy environment around carbon pricing and future biomass subsidies as a critical issue. The company quoted constant policy change as having dented investor confidence and made long-term planning difficult.

Greenergy and **Vivergo** (biofuels) both stated that future government policy regarding biofuels is critical to the success of their businesses.

A former senior director at **SABIC** (chemicals) explained that the disparity in the treatment of energy and fuels compared with higher-value-added chemicals was a restraint on the development of the bio-derived chemicals sector.

FUJIFILM Diosynth stated that public policy is an important factor in determining the pace and direction of the bioeconomy.

and led by the German Bioeconomy Cluster consortium. This lies outside the EU frameworks and provides a network of cluster organisations that allows UK SMEs to participate. Cluster organisations hold the granular, specialist information and connections required by international trade and investment bodies, including technical solutions for export and appropriate local sites for inward investment.

8.7 Conclusions

The bioeconomy is a priority for the UK's scientific and industrial strategies, and is supported by industry bodies advising government. Within the North of England, this is recognised in various aspects by our LEPs, and regional companies are engaged in leading the development agenda. In undertaking this SIA, the consortium built on the region's strong and well-connected research, innovation and industrial foundations. There is a clear and well-founded opportunity to develop the North of England bioeconomy by building on the assets and capabilities of the region.

While the consortium sees advantages in developing the bioeconomy across the North of England as a whole to integrate the full capabilities of the region, there is currently no constituted body with the strategic remit to take forward the recommendations of this audit. A specific body is needed to ensure initiatives align, and investments in research, translation, capital equipment, revenue funding and policy are complementary. Such a body could be formed as a collaborative initiative of the 11 LEPs, it could form a strand of activity within the Northern Powerhouse initiative, or it could be a regional arm of the national government. It should be industry-led and focused firmly on economic development in the bioeconomy. Whichever is the most politically appropriate solution, it is important to have a level of strategy formation and implementation at the North of England level to achieve critical mass and the effective use of resources.

Recommendations: The stakeholders in the regional bioeconomy, including but not limited to the audit consortium, should establish a single entity, provisionally called 'Northern BioInnovation', to coordinate innovation in the bioeconomy across the North of England. Representing these stakeholders, it should:

- be appropriately resourced to deliver practical support across the innovation supply chain
- be industry-led, involve representation from academia, translational organisations and local government/LEPs, and be credible among all stakeholders
- focus on the acceleration and expansion of the regional bioeconomy, setting ambitious goals
- promote insurgency and fund appropriate disruptive innovations in the bioeconomy.

Northern Bioinnovation will be tasked to produce a roadmap for the bioeconomy of the North of England that is aligned with the UK's national bioeconomy strategy and that builds on the evidence presented in this audit. The roadmap will include advice for the UK government on where to direct public sector investment, particularly on routes to the development of one or more bioclusters, where insurgent companies and major biomass-processing facilities can create new value chains.

CHAPTER 9
OVERALL CONCLUSIONS

£25 billion

projected GVA contribution of the North of England to the UK economy by 2030

9 Overall conclusions

The beginning of this report presents the hypothesis that the North of England has the assets, specialised research and innovation capability, and industrial capacity to deliver a world-leading bioeconomy based on agri-tech, agri-science and industrial biotechnology. The subsequent chapters review the foundations of this hypothesis based on the region's capacity to research and translate, the infrastructure base, its skilled people, and the degree to which the bioeconomy is connected. This chapter identifies current gaps and barriers to the development of a successful bioeconomy, and proposes appropriate next steps.

9.1 Strengths and weaknesses and gap analysis

Table 9 summarises the region's strengths and weaknesses in the bioeconomy and compares them with the intended position in 2030 according to the consortium's vision.

The gap analysis highlights the following key barriers:

- lack of coordination of innovation support for companies that may need it throughout their development cycle to give them access to the help they need at each stage without barriers
- limited access to stable, long-term funding for the innovation services that are at the front line in assisting businesses to bring new products, processes and services to market
- the absence of physical biocluster locations where innovative and, especially, insurgent companies can access common facilities and benefit from the integration of their supply chains with those of other businesses
- poor information flows to share innovation between sectors
- over the medium term, the need to develop logistical infrastructure that can accommodate substantial movements of biomass
- limited regional access to finance for growing insurgent companies looking to make substantial capital investments in new process technology
- lack of clarity on policy and the degree of financial incentives that will encourage companies to invest in new technologies based on biomass.

9.2 Framework for innovation in the bioeconomy

This audit reviewed organisations and capabilities that cover the technology readiness level[188] (TRL) spectrum from basic research (1) to market readiness (9). Companies will be developing technologies internally at later TRLs and interacting with universities and translational centres operating at earlier TRLs, but healthy pipelines fuelled by skilled people at all levels are needed to maintain innovation in a long-term sustainable bioeconomy. The networks and types of organisation involved in progressing product and process development depend on where in the TRL spectrum innovation is occurring.

- Later TRL developments are facilitated by integrated supply chains and intercompany developments. The consortium believes that the development of bioclusters will promote innovation at later TRLs. Bioclusters are bio-manufacturing locations based around common sources of biomass that transform primary and secondary (co-products or waste) products into higher-value outputs through the application of bioeconomy technologies. Currently, there is no biocluster in the North of England, although such features are emerging in other countries.
- Mid-range TRL developments are facilitated by organisations with specialist equipment and expertise and a remit to help innovative companies develop new products and processes. Typically, their costs are

