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Cambridge Industrial Innovation Policy

Life sciences beyond human health:

modern industrial biotechnology in the UK

Strengths, shape, size and opportunities for the industry

Institute for Manufacturing, University of Cambridge

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Life sciences beyond human health: modern industrial biotechnology in the UK

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This study has been commissioned by the Government Office for Science (GOS) to inform the work of the Government Chief Scientific Adviser, Sir Patrick Vallance. This work included a workshop held on 4 August 2022 with stakeholders across government, academia and industry, in approximately equal proportions.

Contributors

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Disclaimers

The views expressed in this report do not imply the expression of any opinion on the part of the Government Office for Science (GOS).

Designations such as "developed", "industrialised" and "developing" are intended for statistical convenience and do not necessarily express a judgement about the stage reached by a particular country or area in the development process. Names of countries and territories follow widely accepted conventions and do not imply the expression of any opinion whatsoever on the part of the authors, their affiliated institutions or client concerning the legal status of any country, territory, city or area, or its authorities.

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Cambridge Industrial Innovation Policy

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Executive summary

Life sciences beyond human health: modern industrial biotechnology in the UK

Executive summary (1/8)

Section	1. What is modern industrial biotechnology? The non-human health life sciences
	Pages 17–23
Key findings	▪ Life sciences not addressing human health could more helpfully be referred to as 'modern industrial biotechnology' (MIB). ▪ It is suggested that this could help to avoid misconceptualisation by those who understand the life sciences as purely related to human health - a common definition and once recently used within many current government policy documents. ▪ MIB working definition: Modern industrial biotechnology is the application of natural, emulated or engineered biological organisms, systems, processes or parts thereof, to provide consumer goods and services in an economic, eco-friendly, sustainable and energy- and resource-efficient manner for the benefit of mankind ▪ The original definition of industrial biotechnology is outdated. Defined as "using enzymes and microorganisms to make bio-based products" using readily available sources of bio-feedstock, this definition does not encompass the impact of many new underpinning and feeder technologies that collectively allow modification and manipulation of life processes, such as gene editing, AI/ML, metabolic engineering, polyomics, epigenomics, forced evolution, nanoscience, fluidics, 3D bio-printing, bioinformatics, in silico biology. The addition of 'modern' would differentiate it from 'traditional' industrial bioprocesses (e.g. wine, cheese and baking). ▪ The UK's strong life sciences base offers a window of opportunity to establish technological leadership and capture economic and societal value from modern industrial biotechnology ▪ This opportunity is not only enabled by the strength of UK life sciences R&D but also by the ecosystem of technical service firms, suppliers and specialist equipment vendors which evolved to support the health life sciences sector but are also source of important capabilities and potential competitive advantage for modern industrial biotechnology ▪ There are many reasons why the government may wish to support this, including increasing value, addressing resource pressures, securing energy security, job creation and economic growth, and addressing climate change or waste reduction.

Executive summary (2/8)

Section	2. Modern industrial biotechnology landscape in the UK
	Pages 24–47
Key findings	▪ 30% of firms in the UK life sciences sector can be classified as biotech (based on publicly available data from BiotechGate). Of these, 51% can be classified as “R&D services”; 34% as “biotechnology therapeutics and diagnostics”; and 15% as “modern industrial biotechnology” (~202 firms). ▪ Modern industrial biotechnology firms are diverse. The main sub-sectors include: agriculture (22%); veterinary (18%); food (14%); nutraceuticals (12%); industrial processes (8%); environmental (8%); cosmetics (7%); and other (11%). ▪ Modern industrial biotechnology firms in the UK account for a total turnover of £4.7 billion. Biotechnology firms classified as “R&D services”, which provide services to both human and non-human health life sciences, account for £31.9 billion in turnover in comparison. ▪ Top players in the industrial biotechnology landscape include mostly veterinary and cosmetics companies. The sector is dominated by micro (39%), small (31%) and medium (25%) enterprises, while large firms account for 6% of the total. ▪ There are many scientific and technological advances driving modern industrial biotechnology growth. Examples include digitalisation, genomic sequencing technologies, totally artificial organisms, “lab on a chip” technologies, and novel and engineered enzyme catalysts. ▪ The UK modern industrial biotechnology sector received strong early government support from the mid-2000s, particularly in the areas of genetic editing and synthetic or engineering biology. Over time, the United Kingdom, like the United States, has placed great emphasis on synthetic biology in its bioeconomy strategies. ▪ Today, the UK is seen as having excellent, world-leading research in this area, albeit with lower success in commercialisation and scale-up of related technologies. This is in part attributed to infrastructure, skills and the availability of venture capital – an assessment that has remained relatively consistent across the past decade.

Executive summary (3/8)

Section	3. UK international benchmarking (UK research strength)
	Pages 48–66
Key findings	▪ The United Kingdom ranked fifth in the world in terms of research productivity (measured by number of publications) in biotechnology, and seventh for productivity seen between 1996 and 2021. During this period, the United States, China and Japan led the biotechnology field. ▪ In terms of research impact (measured by the H index), the United Kingdom ranked fourth in 2021 and third in the period of 1996–2021. During this period, the United States and Germany, and the United Kingdom, were the top three performing countries in biotechnology. ▪ In 2022 the United Kingdom ranked second in terms of the number of universities classified among the top 150 in the world in biological sciences and their average scores, behind only the United States. The University of Cambridge (3rd), the University of Oxford (5th), Imperial College London (11th), University College London (11th) and the University of Edinburgh (22nd) are the top five universities in biological sciences in the UK. ▪ The United States, Japan, Germany, Korea and China are the top five innovators in biotechnology patents. During 2011–18, the United Kingdom ranked fifth, out of 52 countries, by the number of triadic patents in biotechnology, and seventh by the number of IP5 patents. ▪ Key barriers to the effective use of the intellectual property system include skills, awareness and cost. In particular, efficient IP management requires an array of skills ranging from the legal to the scientific/technical and the commercial, which not all SMEs have in-house. ▪ Graduates in STEM disciplines accounted for 43.4% of the total graduates in the UK in 2019. This value was above that for comparator countries such as France (36.8%), Canada (37.8%) and the United States (37.6%).

Executive summary (4/8)

Section	3. UK international benchmarking (UK business strength)
Key findings	▪ The United Kingdom ranked fourth in the world in terms of countries by the number of modern industrial biotechnology companies, behind China, the US and Canada. Close followers include Germany, France, Spain, Italy, the Netherlands and India. ▪ In terms of ownership structure, the UK shows a higher level of subsidiaries than Canada, Germany and Korea. However, publicly listed firms remain below Canada and South Korea (no data is available for the US and China). ▪ Regarding venture financing, UK firms received over USD$3 billion in private equity investments in 2021. This is significantly higher than comparable countries such as Canada, France, Germany, the Netherlands, Switzerland and South Korea (no data is available for the US and China). ▪ The UK had a lower number of modern industrial biotechnology firms founded between 2010 and 2018 than Canada (38 and 52, respectively). This number was greater than comparator countries such as Denmark, Germany, the Netherlands, Switzerland, South Korea and Spain (no data is available for the US and China). ▪ Overall, the experts consulted identified a lack of deep or patient capital to invest in start-ups beyond seed or series A funding. While the skills were available, there are perceived to be only one or two large funds investing in this space. Some participants suggested the British Business Bank could play a role in setting up large funds. ▪ There was a perception among the consulted stakeholders that the largest investments in manufacturing in modern industrial biotechnology are occurring in companies abroad in countries such as Denmark, the Netherlands and Germany. This may be consolidated as a self-perpetuating cluster to the detriment of the UK if manufacturing investment is not increased in the future. ▪ Low margins within industries that may purchase modern industrial biotechnology-derived products may limit investment. The consulted stakeholders suggested that perhaps identifying low-volume, high-value products may present a better market for the UK to target.

Pages 48–66

Executive summary (5/8)

Section	4. Capturing value from UK modern industrial biotechnology Pages 67–78
Key findings	▪ Through engaging over eighty SMEs, the Engineering Biology Leadership Council found that many companies consider carrying out R&D in the UK but manufacturing abroad is ultimately the best option. From a UK standpoint, this is a matter of concern because significant amounts of revenue (and taxation) are derived from manufacturing and not from R&D. ▪ Many value chains in biotechnology, for high-volume products, will be determined by feedstock availability. Depending on the process, these feedstocks may be distributed (which may require production networks) or available on seasonal cycles (e.g. annual crop waste), presenting potential challenges to traditional business models. ▪ UK companies could be supported to capture value within early (e.g. R&D and design) and later stages (e.g. marketing and add-on services). At the early stages, this includes a strong need to capture value through intellectual property, support for patenting and enabling conditions for spin-outs and scale-ups. This includes incentives to keep these innovative firms in the UK. IP should be used to capture value from products that cannot be manufactured locally. ▪ The consulted stakeholders see the work of the BBSRC positively, with strategic investment – though there are perceived gaps in funding between the remits of individual councils. There is a need for mechanisms that utilise the interdisciplinary space of UKRI to work better within these interfaces in practice. ▪ The workshop participants expressed a perception that more funding for industrial biotechnology is needed through Innovate UK, while more efforts are also required to provide connected funding. There are some tensions inherent in this, including at what stage companies benefit from external investment and whether companies that require continued grant funding are more likely to be non-competitive in the marketplace. Despite these concerns, the workshop participants expressed a clear call for increased investment in later-stage TRLs and translational research.