Table 9. Gap analysis

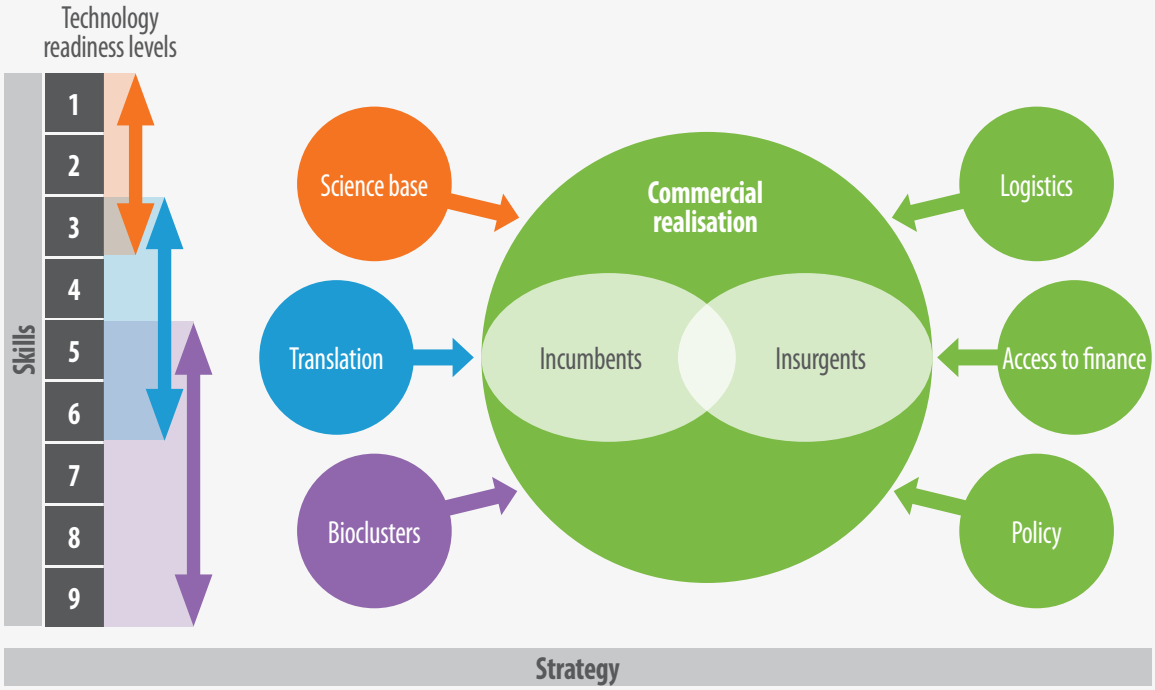
Current state We have…	2030 state We want to be…
Strong sector-specific research and a differential strength in translating research into innovation, but this is not fully coordinated; the innovation support system for businesses is piecemeal, short-term and project-based	Strategic and joined up in our approach to innovation, accelerating new products and processes to market
Joined-up applied research capability in agri-food by combining the work of the eight largest universities (N8)	World-leading in our connected industrial biotechnology and agri-food applied research, offering large-scale and single point of contact benefits to industry
EU funding used to accelerate innovation via short-term applied research projects between businesses and open-access innovation centres	Providing a comprehensive 'innovation to market' support service to business through integrated, self-sufficient applied research and scale-up centres with public sector support for SMEs
A strong incumbent industry base, but the insurgent, innovation-driven bioeconomy sector is not well developed	Driving economic activity and innovation through bioclusters, providing a focal point around which publicly funded support can be channelled to assist early-stage insurgent companies in developing disruptive technologies
A core base and future pipeline of technical skills in the bioeconomy, but less strength in commercial and entrepreneurial skills	The destination of choice for skilled scientists, engineers and entrepreneurs, who are attracted to a thriving bio-based industry
Good logistical infrastructure around the deep-water ports, but an east–west transport bottleneck across the Pennines	Able to move substantial quantities of biomass around the region as part of a high-capacity transport network
Regional, non-sector-specific venture funds providing seed funding to emerging businesses	Allowing insurgent bioeconomy companies to access £10–30 million capital rounds to establish production facilities in the region
An uncertain policy framework for biofuels and bioenergy, and no equivalent renewables incentives for using biomass for higher-value products	Operating under a policy regime that actively promotes the replacement of petroleum-derived with biomass-derived products, and gives the process industries a reason to change their supply chains

covered by a combination of core public funding, grant funding and commercial revenue. The region has several such organisations. Their primary issue is maintaining a stable income stream, particularly when core revenue funding is not available. European funds (Horizon 2020 and European Structural Investment Funds) constitute an important part of their funding mix, and this is now under threat.

- Early-stage TRL innovations are facilitated and often generated in the academic sector. They require challenge-led and applied research funding streams to stimulate commercial concepts that can be spun out or adopted by existing companies.

The audit shows that a successful bioeconomy also requires good logistics infrastructure (to move biomass at a large scale), access to finance for insurgent companies, and a stable policy environment encouraging the use of biorenewable resources. Finally, the consortium proposes that the parts of this framework interact best together when driven by a strategic plan and interventions that improve the system as a whole. Figure 17 provides a schematic representation of the factors underpinning the commercial realisation of an innovation-based bioeconomy involving both incumbent and insurgent companies.

FIGURE 17: INNOVATION FRAMEWORK FOR THE COMMERCIAL REALISATION OF THE BIOECONOMY



9.3 Proposals

Using data from the Capital Economics report *Evidencing the Bioeconomy*,[189] the transformative bioeconomy (not including upstream, downstream or induced effects) currently provides £12.5 billion GVA per annum to the North of England. The Capital Economics report projects UK growth of 13 per cent to 2030. Our consortium sets an ambition to double the GVA contribution made by the North of England to £25 billion during this period, consistent with the ambition of the IBLF for the UK as a whole. Building on the framework given in Figure 17, the consortium proposes a series of interventions to improve the innovation system and begin to deliver this ambition.

9.3.1 Northern Bioinnovation: Leadership, vision and coordinated innovation

This SIA reveals a need for strategic leadership and coordination to deliver innovation to the bioeconomy through the proposed framework. In the North of England, this requires working across the 11 LEPs and three NUTS 1 areas; this will be inherently challenging, but the goodwill and engagement of consortium members indicate an appetite to collaborate. Establishment of a single entity, Northern Bioinnovation, is proposed. This will own the vision and coordinate innovation support for the regional bioeconomy.

Northern Bioinnovation would be tasked to:

- construct and monitor a roadmap for the development of a highly productive North of England bioeconomy aligned with the UK's bioeconomy strategy
- provide a single point of contact and account management for businesses and policymakers engaging with technology development in the bioeconomy, facilitating commercial value chains and access to translational support
- work with translational organisations, research centres and skills providers to develop services that are appropriate to business needs
- make recommendations for the allocation of economic development funding to support the long-term health of the innovation ecosystem and ensure that innovation services are maintained.

Northern Bioinnovation would be governed by a board drawn from the private sector and LEPs, advised by a science and policy group drawn from higher and further education and translational organisations, and led by an experienced chief executive. Activities would be undertaken by a team of business development and innovation specialists with experience in trade and investment.

9.3.2 Bioclusters and an advanced bio-manufacturing park

Bioclusters are commercial-scale demonstrations of an integrated bioeconomy. In a biocluster, a common source of biomass (e.g. energy fuel, biofuel feedstock, large-scale food-processing or municipal solid waste) is used as the base of a biorefinery for multiple technologies that use different fractions of the raw material to create a suite of products that maximise the total added value. Analogous to a petrochemical refinery, a biocluster is likely to be centred on a single core process (as with fuel production in the petrochemical situation), with satellite plants creating secondary products that would otherwise be wasted or used for lower-value purposes.

The future bioeconomy will be characterised by the emergence of such entities. Although they are beginning to develop overseas, no large-scale bioclusters currently exist in the North of England and their viability and ability to catalyse and utilise new technology needs to be demonstrated. The consortium proposes the creation of an advanced bio-manufacturing park (ABMP), centred on a large existing biomass process, to serve as the nucleus for emerging technologies and with incentives for innovative companies to experiment in adding value to the core process. The ABMP would be a first demonstration of a functioning biorefinery and allow the commercial and innovative benefits of integrated technology and supply chains to be proven.

While various core biomass processes can be envisaged, at the time of writing there is opportunity to establish an ABMP in association with an emerging proposal for a new sugar beet processing plant (see Box 18).

9.3.3 Translational support programme

Translational centres (e.g. BDC, CPI and Fera) have accelerated growth in the bioeconomy partly by using EU economic development funds to support SMEs through short technology-support projects that provide access to research and development capability and equipment. Post-Brexit, such funding will no longer be available and it is proposed to fill this gap by setting up a translational support programme. This will include several components:

- Funded access for industry to the expertise and scale-up facilities of the open-access translational centres across the North of England, which will deliver targeted, business-led project work. Through the BioPilots UK alliance, BDC and CPI will be able to draw upon further open-access facilities across the UK.

BOX 18

Al Khaleej International recently proposed plans to double UK sugar production by building a new sugar beet processing plant in North Yorkshire.[190] This will be supplied by up to 3,500 farmers, mostly from the North of England. It will employ almost 300 workers and process around 30,000 tonnes of sugar beet per day. In addition to the 50 hectares required for the plant, the company is looking at a further 50 hectares to accommodate associated businesses.

Sugar processing produces co-products (waste) that can be converted into valuable products through applications of industrial biotechnology. The plant therefore provides a nucleus for establishing a concentration of known production facilities (e.g. anaerobic digestion, biofuels and animal feed) and more experimental technologies (e.g. second-generation biofuels and algae-produced oils) at an ABMP, collectively forming a biorefinery. The park could act as an example biocluster and would raise the profile of the bioeconomy, house demonstration units for experimental technologies and inspire a series of industry-led challenges to maximise the productivity of sugar beet processing.

Detailed objectives for new processes and products to bring to market, new jobs, new companies and inward investment to the UK will be agreed for the programme and monitored on an annual basis.

- A programme of placements for undergraduates, postgraduates and apprentices seeking to develop a career in the bioeconomy. All translational centres have the capacity to offer such placements, and trainees will gain front-line exposure to the assessment, development and delivery of industry support activities across a range of bioeconomy areas. Trainees will also have the opportunity to move between centres to develop a broad range of expertise and improve their professional networks.
- An industry-matched capital grant scheme (£50,000–£100,000) to prime business innovation in the bioeconomy. Similar capital grant schemes have been delivered through European Structural and Investment Funds, and these have been shown to stimulate the creation of novel processes and products, together with new jobs and UK-based businesses.

9.3.4 Applied research

To promote the creation of insurgent companies that will bring new products and processes to market, the consortium recommends that the agri-tech and industrial biotechnology research of the region's universities should be focused on applied projects that are likely to lead to technology that can be commercialised. The N8 group of universities has already demonstrated a capacity to work together (in N8 AgriFood) and this inspires two further proposals.

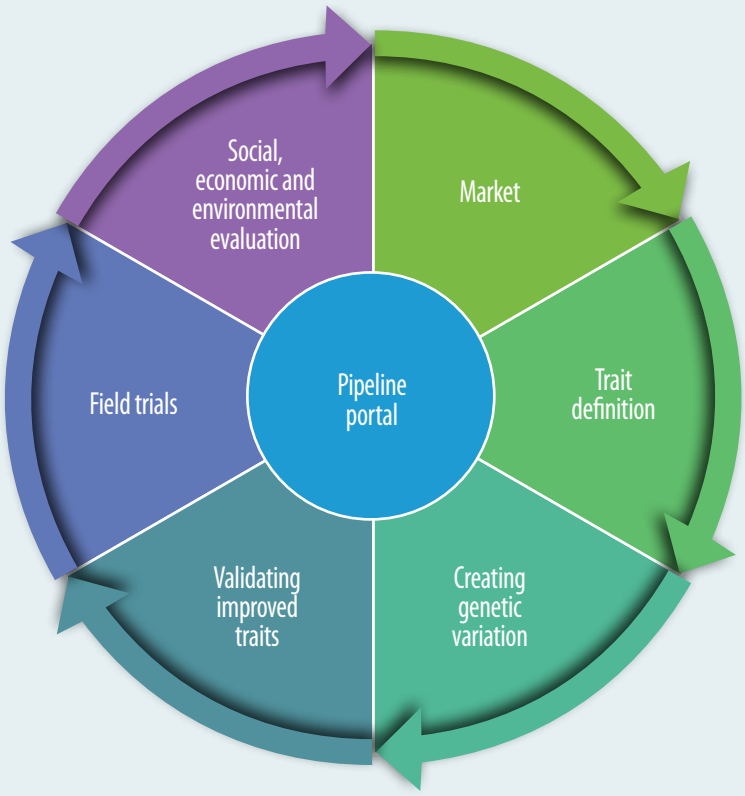
The first is to explore the potential within the region to create a collaborative research programme in industrial biotechnology analogous to the five-year, £16 million N8 AgriFood programme. Areas of focus will include the use of microbes and enzymes in fermentation and anaerobic digestion, catalytic and biocatalytic conversion of biomass, and the microwave and hydrothermal treatment of lignocellulosic materials (e.g. wood chips, grasses, etc.) to release substrates for conversion into food, feed, chemicals and fuels. Because the underpinning technologies cross disciplinary boundaries, this programme could include life science and therapeutic applications within its scope. Like N8 AgriFood, the ambition of the collaboration would be to create a world-leading concentration of research excellence, working with industry on business-led applications and delivering intellectual property for further commercial development.