Executive summary (6/8)

Section	5. Regulation and innovation in UK modern industrial biotechnology Pages 79–84
Key findings	▪ It is important for any approach to biotechnology to acknowledge and account for the risks involved. It is estimated that up to 70% of the total potential impact of biotechnologies could hinge on consumer, societal and regulatory acceptance, based on an analysis of areas where regulations exist today in major economies. ▪ The UK has very high awareness of biological risk, which puts it in good stead to tackle these issues. There are some learnings from the GMO debate, the success of the Human Fertilisation and Embryology Authority (HFEA) and some parallels with current regulatory issues around AI, which should be explored further by the government in the context of non-human health biotechnology. ▪ For many technologies, regulation will be a key mechanism by which the government can manage the risks from biotechnology. The implications of regulation on innovation are complex: while disproportionate regulation may impede innovation, regulation can also drive innovations. In addition to regulation, there is also a role for standards and similar guidelines. ▪ Moving forward, there may be issues associated with “naturalness”. For example, acetic acid produced by fermentation is a “natural” product, while chemically synthesised but otherwise identical acetic acid requires designation in a product with an E number (i.e. the code for substances used as food additives). A likely scenario when industrial biotechnology becomes more prominent is that products will be produced partly by “biological” processes and partly by “chemical” processes. The question of how they will be classified is yet to be answered. ▪ Land use might be another source of future regulatory discussion. This includes what proportion of land (and fresh and sea water) is devoted to food production (food security), industrial production (industrial security), rewilding (environmental and biodiversity security) and urban development (housing security).

Executive summary (7/8)

Section	6. Sectoral futures in UK modern industrial biotechnology (1)
	Pages 85–94
Key findings	▪ Non-health biotech has significant room to grow. In its 2020 report McKinsey estimated that more than half of the impact from applications of biotechnology will lie outside healthcare, with the most significant proportion being in agriculture, aquaculture and food (USD$0.8–1.2 trillion globally by 2030–40), followed by consumer products and services (USD$0.2–0.7 trillion globally by 2030–40) and materials and energy production (USD$0.2–0.3 trillion globally by 2030–40). ▪ There are several broad areas in which the UK may have strengths and may be able to develop competitive advantage. These include: agribiotech (global market estimated to grow from USD$49 billion in 2021 to USD$114 billion in 2030); food and drink (bio-based flavours and fragrances represent a potential niche of low-volume, high-value products, with a global estimated market of €29 billion by 2026); commercial genomics for well-being (global market estimated at USD$94.65 billion in 2028); animal health (the global animal biotechnology market size was valued at USD$22.66 billion in 2021); and underpinning technologies and platforms (the UK has key strengths in the platforms, detection methods and technologies that underpin advances in this field. For example, the UK is well organised on high-throughput sequencing, longitudinal cohorts and population genetics. Gene editing is also a research strength). ▪ One key area that could lead to greater success of modern industrial biotechnology in the UK is perceived to lie in the translation from R&D to commercialisation. There are twofold issues with not having good scale-up capacity: that inventions will not get scaled up; and also that good companies will leave for more favourable funding or regulatory environments. ▪ Capturing value in modern industrial biotechnology will almost certainly require an increased volume of patenting by UK academics, and strategies could be explored to promote this. This may include consideration of a number of incentives, which may be connected to funding and promotion within and across UK universities, but also in the technology-transfer offices of universities.

Executive summary (8/8)

Section	6. Sectoral futures in UK modern industrial biotechnology (2) Pages 85–94
Key findings	▪ The consulted stakeholders suggested that scale-up facilities in the UK are sometimes limited, expensive or unfit for some purposes. The UK could look at what is being offered by other countries in the scale-up space and whether this represents a threat to the UK ecosystem (e.g. Denmark, the Netherlands, Belgium and the US). The consulted stakeholders mentioned that the high rents in specific UK regions lead manufacturers to cheaper areas of the country or abroad, where staff are generally considered to be less skilled. • Workshop participants also suggested that because of the lack of domestic resources, scale-up facilities in other countries are being used by some UK firms. These are often commercially operated facilities. The question as to why the UK does not have the capacity and scale needed could be further explored. It may be the case that demand may not yet be high enough to ensure that scale-up is sustained, and if so, this may be the key point in the product life cycle when government investment is needed. • Into the future, the non-health life sciences will be in competition with human health biotechnology and other industries for key STEM skills and highly skilled technical workers. This particularly speaks to the UK economy-wide issue with technician shortages, which T-levels aim to address. • The success of the “golden triangle”, and its perception as a “low-risk place to do high-risk science”, gives a clear branding for inward investment. There is clear value in attempting to enhance existing clusters when it comes to R&D, including infrastructural ones. However, there are already tensions in clusters regarding land availability, lab and office space, and affordable housing. While the enhancement of clusters should be balanced with place-based considerations, it is worth noting that many biotechnology feedstocks will be distributed across agricultural land and manufacturing regions, and it is likely that these will require dispersed networks for production, which may have positive effects in local areas outside R&D clusters. • It is seen to be “too easy for innovative biotech to be bought out by non-UK companies and taken overseas” because of a lack of local VC funding. It is argued that increased IPO exits would enhance the domestic base; however, most exits in industrial biotechnology are mergers or acquisitions. What represents success for an individual company (e.g. a start-up being acquired by a multinational) may not be seen as a national benefit. What can the UK do to influence this, and to promote the retention of jobs and skills development within the UK, even when companies are acquired by multinationals?

Introduction

Life sciences beyond human health: modern industrial biotechnology in the UK

Introduction (1 of 2)

The importance of the life sciences has been thrown into sharp relief by the COVID-19 pandemic, and the potential for the UK to both advance human health and capture economic value has been at the core of the recent series of UK government policies, including the 2011 Strategy for UK Life Sciences, the 2017 and 2018 Life Sciences Sector Deals and the 2021 Life Sciences vision. These policies have all focused on the human health-related potential of advances in biology and technology.

Outside human health, there is low confidence that modern industrial biotechnology is as successful at reaching high TRL application and commercialisation. However, there are gaps in the evidence base for this sub-sector, as it does not fit neatly within existing industry codes, and it is thus difficult to characterise. There is a need to better characterise those areas of biotechnology that are not directly aimed at human health outcomes from other life science sectors, and to quantify the opportunities for the UK over the coming years.

Against this backdrop, the Government Office for Science (GOS) has conceived this report to better understand and inform strategic thinking on the opportunities for the modern industrial biotechnology sector in the UK over the coming years.

Introduction (2 of 2)

With £88.9 billion in turnover and over 268,000 employees, the UK is seen to have a globally leading and innovative value chain in life sciences. This can help to support the non-health life sciences value chain, as many of the underpinning and feeder technologies, foundational services and equipment may be deployed in both health and non-health applications.

These "industrial commons" between the health and non-health life sciences – defined as the R&D and manufacturing infrastructure, knowhow, process-development skills and engineering capabilities embedded in firms, universities and other organisations (Pisano and Shih, 2012) – not only provide the foundation for growth and innovation in the UK modern industrial biotechnology industry, but they also represent a key source of competitive advantage against countries where such foundations are absent.

The rest of this report discusses what is modern industrial biotechnology (Section 1), the current landscape of this industry in the UK (Section 2) and how it compares to other comparator countries (Section 3). The report also examines ways in which the UK can capture value from modern industrial biotechnology (Section 4), the regulatory and innovation landscape (Section 5) and future trends (Section 6).