The second is to challenge N8 Agri-Food to develop a pipeline of genuinely commercial technologies that can be exploited to generate jobs and economic growth in the regional bioeconomy. The N8 universities are developing a crop and soil innovation pipeline to enable the rapid development of novel crops, providing a single point of contact with businesses to support any or all steps of the pipeline, from defining the desired traits, through genetic selection and modification, to ensuring plants display the intended traits, testing in the field and socio-environmental evaluation (Box 19 contains further details).

BOX 19

The bioeconomy relies upon the development of novel crops and management systems that reflect the needs of the market (e.g. improved nutritional quality or modified chemical composition) and are resilient to the effects of environmental change (e.g. resistance to flooding and drought). The development of such crops is outside the typical scope of current crop-breeding programmes, and beyond the capabilities of all but the largest businesses. The processes involved include conventional genetic modification and gene-editing techniques. It is estimated that a single trait improvement, such as a Septoria leaf blotch disease-resistant wheat variety, could have an economic impact of £100 million in the UK alone.[191] With an estimated capital cost of £28 million and £3 million revenue costs to establish the pipeline, this initiative is projected to be financially self-sufficient within five years through sales of services to industry.

CROP AND SOIL INNOVATION PIPELINE



9.4 Recommendations

Although this audit focuses on science and innovation, it has identified barriers to development in the regional bioeconomy that the consortium recommends should be addressed. These are as follows.

- The logistics of moving large quantities of biomass within the region are considerable (see Box 9, illustrating the investment required to deliver biomass to the Drax power station). Within this context, planned upgrades to the east–west transport routes of the region are important. Substantial new biomass-processing plants will put a strain on the region's current transport networks and this will need to be factored into future planning.
- Disruptive insurgent companies will bring new products to market at a pace that cannot be achieved by established businesses working alone, nor by universities or translational centres. Access to capital has been identified as a requirement for such companies. The consortium recommends that a substantial investment fund should be set up with a focus on the North of England bioeconomy, with the objective to provide post-seed investment for companies that have market-ready technology already at the pilot scale.
- The SIA highlights the fact that initiatives such as the US government's BioPreferred programme have stimulated growth in the US bioeconomy by providing incentives for government departments to purchase bio-derived products. It also notes that the policy environment for bioenergy and biofuels in the UK is uncertain, and that there are no policy incentives for other bio-derived products. The consortium therefore recommends that the UK government should act to put in place a bio-preferred programme and review fiscal policy to provide consistent support for biofuels, bioenergy and bio-derived chemicals and materials.

9.5 Final word

The consortium is pleased to have had the opportunity to conduct this SIA. The data review and interactions with companies and other stakeholders in the region has led us to conclude that there is a significant opportunity for the North of England to increase productivity and improve economic performance through the development of its bioeconomy, while contributing to the financial and environmental sustainability of the UK as a whole.

Given the right drivers and enablers, economic activity is capable of rapid change and the government's industrial strategy is the appropriate context in which to leverage the region's demonstrated assets and capabilities. Integration of agri-food, chemical and bioenergy supply chains alongside the adoption of new technology will provide the mechanism whereby the region can achieve the ambition of doubling the size of the bioeconomy by 2030. Consortium members are committed to taking every opportunity to work together and with others in the region, as well as nationally, to adopt bio-based products and processes, explore bio-based feedstocks, accelerate the route to market of disruptive technologies and provide a fertile environment for bio-based companies to innovate.

Acronyms and abbreviations

ABMP	advanced bio-manufacturing park
BBSRC	Biotechnology and Biological Sciences Research Council
BDC	Biorenewables Development Centre
bn	billion
CAGR	compound annual growth rate
CO_2	carbon dioxide
CPI	Centre for Process Innovation
CTP	collaborative training partnership
DNA	deoxyribonucleic acid
DTC	Doctoral Training Centre
DTP	Doctoral Training Partnership
EPSRC	Engineering and Physical Sciences Research Council
EU	European Union
Fera	Fera Science Ltd
FP7	Framework Programme 7 (EU)
FWCI	field-weighted citation index
GVA	gross value added
IAR	Industry and Agro-Resources (France)
IBLF	Industrial Biotechnology Leadership Forum
IEA	International Energy Agency
k	thousand
LEP	Local Enterprise Partnership
LQ	location quotient
MIF	Materials Innovation Factory (University of Liverpool)
mn	million
N8	consortium of the eight research-intensive universities in the North of England
NAFIC	National Agri-Food Innovation Campus
NERC	Natural Environment Research Council
NIBB	national network in industrial biotechnology and bioenergy
NUTS	Nomenclature of Territorial Units for Statistics
NVQ	National Vocational Qualification
OECD	Organisation for Economic Co-operation and Development
PhD	Doctor of Philosophy
R&D	research and development
REF	Research Excellence Framework
SARIC	Sustainable Agriculture Research and Innovation Club
SEP	strategic economic plan
SIA	science and innovation audit
SIC	Standard Industrial Classification
SME	small- and medium-sized enterprise
STEM	science, technology, engineering and mathematics
TRL	technology readiness level
TWh	terawatt hours
UK	United Kingdom
USA	United States of America
YNYER	York, North Yorkshire and East Riding