Difficulties in analysing the UK modern industrial biotechnology sector

Limitations in the analysis presented within this study

This report attempts to estimate the size of the modern industrial biotechnology sector within the UK and its international competitiveness. This presents a number of difficulties:

- Typically, economic activity is characterised by the products it produces. However, biotechnology processes can be applied to produce products that are also derived from other sources (e.g. bioplastics vs plastics produced from petrochemicals), leading to statistical inaccuracy.
- Statistical classification difficulties also originate from the cross-sectoral nature of the application of biotechnology (see an example, on the right, of current genomics firms in the UK and their self-identified sectoral classifications).
- Furthermore, it is difficult to estimate the share of biotechnology-related processes within larger, multi-faceted businesses.
- In looking to focus on the non-health life sciences sector, there are a number of companies that may produce both health and non-health products using biotechnology, or which may supply equipment that can be used both in biotech and non-biotech applications.

As such, **the results in this report represent our best estimates only.**

A further analytical caveat originates from the fact that large companies from sectors such as pharma or agriculture might have significant biotech divisions, raising the question of which sector should be allocated to such firms. To minimise these issues, this report uses publicly available data from a specialised biotech databases, curated by experts in the field, as shown in the following sections.

Genomics Firms

And their official SIC Codes…

Company name	SIC Code
PrecisionLife	Engineering related scientific and technical consulting activities
Seven Bridges Genomics	Other software publishing
Fios Genomics	Research and experimental development on biotechnology
Genestack Limited	Other service activities not elsewhere classified
Repositive	Business and domestic software development
Sano Genetics	Other information technology service activities

Source: Dr Eoin O'Sullivan, IfM, University of Cambridge (2022).

1. What is modern industrial biotechnology? The non-human health life sciences

Life sciences beyond human health: modern industrial biotechnology in the UK

What is modern industrial biotechnology? (1 of 2)

The non-human health life sciences

It is suggested that the non-health life sciences could more accurately be referred to as **modern industrial biotechnology (MIB)**, to avoid mis-conceptualisation from those who understand the life sciences as purely related to human health, a common definition and once recently used within many current government policy documents.

The following is suggested as a working definition of modern industrial biotechnology, which capitalises on the application of these new principles. It does not include the fundamental, platform and feeder technologies per se, which are generally applicable across all life sciences sectors. The principal drivers are to create consumer goods and services that are economically competitive and eco- and resource-friendly. This definition excludes military and security use of these new biotechnologies, but it emphasises the application of natural and engineered organisms and their systems, and systems that emulate natural, namely, biomimetic systems. Irrespective of the up-front feeder technology, modern industrial biotechnology must satisfy the multiple criteria as an economic, sustainable and resource-efficient process. The addition of "modern" in the definition is to differentiate it from "traditional" industrial bioprocesses such as wine, cheese and baking.

Modern industrial biotechnology is one of the fastest-growing and most innovative areas of modern science combining biological, design, engineering and software disciplines to shape, improve and create entirely new products and systems de novo.

Working definition

Modern industrial biotechnology is the application of natural, emulated or engineered biological organisms, systems, processes or parts thereof, to provide consumer goods and services in an economic, eco-friendly, sustainable and energy- and resource-efficient manner for the benefit of mankind.

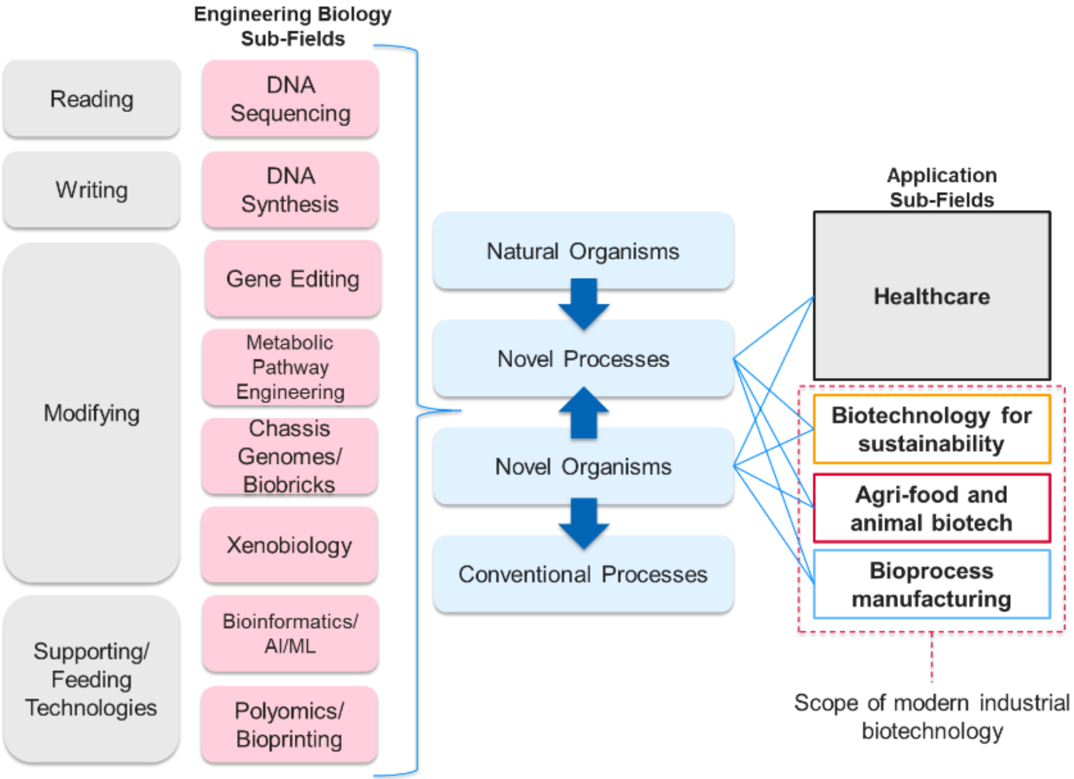
Source: Prepared by Professor Christopher R Lowe OBE, FREng, FInstP, FRSC, for the Policy Links team of IfM Engage, as part of the non-health life sciences project commissioned by the Government Office for Science.

What is modern industrial biotechnology? (2 of 2)

The non-human health life sciences

The original definition of industrial biotechnology was "using enzymes and microorganisms to make bio-based products"[2,3] using readily available sources of bio-feedstock. To some extent, this definition is outdated in that it does not encompass the impact of many new underpinning and feeder technologies in modern life sciences that collectively allow modification and manipulation of life processes, such as gene editing, AI/ML, metabolic engineering, polyomics, epigenomics, forced evolution, nanoscience, fluidics, 3D bio-printing, bioinformatics, in silico biology and quantum computing.

The evolution of modern industrial biotechnology has similarities with the computer industry in that the programming language, DNA, can now be read, stored, copied, modified and rewritten. New software tools and genome editing technologies (CRISPR-Cas9, PRIME) allow plants, animals and microorganisms to be designed de novo to produce, safer and more nutritious foods, plastics, detergents, textiles, novel materials, speciality chemicals and biofuels and create novel pest-control strategies through ethical, sustainable, efficient and economic routes. The figure on the right illustrates how reading, writing and modifying the DNA that governs particular functions in an organism can be combined on a design, build and test basis to create novel organisms and processes for multiple applications.



[2]IBioIC; What is Industrial Biotechnology? http://www.ibioic.com
[3]Clarke, L. and Kitney, R. (2020). *Biochem. Soc. Trans.* 48, 113–122.

Source: Prepared by Professor Christopher R. Lowe OBE, FREng, FInstP, FRSC, for the Policy Links team of IfM Engage, as part of the non-health life sciences project commissioned by the Government Office for Science.

The potential of modern industrial biotechnology

There is significant potential for industrial biotechnology to contribute to sustainable growth

Biotechnology harnesses the potential of the natural world, using plants, animals, fungi and microbes, as well as modern advances in genetics, and it is applying these to global challenges across both traditional and innovative new ways.

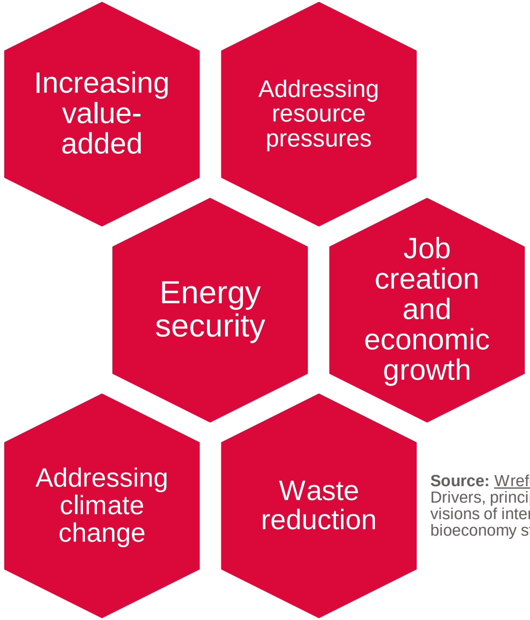
The major opportunities of biotechnology are often seen as the possibility to promote sustainable growth across economic sectors (Dietz et al., 2018), the sustainable use of natural resources, a reduction in waste and pollutants, and reducing energy costs and dependence on fossil fuels (Wreford et al., 2019), among others. Further opportunities for the UK are discussed in Section 6.