Endnotes

1 Bauen, A. et al. (2016) Evidencing the Bioeconomy, Capital Economics, TBR and E4tech.
2 OECD (2009) The Bioeconomy to 2030: Designing a Policy Agenda: Main Findings and Policy Conclusions, Organisation for Economic Co-operation and Development International Futures Project.
3 Bioökonomierat (2017) International Bioeconomy Strategies, http://biooekonomierat.de/en/international0/
4 Bauen et al. (2016) Op. cit.
5 Ibid.
6 Information collected by Kepier and Co. during the conduct of this audit.
7 Il Bioeconomista (2016) In EU5 the bioeconomy is worth €1.27 trillion and employs 7 million people, https://ilbioeconomista.com/2016/01/12/new-report-in-eu5-the-bioeconomy-is-worth-e1-27-trillion-and-employs-7-million-people/
8 Durham University, Lancaster University, University of Leeds, University of Liverpool, University of Manchester, Newcastle University, University of Sheffield, University of York.
9 Office for National Statistics (2017) Labour Force Survey, four quarter average, October 2015–September 2016.
10 Skills Funding Agency (2016/17) Apprenticeship Starts by Region and Sector Subject Area. SSA's selected of relevance to the bioeconomy were science, maths, engineering, manufacturing, agriculture, horticulture and animal care.
11 Higher Education Statistics Agency Student Record 2014/15.
12 World Wide Fund for Nature (2009) Industrial biotechnology: More than green fuel in a dirty economy? Quoted in Chambers, G. et al. (2015) Biotech Britain: An Assessment of the Impact of Industrial Biotechnology and Bioenergy on the United Kingdom Economy, Capital Economics, TBR and E4tech.
13 La bioraffinerie de Bazancourt-Pomacle: un modèle d'intégration au cœur du pôle IAR, https://www.rfeit.fr/Actes/rfeit_2014_07_visite_pomacle.pdf
14 Bauen et al. (2016) Op. cit.
15 The Department for Business, Energy & Industrial Strategy uses the definition: "The bioeconomy includes all economic activity derived from bio-based products and processes. It involves the use of biology to help solve global challenges we face in food, chemicals, materials, energy production, health and environmental protection, delivering economic, environmental and social benefits to the UK." The main point of difference with the definition used in this audit is the exclusion of healthcare and biomedical applications.
16 See Appendix C for the SIC code definition of the bioeconomy used in this audit.
17 Durham University, Lancaster University, University of Leeds, University of Liverpool, University of Manchester, Newcastle University, University of Sheffield, University of York.
18 For examples from Canada and the EU, see: http://www.agr.gc.ca/eng/industry-markets-and-trade/statistics-and-market-information/agriculture-and-food-market-information-by-region/socially-conscious-consumer-trends-sustainability/?id=1410083148827; http://blog.euromonitor.com/2016/11/new-age-sustainability.html
19 One in which resources are kept in use for as long as possible to extract the maximum value from them, then products and materials are recovered and regenerated, see: http://www.wrap.org.uk/about-us/about/wrap-and-circular-economy
20 The 'transformative bioeconomy' is where value is added through a physically or chemically transformative process that involves, either as outputs or as processors, biological resources (tissues, cells, genes or enzymes); see Bauen et al. (2016) Op. cit.
21 Bolshaw, E. (undated) Can corporate venture solve the innovation paradox? https://betterworkingworld.ey.com/disruption/the-innovation-paradox
22 Manders, T. et al. (2012) Socio-economic Developments, in OECD Environmental Outlook to 2050: The Consequences of Inaction, Organisation for Economic Co-operation and Development, http://dx.doi.org/10.1787/env_outlook-2012-5-en
23 El-Chichakli, B. et al. (2016) 'Five Cornerstones of a Global Bioeconomy', *Nature*, 535: 221–23.
24 The EU forecast a similar proportion, see Section 2.1.3.
25 OECD (2009) Op. cit.
26 European Commission (2012) Innovating for sustainable growth: a bioeconomy for Europe, European Commission, http://ec.europa.eu/research/bioeconomy/pdf/official-strategy_en.pdf; and Burns, C. (2016) Bio-based UK: A Review of Barriers and Interventions needed to Stimulate Growth of the Bio-based Economy and Improve UK Competitiveness, National Non-Food Crops Centre and Aberystwyth University.
27 Adopted from the Higher Education Funding Council for England-funded BioVale project.
28 Bioökonomierat (2017) Op. cit.
29 Golden, J.S. et al. (2016) An Economic Impact Analysis of the US Bio-based Products Industry: 2016 Update, Duke University Center for Sustainability and Commerce and the North Carolina State University Supply Chain Resource Cooperative.
30 European Commission (2011), Key Enabling Technology – Industrial Biotechnology, Working Group Report.
31 IEA (2015) Renewable Energy Medium Term Market Report, International Energy Agency, https://www.iea.org/publications/freepublications/publication/MTRMR2015.pdf
32 Ibid.

33 Global Industry Analysts (undated) Biofuels (Bioethanol and Biodiesel) Market Trends, http://www.strategyr.com/MarketResearch/Biofuels_Bioethanol_Biodiesel_Market_Trends.asp.
34 Novozymes (undated) Crescentino biofuel facility, http://www.novozymes.com/en/news/image/crescentino-grand-opening accessed 12/05/2017
35 European Technology and Innovation Platform Bioenergy (2017) Lignocellulosic crops for production of advanced biofuels, http://www.biofuelstp.eu/lignocellulosic-crops.html
36 European Technology and Innovation Platform Bioenergy (2017) Advanced biofuels in Europe, http://www.biofuelstp.eu/advancedbiofuels.htm; European Commission (2011) Op. cit.; Bio-TIC (2015) The Bioeconomy Enabled: A Roadmap to a Thriving Industrial Biotechnology Sector in Europe; Bio-TIC (2014) Cellulosic Ethanol.
37 World Wide Fund for Nature (2009) Op. cit.
38 OECD forecast a similar proportion, see Section 2.1.1.
39 Grand View Research (2016) White Biotechnology Market Analysis by Product (Biofuels, Biomaterials, Biochemicals, Industrial Enzymes), by Application (Bioenergy, Food & Feed Additives, Pharmaceutical ingredients, Personal Care & Household Products) and Segment Forecasts to 2024; McKinsey & Co. (2016) The Biobased Economy: Measuring Growth and Impacts.
40 Bio-TIC (2015) The Bioeconomy Enabled: A Roadmap to a Thriving Industrial Biotechnology Sector in Europe; Aeschelmann, F. and Caris, M. (2015) 'Bio-based Building Blocks and Polymers in the World: Capacities, Production, and Applications–Status Quo and Trends Towards 2020', Industrial Biotechnology, 11(3): 154–159.
41 Aeschelmann, F. and Caris, M. (2015) Op. cit.
42 Aeschelmann, F. et al. (2016) Bio-based Building Blocks and Polymers: Global Capacities and Trends 2016–2021, European Bioplastics and the Nova Institute for Ecology and Innovation.
43 Global Food Security (undated) The challenge menu, https://www.foodsecurity.ac.uk/challenge/uk-threat/.
44 PROteINSECT (2016) Insect Protein – Feed for the Future. Addressing the Need for Feeds of the Future Today, http://www.proteinsect.eu/fileadmin/user_upload/press/proteinsect-whitepaper-2016.pdf
45 Comment from S.D. van de Laat, Innovation Manager Agro & New Business, Cosun Biobased Products.
46 Park, H. et al. (2017) 'Towards the development of a sustainable soya bean-based feedstock for aquaculture', *Plant Biotechnology Journal* 15(2): 227–236, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5258864/
47 European Technology and Innovation Platform Bioenergy (2017) Op. cit.
48 Ibid.
49 European Commission (2015) Sustainable, Safe and Nutritious Food: New Products with High Added-value, Business Innovation Observatory Case Study 54.
50 European Technology and Innovation Platform Bioenergy (2017) Op. cit.
51 Research Councils UK (undated) High Value Chemicals from Plants Network, http://gtr.rcuk.ac.uk/projects?ref=BB%2FL013665%2F1.
52 Ibid.
53 Ibid.
54 PressReader (2017) 10 vegetable seed companies fuelling growth of agriculture, http://www.pressreader.com/india/rural-marketing/20170301/282467118689915
55 Bauen, A. et al. (2016) Op. cit.
56 Chambers, G. et al. (2015) Biotech Britain: An Assessment of the Impact of Industrial Biotechnology and Bioenergy on the United Kingdom Economy, Capital Economics, TBR and E4tech.
57 Bio-Based World News (2017) $5.8 billion invested by VCs in bio-based chemicals; focus shifts to disruptive synthetic biology https://www.biobasedworldnews.com/5.8-billion-invested-by-vcs-in-bio-based-chemicals-focus-shifts-to-disruptive-synthetic-biology
58 British Venture Capital Association (2012 and 2015) Private Equity and Venture Capital Reports on Investment Activity.
59 Arantes-Oliveria, N. (2007) 'A case study on obstacles to the growth of biotechnology'; *Technological Forecasting and Social Change* 74(1): 61–74, http://www.sciencedirect.com/science/article/pii/S0040162506000692
60 Bauen A. et al. (2016) Op. cit.
61 BIO-TIC (2015) Overcoming hurdles for innovation in industrial biotechnology: Non-technological Roadmap, funded by the European Union, http://www.industrialbiotech-europe.eu/new/wp-content/uploads/2015/09/Non-technological-Roadmap.pdf
62 Information compiled during the conduct of this audit.
63 Office for National Statistics (2015) City Regions Article, https://www.ons.gov.uk/economy/economicoutputandproductivity/output/articles/cityregionsarticle/2015-07-24
64 Northern Powerhouse Independent Economic Review (2016) Core Messages.
65 'Nomenclature of Territorial Units for Statistics' is a hierarchical classification of spatial units used for statistical production. At the top are nation states, below that levels 1 to 3, then local administrative units 1 and 2. See: http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/eurostat/index.html

66 Bassetlaw, Bolsover, Chesterfield, Derbyshire Dales, North East Derbyshire, https://sheffieldcityregion.org.uk/about/about-our-city-region/
67 Local Enterprise Partnership Network, https://www.lepnetwork.net/the-network-of-leps/
68 Northern Powerhouse Independent Economic Review (2016) Op.cit.
69 Higher Education Statistics Agency (2017) Students and graduates, https://www.hesa.ac.uk/data-and-analysis/students; Northern Powerhouse Independent Economic Review (2016) Op.cit.
70 Universities UK (undated) Higher education in numbers, http://www.universitiesuk.ac.uk/facts-and-stats/Pages/higher-education-data.aspx
71 Science and Innovation Audits: Bioeconomy of the North of England, Technopolis Group, January 2017 unless stated otherwise.
72 Office for National Statistics data (2015) for the three NUTS1 regions comprising the majority of the SIA area.
73 Ibid.
74 Ibid.
75 Office for National Statistics (2015) UK Gross Domestic Expenditure on research and development, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/ukgrossdomesticexpenditureonresearchanddevelopment/2015
76 Office for National Statistics (2015) UK Business demography, https://www.ons.gov.uk/businessindustryandtrade/business/activitysizeandlocation/bulletins/businessdemography/2015
77 Department for Business, Innovation & Skills (2015) UK Innovation Survey 2015: headline findings, https://www.gov.uk/government/statistics/uk-innovation-survey-2015-headline-findings
78 Durham University, Lancaster University, University of Leeds, University of Liverpool, University of Manchester, Newcastle University, University of Sheffield, University of York.
79 N8 Research Partnership (2017) The Power of Eight, http://www.n8research.org.uk/economic-impact/the-power-of-8/
80 Chemistry Innovation Knowledge Transfer Network (2013) A Strategy for Innovation in the UK Chemistry-using Industries.
81 Chemistry Growth Strategy Group (2013) Strategy for Delivering Chemistry-fuelled Growth of the UK Economy.
82 Ibid.
83 Dinkovski, N. and Atherton, M. (2017) Pea plant to be one of UK's greenest food factories, http://www.foodmanufacture.co.uk/Manufacturing/Pea-processing-plant-to-be-one-of-UK-s-greenest-food-factories
84 The location quotient (LQ) indicates the relative concentration of a sector in a defined geography, and is calculated either for employment or the number of business units. A value of 1 indicates the sector is neither over- nor under-represented in a particular geography but has a concentration equivalent to that of the entire country, as a whole; a value greater than 1 indicates the sector is more concentrated within that particular location compared with the country as a whole; a value less than 1 indicates the sector is less concentrated within that particular location compared with the country as a whole (Technopolis Group).
85 Office for National Statistics (undated) UK Standard Industrial Classification of Economic Activities, https://www.ons.gov.uk/methodology/classificationsandstandards/ukstandardindustrialclassificationofeconomicactivities
86 Technopolis Group (2016) Science and Innovation Audits: Bioeconomy of the North of England; using a custom definition of bioeconomy by SIC code – Technopolis Group and Kepier definitions harmonised.
87 UK Trade and Investment (2009) Chemicals: the UK Advantage: Adding Value for Global Investors and Industry; Centre for Cities and McKinsey and Co. (2014) Industrial Revolutions: Capturing the Growth Potential.
88 Northern Powerhouse Independent Economic Review (2016) Op.cit.
89 Ibid.
90 N8 Research Partnership (2017) The N8 Research Partnership, www.n8research.org.uk.
91 Examples include Sheffield Hallam and Bradford at the N8 Centre for Molecular Engineering (METRC) project funded by the Higher Education Innovation Fund; Leeds Metropolitan, Huddersfield, Plymouth and Teesside on the Policing Research Partnership; Greenwich, Northumbria, Liverpool John Moores and Glasgow on the New Thinking from the North project.
92 Unilever (2017) Open Innovation, https://www.unilever.com/about/innovation/open-innovation/
93 Innovate UK (2017) Financial Year 2016/17 Delivery Plan.
94 Innovate UK funded projects, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/630235/Innovate_UK_funded_projects_between_2004_and_7_July_2017_updated_2.xlsx
95 Ibid.
96 As a benchmark for the comparisons within this chapter, the North of England accounts for around one-fifth of the UK's population and economy. Thus, the SIA region represents 21 per cent of total UK GVA, 24 per cent of the UK population and 22.4 per cent of all UK jobs (Technopolis Group). The SIA region has 32/164 (19.5%) of the UK higher education institutions (www.universitiesuk.ac.uk).
97 BBSRC (2016) £3M awarded to boost sustainable agriculture, http://www.bbsrc.ac.uk/news/food-security/2016/160825-pr-3m-awarded-to-boost-sustainable-agriculture/