The window of opportunity for modern industrial biotechnology

The UK's strong life sciences R&D base means that there is a window of opportunity that may be captured in modern industrial biotechnology in view of the preponderance of shared technologies. There are many reasons why the government may wish to support this, including increasing value, addressing resource pressures, securing energy security, job creation and economic growth, and addressing climate change or waste reduction.

The UK government will not be alone in aiming to enhance its biotech industry. More than forty states worldwide are currently pursuing explicit political strategies to expand and promote their bioeconomies (Dietz et al., 2018; Wreford et al., 2019). In 2008 the US government commissioned a report titled *Ensuring the United States Leads the Coming Biology Revolution*. China's Basic Research Department said that the country was seeking to position itself as a global leader in synthetic biology (McKinsey, 2020).

While much of the work done by the government to support the life sciences in the UK has focused on the health-related life sciences, the spectrum of application areas is far broader (EBLC, 2022). This report aims to address this by providing a landscape map of modern industrial biotechnology in the UK to inform the government's activities in the non-human health life sciences.

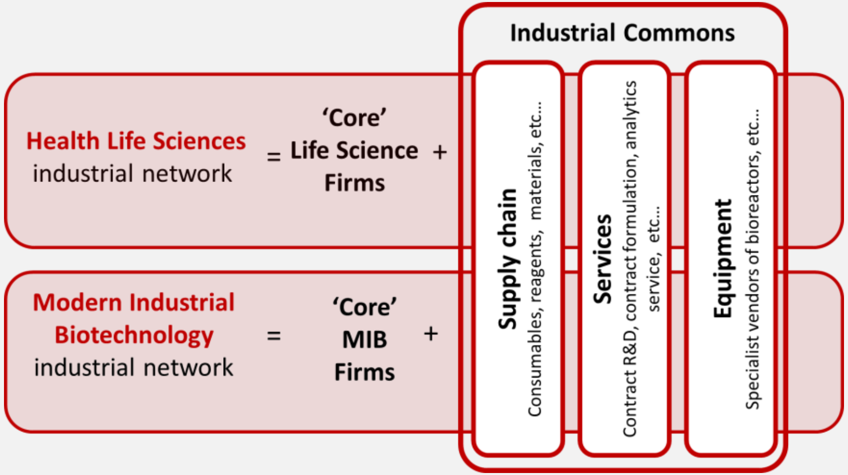


Source: Wreford et al., (2019). Drivers, principles, influences and visions of international bioeconomy strategies.

Shared value chains between health and non-health life sciences (1 of 2)

Spillovers from a strong health sector may support non-health biotech

- The UK is seen as having a strong and innovative value chain in biopharma. Many health-related advances in this area are already spilling over into consumer applications (McKinsey, 2020).
- Biopharmaceuticals comprise around 40% of pharmaceuticals in development globally (Philip, 2021), and the non-health life sciences value chain may be supported by a strong health biotechnology sector, as many of the foundational services, machinery, services and equipment may be deployed in both health and non-health applications.
- Overall, this is expected to provide a positive basis for the non-health life sciences industries in the UK. There are, of course, a few areas that may be exceptions, including skills competition and dominance of the health paradigm.
- There are also potential weaknesses in the dominance of health-related pathways for scale-up. Despite being long and expensive, the clear medical pathways to commercialisation may dominate reference frames, particularly where the same clear commercialisation pathways for non-health biotech do not exist. This may anchor expectations around health-related approaches; for example, TTOs may request excessive royalties from spin-outs.
- This may also represent an opportunity for non-health biotech. Non-health life sciences typically have a less risky commercialisation pathway, as they require less capital than human trials. As such, a specialised and flexible funding and VC approach will be needed to support this commercialisation in the UK.



Source: Dr Eoin O'Sullivan, IfM, University of Cambridge (2022).

'Industrial commons': The ecosystem of firms that support a sector's core manufacturing companies, including those firms providing materials and components, production equipment and specialist technical services (Pisano and Shih, 2009).

The UK Health Life Sciences and Modern Industrial Biotechnology sectors share a significant 'industrial commons'.

Shared value chains between health and non-health life sciences (2 of 2)

Ecosystem context: how good is the UK at human-health biotech?

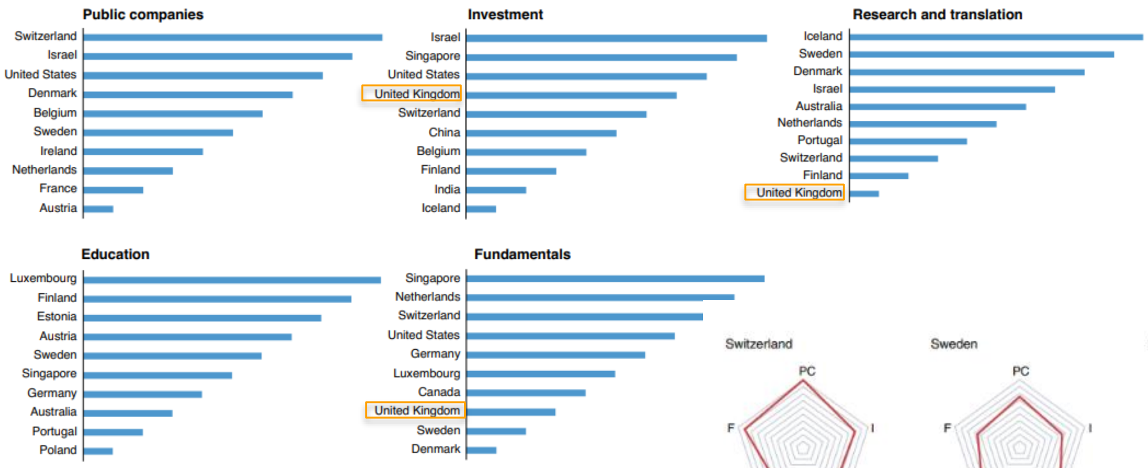


Fig. 2 | Top ten nations for the five Worldview pillars.

ani

The UK is seen as having significant strengths in fundamentals, education, research and translation, and investment, although it has lower numbers of public biotech companies.

However, **Switzerland, Sweden and the United States** are considered the world-leading centres for innovative health-related biotech.

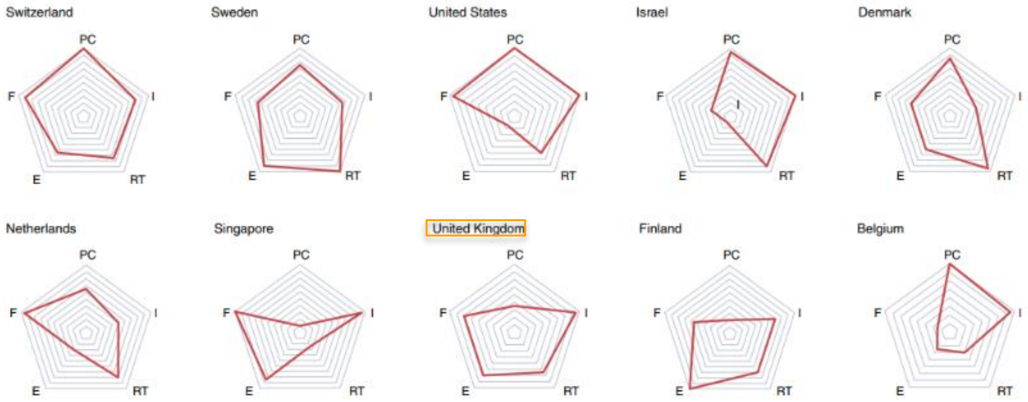


Fig. 1 | Strengths of the leading nations. Relative strengths in each of the Worldview pillar of the ten leading nations. Pillars: Public Biotech Companies (PC); Investment (I); Research and Translation (RT); Education (E); Fundamentals (F).

Source: images from Hodgson and Schreiber-Gregory (2022). The Worldview national ranking of health biotech sectors, Nature *Biotechnology*, 40, pp. 821–832.

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2. Modern industrial biotechnology landscape in the UK

Life sciences beyond human health: modern industrial biotechnology in the UK

Modern industrial biotechnology in the UK economy

What are the major applications of the non-human health life sciences in the UK economy now and into the future?

Biotechnology is broad, encompassing every application of microbes, animals, fungi and plants to create products and services. This vast spectrum includes everything from, for example, the fermentation of bio-feedstocks for the production of fine chemical intermediates, and fibres and plastics produced from plant sources rather than fossil sources (which loosely come under “biomaterials”), through to the design of absorbents via synthetic biology that can remove micropollutants from water.