98 BRIC Projects Map, https://www.google.com/maps/d/u/0/viewer?ll=53.5053387684477%2C-1.9775391562500317&spn=10.049252%2C19.753418&msa=0&mid=1GokZr1dIpJ0j4JSRN7dmKtl4ZrQ&z=8
99 Research Excellence Framework (2014) Units of Assessment, http://www.ref.ac.uk/panels/unitsofassessment/
100 Analysis carried out using the REF 2014 impact case studies database and subject area categorisations.
101 Research Councils UK (2017) Priming of plant defences against pests and pathogens using seed treatments, http://gtr.rcuk.ac.uk/projects?ref=BB%2FG021791%2F1&pn=0&fetchSize=10&selectedSortableField=parentPublicationTitle&selectedSortOrder=ASC
102 Technopolis Group (2016) Science and Innovation Audits: Bioeconomy of the North of England.
103 Technopolis Group (2016) Op. cit.; European Patent Office PATSTAT data 2004–2014, https://www.epo.org/searching-for-patents/business/patstat.html#tab1
104 Witty, A. (2013) Encouraging a British Invention Revolution: Sir Andrew Witty's Review of Universities and Growth, Department for Business Innovation and Skills, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/249720/bis-13-1241-encouraging-a-british-invention-revolution-andrew-witty-review-R1.pdf
105 From the UK's top 20 organisations ranked by number of agri-science publications.
106 Ranked by number of publications.
107 From the UK's top 20 organisations ranked by number of agri-tech publications.
108 Ranked by number of publications.
109 SciVal is Elsevier's research evaluation tool: https://www.elsevier.com/solutions/scival.
110 Durham, Hull, Lancaster, Leeds, Liverpool, Manchester, Newcastle, Sheffield, Sheffield Hallam, York.
111 Technopolis Group: Gateway to Research 2006–2016 semantic analysis.
112 Horizon 2020, https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020
113 European Commission Research and Innovation, FP7 in brief, https://ec.europa.eu/research/fp7/understanding/fp7inbrief/what-is_en.html
114 Technopolis Group: Horizon 2020 and FP7 semantic analysis.
115 Funded by UK Research Councils, apart from the Medical Research Council and the EU FP7 and Horizon 2020; see http://gtr.rcuk.ac.uk/
116 Technopolis Group: Gateway to Research 2006–2016 semantic analysis.
117 Witty, A. (2013) Op. cit.
118 From the UK's top 20 organisations ranked by number of agri-science publications.
119 Of cited publications across the world.
120 From the UK's top 20 organisations ranked by number of agri-tech publications.
121 Of cited publications across the world.
122 Hull (#4), Leeds (#6), York (#10).
123 The N8 universities plus the University of Hull and Sheffield Hallam University.
124 An FWCI of 1.00 indicates that the publications have been cited at world average for similar publications. An FWCI of greater than 1.00 indicates that the publications have been cited more than would be expected based on the world average for similar publications; for example, a score of 1.16 means that the outputs have been cited 16% more times than expected. An FWCI of less than 1.00 indicates that the publications have been cited less than would be expected based on the world average for similar publications; for example, a score of 0.85 means 15% less cited than world average.
125 BBSRC (2016) Evidencing the bioeconomy, http://www.bbsrc.ac.uk/news/policy/2016/160726-pr-evidencing-the-bioeconomy/
126 REF (2014) Research Excellence Framework, http://www.ref.ac.uk
127 Research power is taken to be the grade point average multiplied by the number of full-time equivalents (FTEs) submitted; N8 Research Partnership (2017) The Power of Eight, http://www.n8research.org.uk/economic-impact/the-power-of-8/
128 And in the UK's top ten institutions for these Units of Assessment.
129 National Aeronautics and Space Administration (2015) Technology Readiness Level, https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html
130 European Cluster Collaboration Platform (undated) Flanders Biobased Valley, https://www.clustercollaboration.eu/cluster-organisations/flanders-biobased-valley
131 Kepier & Co. (2017) Science and Innovation Audits: Bioeconomy of the North of England.
132 N8 Research Partnership (2017) Op. cit.
133 Northumbria University Newcastle (2017) Bioeconomy, https://www.northumbria.ac.uk/research/research-themes/theme-1/
134 Kepier & Co. (2017) Op. cit.
135 N8 Research Partnership (2017) Research Community: Industriai Biotechnology for the Bioeconomy, http://www.n8research.org.uk/research-focus/bioeconomy/
136 Information collated by the Centre for Process Innovation for this audit.
137 Information collated by Fera for this audit.

138 CPI (2017) National Industrial Biotechnology Facility, https://www.uk-cpi.com/case-studies/national-industrial-biotechnology-facility/
139 CPI (2016) CPI opens plant for sustainable fish feed development, https://www.uk-cpi.com/news/cpi-proudly-opens-ground-breaking-plant-development-sustainable-animal-feed-wilton/; CPI (2017) Calysta Collaboration reaches significant milestone, https://www.uk-cpi.com/case-studies/calysta-collaboration-reaches-significant-milestone
140 Information provided by BDC for this audit.
141 Information provided by the University of Liverpool for this audit.
142 Manchester Evening News (7 March 2016) Smart motorway from Manchester to Leeds will open in 2011, say northern transport chiefs, http://www.manchestereveningnews.co.uk/news/greater-manchester-news/smart-motorway-manchester-leeds-open-11005153
143 Transport for the North, http://www.transportforthenorth.com
144 Crunchbase, www.crunchbase.com
145 Invest North East Lincolnshire (undated) Rail boost for Drax as it gets ready to push £135m 'pellet port' to the limit, http://investnel.co.uk/news/rail-boost-for-drax-as-it-gets-ready-to-push-135m-pellet-port-to-the-limit
146 Office for National Statistics (2017) Op. cit.
147 Science Industry Partnership (2015) Demand Assessment and Feasibility Study into the Establishment of Advanced Training Partnerships in Industrial Biotechnology.
148 Science Industry Partnership Skills Strategy 2025.
149 Office for National Statistics (2017) Op. cit.
150 Skills Funding Agency (2016/17) Apprenticeship Starts by Region and Sector Subject Area. Op. cit.
151 Another institution is seeking designation.
152 Data sourced by the consortium from the privately commissioned report: Landex (2016) Mix and Balance of Land Based Education and Training in England, Landex (Land Based Colleges Aspiring to Excellence), unpublished.
153 Ibid.
154 Enterprise Partnership, Innovative new facilities open at Askham Bryan College, http://www.businessinspiredgrowth.com/news/funding-sees-innovative-new-facilities-open-at-askham-bryan-college/
155 Myerscough College: http://www.myerscough.ac.uk/why-myerscough/superb-facilities/
156 Reaseheath Food Centre: http://reaseheathfoodcentre.com
157 Science Industry Partnership (2016) The Demand for Skills in the UK Science Economy. The science-based industries covered in the report include chemicals, industrial biotechnology and polymers
158 Destinations of Leavers from Higher Education Survey 2015 .
159 Higher Education Statistics Agency Student Record 2014/15.
160 High Level Skills for Food (2010): Food Research Partnership Skills Sub-Group (2010) High-level Skills for Food, http://www.bbsrc.ac.uk/documents/1001-high-level-skills-for-food-pdf
161 Science Industry Partnership (2015) Demand Assessment and Feasibility Study into the Establishment of Advanced Training Partnerships in Industrial Biotechnology.
162 Office for National Statistics (2015) Business demography, UK, https://www.ons.gov.uk/businessindustryandtrade/business/activitysizeandlocation/bulletins/businessdemography/2015
163 Science Industry Partnership (2015) Op. cit.
164 Information collated by Cogent Skills for this audit.
165 Ibid.
166 Office for National Statistics (2015) Op. cit.
167 N8 Research Partnership (2017) AEF (France) – N8 chair on our research impact and international relations, http://www.n8research.org.uk/n8-chair-speaks-of-n8s-research-impact-and-international-relations-at-paris-conference/
168 Frenken, K. et al. (2005) 'The citation impact of research collaborations: the case of European biotechnology and applied microbiology (1988–2002)', *Journal of Engineering and Technology Management*, 22(1–2): 9–30; the correlation between international co-authorship and a publication's scientific impact as measured by its citation rate has been observed.
169 Using the SciVal tool, UK international collaboration as measured by the prevalence of overseas co-authors on publications was, on average, 46.8 per cent between 2011 and 2016 (all subjects).
170 Technopolis Group: Horizon 2020 and FP7 semantic analysis.
171 Information collected by Fera for this audit.
172 Department for International Trade (in press) UK Chemicals Industry, draft copy supplied by CATCH.
173 BioNow, http://www.bionow.co.uk/home.aspx
174 Information collated from project records for this audit by BDC.
175 Department for International Trade (in press) Op. cit.
176 Department for International Trade (2016) UK Chemicals Industry.
177 BASF News and Media, https://www.basf.com/gb/en/company/news-and-media/news-releases/2016/04/P0162.html

178 PotatoPRO.com (2017) McCain Foods announces an investment of £100m in its Scarborough Potato Processing Plan http://www.potatopro.com/news/2017/mccain-foods-announces-investment-£100m-its-scarborough-potato-processing-plant-united
179 BBSRC (2017) Core narrative, http://www.bbsrc.ac.uk/about/vision-mission-strategy/core-narrative/
180 The third strategic priority is Bioscience for Health with a budget of £57 million.
181 BBSRC (2017) Spending overview, http://www.bbsrc.ac.uk/about/spending/
182 HM Government (2017) Building our Industrial Strategy, https://beisgovuk.citizenspace.com/strategy/industrial-strategy/supporting_documents/buildingourindustrialstrategygreenpaper.pdf
183 Gov.UK (2017) PM unveils plans for a modern Industrial Strategy fit for Global Britain, https://www.gov.uk/government/news/pm-unveils-plans-for-a-modern-industrial-strategy-fit-for-global-britain
184 United Stated Department of Agriculture (undated) BioPreferred, https://www.biopreferred.gov/BioPreferred/faces/Welcome.xhtml
185 British Business Bank (2017) Northern Powerhouse Investment Fund, http://british-business-bank.co.uk/ourpartners/northern-powerhouse-investment-fund/
186 BBSRC (2016) Evidencing the Bioeconomy, http://www.bbsrc.ac.uk/news/policy/2016/160726-pr-evidencing-the-bioeconomy/
187 BioVale (2017) Beechwood International, https://www.biovale.org/about-us/biovale-projects/beechwood-international/
188 Horizon 2020 (undated) Technology readiness levels, extract from Work Programme 2014–2015, https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf
189 Bauen, A. et al. (2016), Op. cit.
190 Insider Media Limited (2017) Massive Sugar Processing Plant Plans Emerge, https://www.insidermedia.com/insider/yorkshire/massive-sugar-processing-plant-plans-emerge
191 Fones H. and Gurr, S. (2015) 'The impact of Septoria tritici Blotch disease on wheat: An EU perspective', *Fungal Genetics and Biology*, 79: 3–7, doi:10.1016/j.fgb.2015.04.004.

University of York
York
YO10 5DD
United Kingdom
www.york.ac.uk

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