In this report we focus on four main application categories:

- Biotechnology for sustainability
- Biotechnology for agrifood and animals
- Bioprocess manufacturing, and
- Services and supply for biotech

Sectors

Biotechnology for sustainability

- Climate mitigation
- Bioenergy from biotech
- Waste management & environmental biotech

Agrifood and animal biotech

- Biotech for agrifood and drink
- Biotech for animal health

Bioprocess manufacturing

- Biorefineries and bioprocessing
- Biomaterials from biotech

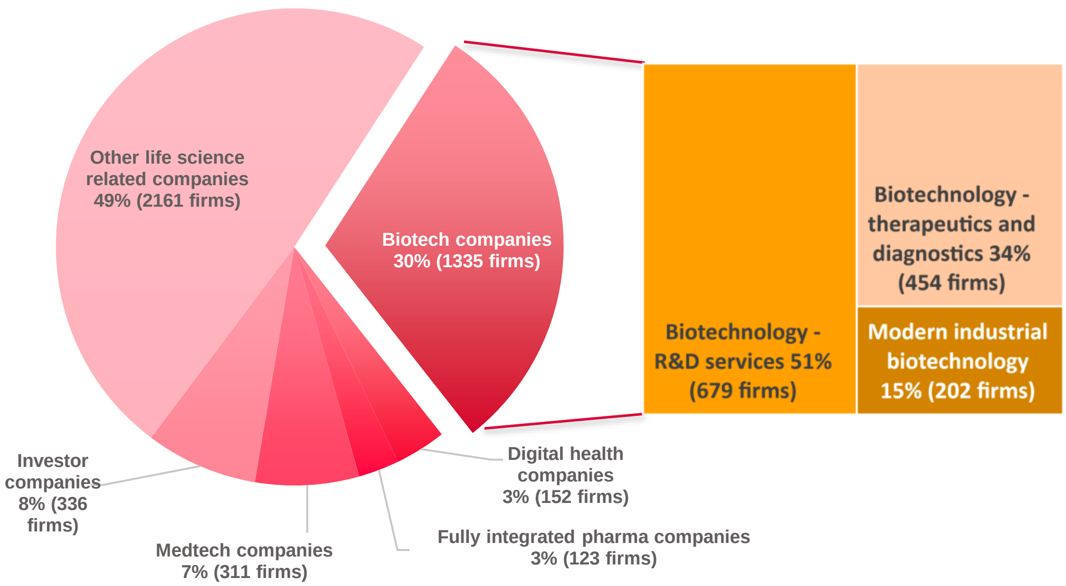
Service and supply

Services and supply for biotech

- Biotech equipment
- Supply chain for biotech
- Technical services for biotech
- Specialist professional services for biotech

Overview of the UK life sciences sector

(% of total firms)



Source: BiotechGate (2022). Life Science Trend Analysis. Accessed on October 2022.

Definition of biotechnology sub-sectors:

- **Biotechnology – therapeutics and diagnostics:**
  - Companies categorised as biotechnology – therapeutics and diagnostics are those whose core business is the application of biotechnology to the discovery and development of novel therapeutic compounds and probe molecules for applications in medicine.
- **Biotechnology – R&D services**
  - Companies that fall under the biotechnology – R&D services category are those that provide support services such as product development services, analytical services, screening, contract manufacturing and contract R&D to the biotechnology industry.
- **Modern industrial biotechnology**
  - Companies that fall under this category are those that apply the concepts of biotechnology (using living organisms or biological substances for the development of products and services) to areas other than drug development for medical use.

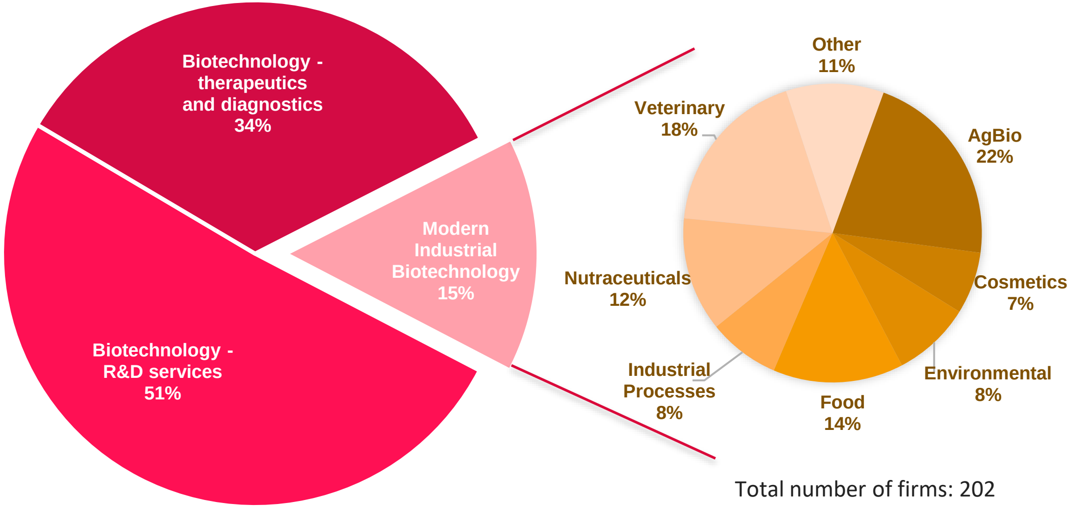
Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

See full sector definitions in Appendix.

Overview and size of the UK biotechnology sub-sector

(% of total firms, turnover and employment)

	Turnover (m GBP)	Employment	Micro firms	Small firms	Medium firms	Large firms
Modern industrial biotechnology	4,723	23,253	39%	31%	25%	6%
UK biotechnology – R&D services	31,931	132,845	44%	31%	16%	10%



Total number of firms: 202

Source: IfM Engage's own elaboration, based on BiotechGate, 2022 (Life Science Trend Analysis) and FAME database for turnover and employment estimates (accessed on October 2022).

UNIVERSITY OF CAMBRIDGE

Cambridge Industrial Innovation Policy

Definition of modern industrial biotechnology categories:

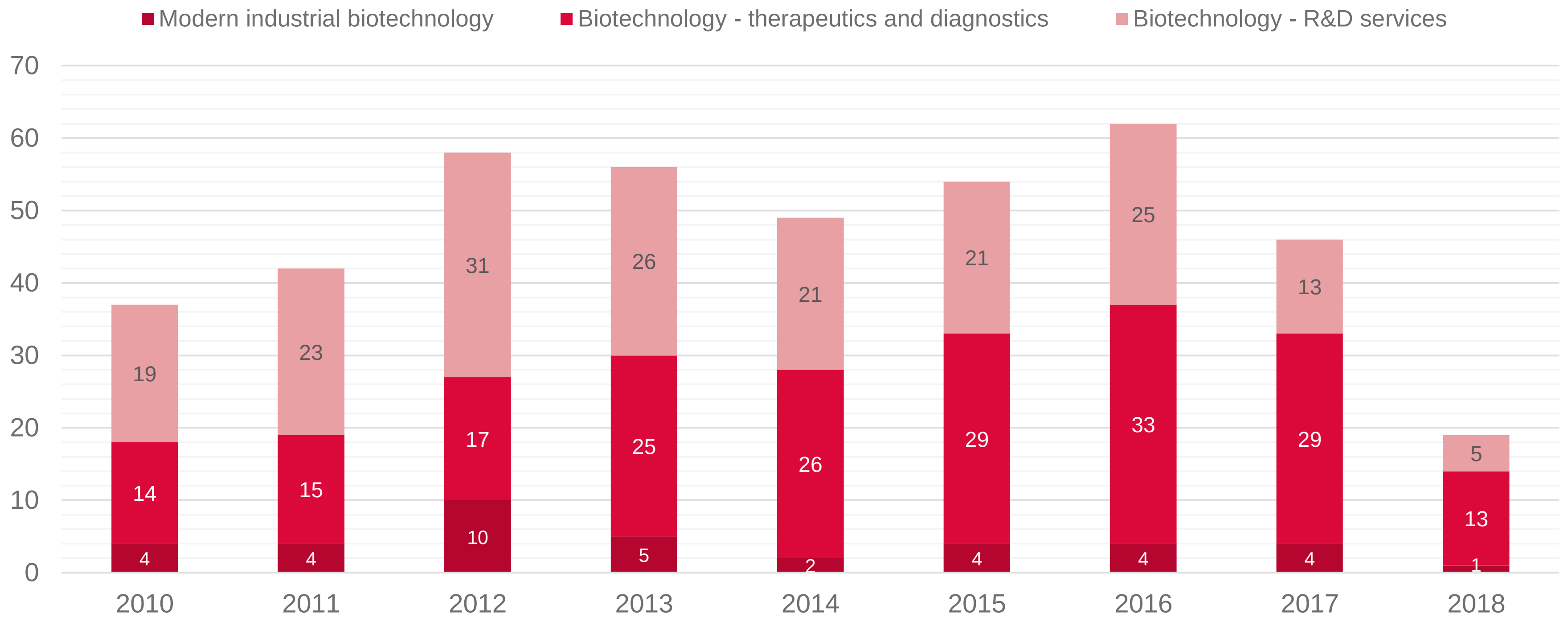
- **AgBio:** companies that apply the principles of biotechnology to agricultural uses such as the production of pesticides or the extension of fruit and vegetables' shelf life.
- **Cosmetics:** companies that apply the principles of biotechnology to the production of cosmetics.
- **Environmental:** companies that apply the principles of biotechnology to the protection and restoration of the environment through processes such as wastewater treatment and clean energy production.
- **Food:** companies that apply the principles of biotechnology to the production and processing of food.
- **Industrial processes:** companies that apply the principles of biotechnology to industrial processes, for example, using biomolecules instead of chemicals.
- **Nutraceuticals:** companies that develop natural products for a therapeutic purpose.
- **Veterinary:** companies whose primary product area is centred on the diagnosis and treatment of diseases and injuries in animals, particularly domestic animals.
- **Other:** companies that apply the principles of biotechnology in an area not mentioned above that does not involve therapeutic medicine or the provision of a service.

Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

See full sector definitions in Appendix.

Number of UK biotechnology firms founded by year

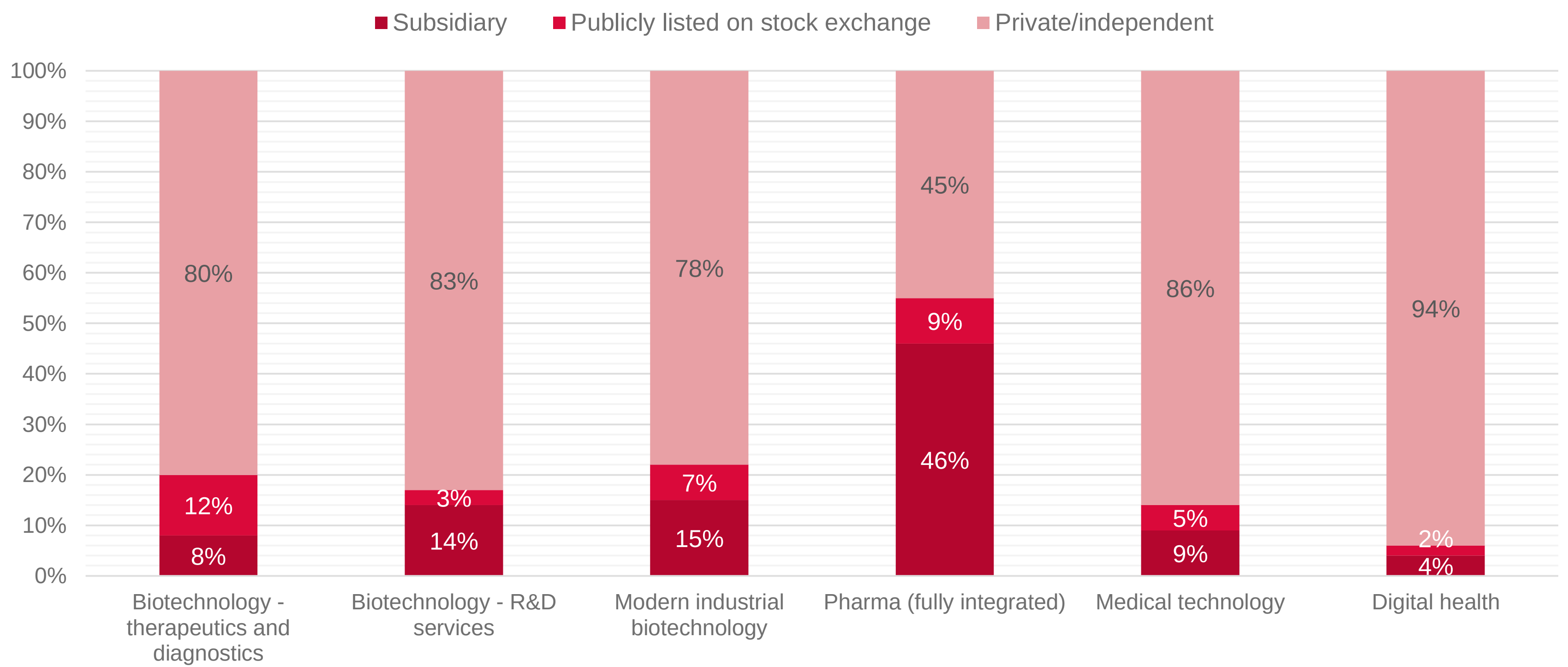
Companies by sub-sector



Source: BiotechGate (2022). Life Science Trend Analysis. Accessed on October 2022.

UK life sciences – ownership structure

Companies by ownership and sector



Source: BiotechGate (2022). Life Science Trend Analysis. Accessed on October 2022.

"Big players" in the UK industry

Top five firms by turnover (modern industrial biotechnology)

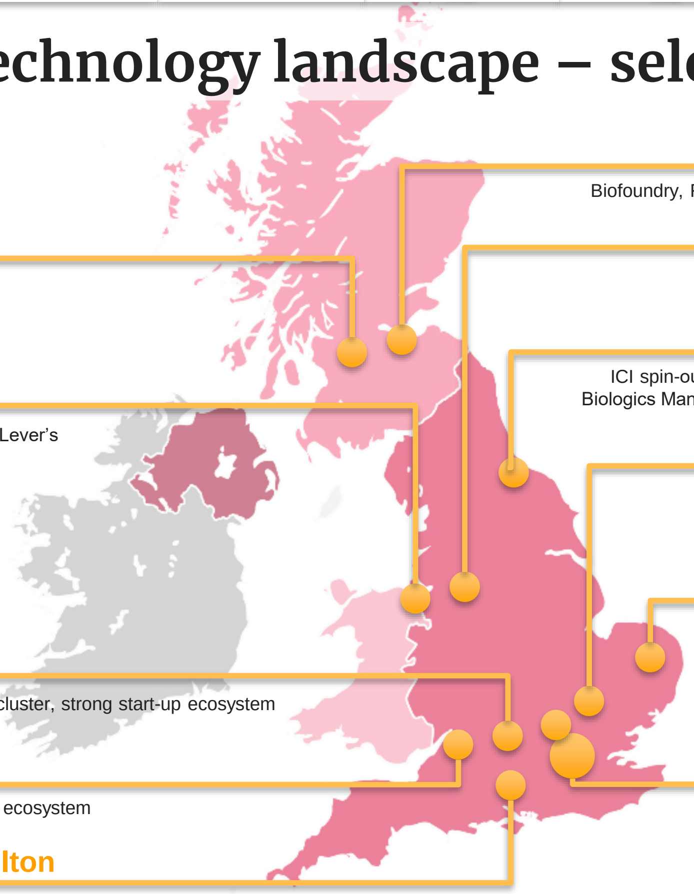
Companies	Sub-sector	Turnover (m GBP)
Company 1	Veterinary	682
Company 2	Veterinary	574
Company 3	Veterinary	554
Company 4	Veterinary	196
Company 5	Cosmetics	170

Note: company names and descriptions not included to maintain confidentiality.

Source: Turnover data from FAME database. Accessed on October 2022.

- It is perceived that there is an insufficient number of "big players" (or "tall trees" or "anchors") in the UK biotechnology space (NESTA, 2011), which may reinvest locally or act as catalysts for further growth in the UK business ecosystem.
- This is often contrasted with the pharmaceutical industry, with the UK-based GlaxoSmithKline and AstraZeneca. This is seen to be stronger for non-human health biotechnology in other countries – the US has Dow-Dupont, the Netherlands has DSM, Germany has BASF, and so on. The UK is not seen to have the same industrial footprint.
- In *Nature Biotechnology* (Hodgson J., Schreiber-Gregory D., 2022), of companies with biotech company HQs, the UK was ranked eighth out of 24 for the relative competitiveness of its national health biotech sector, behind Switzerland, Sweden and the UK.
- There has been significant interest in the Benelux region (Belgium, the Netherlands and Luxembourg) as the potential to become a leading hub for the European health biotech industry (and key competition to the UK's ambitions to do so) – in part due to the role of large leading biotech firms (e.g. Galapagos, Argenx and UniQure). However, despite the absence of large players, the UK had more biotech launches than these combined regions between 2012 and 2018 (McKinsey, 2020).

UK industrial biotechnology landscape – selected clusters



Edinburgh

Biofoundry, Roslin Institute, Centre for Mammalian Synthetic Biology

Glasgow

Industrial Biotechnology Innovation Centre (IBioIC)

Manchester

Future Biomanufacturing Research Hub, strong SynBio R&D, Henry Royce Institute

Teeside

ICI spin-outs, Centre for Process Innovation's (CPI) flagship National Biologics Manufacturing Centre, Teesside University's National Horizons Centre

Liverpool

Microbiology cluster, CPI, UniLever's Materials Innovation Factory, Biofoundry,

Cambridge

Strong biotech R&D, strong biotech start-up cluster, MRC Laboratory of Molecular Biology.

Norwich and Earlham

Quadram Institute, Norwich Research Park, John Innes Centre, Biofoundry, Earlham Institute

Oxford

UK Catalysis Hub, biocluster, strong start-up ecosystem

Bristol

BrisSynBio, strong biotech start-up ecosystem

Central and Greater London

Significant biocluster, SynbiCITE, Biofoundries, Centre of Excellence for Engineering Biology, Metrology and Standards, start-ups, strong VC presence, Pirbright Institute, Stevenage Bioscience Catalyst

Wilton

Centre for Process Innovation

The Engineering Biology Leadership Council has suggested considering a blend of local clustering and national networking options, building around the key hubs and centres of expertise established to date (EBLC, 2021).

Note that some companies rely upon facilities outside the UK for R&D work (EBLC, 2021).

UK modern industrial biotechnology landscape in science and innovation audits (SIAs)

What regions self-identified as potential for growth in biotechnology-related areas during the UK government's SIAs?

Published in 2016 and 2017, science and innovation audits (SIAs) were led by BEIS to help regions map their research and innovation strengths and identify areas of potential global competitive advantage. These were carried out by groups including local businesses, universities and local enterprise partnerships (LEPs).

The key regions that emerge as self-identified potential hotspots for biotechnology adoption and commercialisation from analysis of the science and innovation audits include the **Northern Powerhouse**, **the North of England**, **Greater Manchester** and **the East of England**. A number of other regions identified potential aims in biotechnology-adjacent areas.

Location	Description
Northern Powerhouse	The Northern Powerhouse's SIA identified that it wanted to lead the **adoption of bioprocessing solutions for chemicals production.**
North of England	The North of England identified a specific focus on the **bioeconomy** and a desire to capture value from **agriscience, agritechnology and industrial biology**.
East of England	The East of England SIA identified the **life sciences and agritech**, as well as advanced materials and manufacturing, as key areas for the region.
Greater Manchester	Greater Manchester's SIA focused on the future growth potential in **industrial biotechnology**.

North East of England	The North East SIA identified a strength in chemical and pharmaceutical manufacturing.
Highlands and Islands	The Highlands and Islands SIA identified ambitions to apply marine biotechnology and increase sustainable aquaculture.
North West	The North West SIA identified an aim of eco-innovation for clean and sustainable growth.
South Wales	South Wales identified a focus on agrifood tech, including improvements in crops, animal health and the waste streams from the agrifood supply chain.
Central Belt (Scotland)	The Central Belt of Scotland's SIA looked at developing enabling technologies for manufacturing, including industrial biotechnology, alongside primarily digital solutions.
Liverpool	Liverpool's SIA identified strengths in materials chemistry and commercialisation.
The Midlands	The Midlands SIA identified a goal to capture future food processing covering the areas of: "food processing efficiency", "delivering a zero waste food chain" and "food product innovation" in the food and drink sector.

Biotechnology for sustainability

Insights from literature and stakeholder consultation

Evidence from literature and an expert workshop with stakeholders across government, academia and industry highlighted a range of existing applications of biotechnology for sustainability, including:

- **Climate mitigation**, including carbon capture, utilisation and storage using biotechnology (e.g. bacteria that capture and use carbon from industrial processes) and climate mitigation through the application of biotechnology in agriculture and animal health (e.g. seaweed feed for cattle to reduce methane emissions).
- **Bioremediation, biotech water quality monitoring and management**, biotech waste management and biotech soil improvement (e.g. microbes that remove heavy metals from soils). Many current remediation technologies damage the soil, while bioremediation may improve soil quality (Philip, 2021).
- **Environmental management** applications of biotechnology (e.g. management of mosquito populations using genetic engineering to reduce malarial incidence). Biotechnology can also form part of the circular economy, where waste products from agriculture or industrial processes are used as feedstocks to produce new chemicals or materials.
- **Bioenergy**, including both bioheat and biofuels made using biotechnology processes (e.g. fermentation of feedstocks to produce jet fuel).

Biotechnology for sustainability

Climate mitigation	Bioenergy from biotech	Waste management & environmental biotech

Business example

CyanoCapture

CyanoCapture aims to provide affordable, long-term carbon capture on an industrial scale by harnessing genetically modified cyanobacteria. They envision a solution to be at the centre of the global roadmap towards achieving “net zero” by 2050.

CyanoCapture provides point-source carbon capture to power stations, cement factories and other emission sites. The CCS technology costs industries less to capture each tonne of CO2 than the cost that would otherwise be paid in emission tax.

CyanoCapture buries its excess biomass and bioproduct deep underground in approved geological facilities – qualifying us as true CCS. A 750m x 600m area CyanoCapture installation is estimated to be able to capture 0.10–0.15 million tonnes of CO2 each year for the adjacent power plant, saving up to 5.2 million euros in tax.

Biotechnology for sustainability

- Climate mitigation
- Bioenergy from biotech
- Waste management & environmental biotech

CYANOCAPTURE

Scalable carbon capture technology

Source: text extracted from (BIA, DIT 2022). This business example is meant to be illustrative and does not imply government endorsement of the company or its solutions.

Agri-food and animal biotech

Insights from literature and stakeholder consultation

Applications of biotechnology in agri-food and animal biotech include:

- **Biotechnology for agri-food and drink**, including biopesticides, biofertilisers, the production of cultured meat, genetic engineering for agrifood, bioagrochemicals, biotech-produced flavours and fragrances, viticulture, and plant-based proteins for yogurt, milk, egg and cheese products as an alternative to dairy and egg-based goods, among others.
- **Animal health** applications of biotechnology, including vaccines, pharmaceuticals and biotechnology for animal feedstocks, and so on. Animals include farm, veterinary, sporting and companion animals.

Reasons to prioritise biotechnological development in agri-food
(from the Engineering Biology Leadership Council, 2022):

- Produce adaptable crops
- Genetic improvement of farmed animals
- Produce alternative agrochemicals
- Improve soils
- Develop diagnostic tools
- Produce sustainable feedstocks
- Produce alternative foods
    - Develop alternative food production systems
    - Develop alternative manufacturing systems
    - Develop novel chemistries
- Waste processing
- Capturing CO2 in agrifood processes

Agrifood and animal biotech

Biotech for agrifood and drink	Biotech for animal health

Business example

ENOUGH

As the world's population increases and the demand for protein grows, ENOUGH's goal is to "Make Protein Sustainable". ENOUGH uses the natural process of fermentation. By feeding their fungi the naturally occurring sugars in grains, this grows into a complete food, ABUNDA mycoprotein.

The simplicity of the process means ABUNDA is highly scalable to meet future demands. ABUNDA is a sustainable protein relevant to multiple categories and product applications. ABUNDA mycoprotein is a fermented food ingredient, rich in protein and fibre. With nine essential amino acids, zinc and iron, ABUNDA is highly nutritious. The fibrous nature of the product produces an outstanding meaty texture, naturally.

Agrifood and animal biotech

Biotech for agrifood and drink	Biotech for animal health

ENOUGH®

delicious. nutritious. sustainable.

Source: text extracted from (BIA, DIT 2022). This business example is meant to be illustrative and does not imply government endorsement of the company or its solutions.

Bioprocess manufacturing (1 of 2)

Insights from literature and stakeholder consultation

Bioprocess manufacturing is the broadest category capturing the production of materials and chemicals using biotechnology, and it has some overlaps with the previous categories:

- **Biorefineries and bioprocessing** involve the application of biological processes for the production of chemical or industrial products and biorefinery products, including biofuel production using biotechnology. Some examples include bioproduction of important solvents (e.g. butanol, bioethanol, methanol), oils from bio-engineered crops, biobatteries and fuel cells, algal and microbial energy production systems. Bio-based chemicals typically use less energy and produce fewer greenhouse gas emissions than conventional production of the same chemicals (Phillip, 2021). It also includes the microbial fermentation of waste from industrial processes into useful by-products (Phillip, 2021).
- **Biomaterials** production includes, for example, textiles produced through biotech processes, biopolymers and bioplastics, biosensors, bioelectronics. One example is artificial spider silk, which is incredibly strong and tough and has applications from bike helmets to bulletproof jackets and airplane wings. The wood of the foxglove tree, *Paulownia tomentosa*, could be used for aerospace applications. Other woody biomaterials could be used for microfluidic devices and specialised papers.

Bioprocess manufacturing

Biorefineries and bioprocessing	Biomaterials from biotech

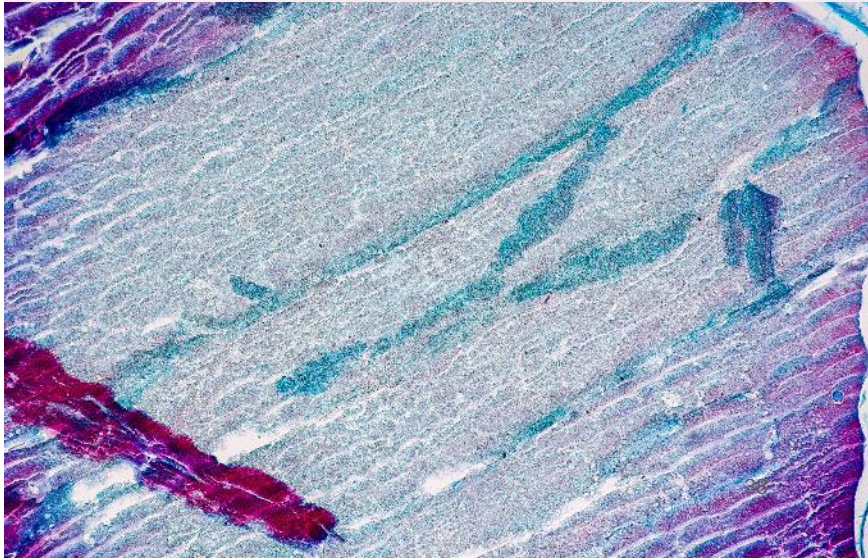
Bioprocess manufacturing (2 of 2)

Insights from literature and stakeholder consultation

- The industrial biotechnology sector is rapidly progressing and a number of biocommodities are currently in production processes for vitamins, bulk enzymes, ethanol, steviol glycosides and other fine chemicals, which exploit microorganisms to convert plant-derived renewable feedstocks into market-ready products at an industrial scale.
- However, most valuable biosynthetic products are toxic to the host microorganism at the high concentrations required to ensure economic viability at an industrial scale. Current key challenges include the lack of reliable substrate supplies, high water consumption rates and the metabolic burden associated with heterologous pathways, although these can be mitigated against to some extent by metabolic engineering and adaptive evolution.
- Nevertheless, novel cell factories based on *Yarrowia lipolytica*, *Trichosporon oleaginosus*, *Ustilago cynodontis* and *Debaryomyces hansenii* have desirable process features such as the ability to catabolise glycerol, metabolise lignocellulosic inhibitors, broad pH tolerance and function in non-pure water sources.
- Sequential bioreactor systems comprising more than one cell-based system and integrated with suitable downstream processing techniques may boost productivity by minimising metabolic burden and result in higher yields of recovered product.
- However, examples of effective integrated bioreactor and downstream processing for the recovery of heterologous products of metabolically engineered organisms at an industrial scale remain few and far between. Nevertheless, attractive prospects remain for the production of high-value products at scale by engineered microbial, yeast, mammalian and plant systems.

Bioprocess manufacturing

Biorefineries and bioprocessing	Biomaterials from biotech



Source: Prepared by Professor Christopher R Lowe OBE, FREng, FInstP, FRSC, for the Policy Links team of IfM Engage, as part of the non-health life sciences project commissioned by the Government Office for Science.

Business example

CelluComp

CelluComp are working to develop and commercialise Curran®, a material developed from the extraction of nanocellulose fibres of root vegetables, primarily from sugar-beet pulp (a by-product of the sugar industry).

Curran® offers exceptional mechanical properties compared to other fibre reinforcements at an affordable price. Curran® has the capability to enhance products in sporting goods, construction, paints, automobile, marine and many more potential applications.

Bioprocess manufacturing

Biorefineries and bioprocessing

Biomaterials from biotech

Source: text extracted from (BIA, DIT 2022). This business example is meant to be illustrative and does not imply government endorsement of the company or its solutions.

Services and supply for biotech

Insights from literature and stakeholder consultation

The provision of machinery and services represents a likely strength of the UK's ecosystem, but one that often gets overlooked when taking a sectoral focus. This includes:

- **Biotechnology machinery.** This equipment includes, for example, bioreactors, genetic sequencing, microfluidics, scientific and testing equipment, sensors and processing systems.
- **Supply services.** This includes, for example, the supply chain, such as specialist logistics for genetic material, reagents, materials, tests. It also includes waste as a feedstock for biorefineries, and bio-product recovery, as part of the circular economy.
- **Technical services.** This includes contract biotechnology research and development, contract biotech manufacturing, contract testing and equipment for biotechnology. It also includes synthetic/engineering biotechnology services, such as genetic sequencing, DNA editing, synthetic/engineering biology firms, biomolecular design and engineering, plant synthetic biology. It can include engineering services for biotechnology processes, or specialist ICT (e.g. artificial intelligence/machine learning for biotechnology, or biotech process monitoring).
- **Specialist professional services.** This includes, for example, biotech regulation consultants, biorisk and biosecurity professionals.

Services and supply for biotech

Biotech equipment	Supply chain for biotech
Technical services for biotech	Specialist professional services for biotech

Business example

Algenuity

Algenuity serves the algal biotech industry at a foundational part of the value chain. Algenuity researches, develops, manufactures and provides lab-scale photobioreactors to optimise growth parameters and algal genome modification services to increase desired traits and to harness microalgal strains as synthetic biology chassis organisms.

Microalgae are a potential source of high-quality plant-based protein, which can be used in plant-based products to replace animal protein. These products will be attractive to all kinds of consumer. Microalgae are a good source of essential macronutrients and micronutrients, including antioxidants and minerals such as iron, with many also being a good source of fibre. Microalgae also contain vitamins and essential amino acids. Our bodies cannot produce these critical nutrients; therefore, it is important that we obtain them from our diet.

Services and supply for biotech

- Biotech equipment
- Supply chain for biotech
- Technical services for biotech
- Specialist professional services for biotech

Source: text extracted from (BIA, DIT 2022). This business example is meant to be illustrative and does not imply government endorsement of the company or its solutions.

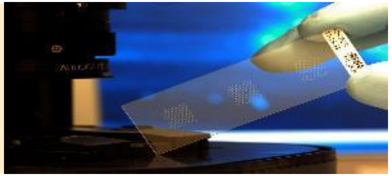
Scientific and technological advances driving industrial biotechnology

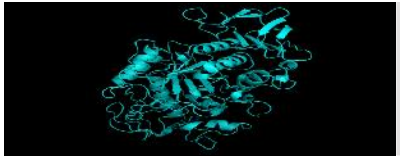
There are many scientific and technological advances driving modern industrial biotechnology growth. Here are a few examples:

Digitalisation in these industries is expanding and can also positively influence commercialisation activities in firms. Digitalisation drivers often include: reducing costs, enhancing performance, promoting internal efficiency, improving or implementing smart production processes, adding value to a supply chain, creating a new product or service, adapting to new changes, competition and stimulating demand. AI, including machine learning techniques, has the potential to be used to accelerate the development of novel and optimised materials, particularly when used in iterative processes (Le Feuvre and Scrutton, 2018).

The speed of **genomic sequencing technologies** has increased significantly (Engineering Biology Leadership Council, 2022). Genome editing techniques have advanced significantly – the most prominent of these being CRISPR-Cas9 technology (EU Commission, 2021) and PRIME gene editing. These have allowed the acceleration of plant-breeding techniques that previously took 8–12 years to 2–5 years (Siksnys, 2021). **Totally artificial organisms** based on “chassis” organisms with functions added from a catalogue of “bio-bricks” are still at an early stage but could be relevant in the future.

“Lab on a chip” technologies have the potential to improve the speed, efficiency and cost of bioanalyses. These could be deployed across industry (e.g. quality control, contaminant detection), defence (e.g. on-site testing of biological agents), environment (detection of pollutants, soil status monitoring), as well as health applications (European Commission, 2021)





Novel and engineered enzyme catalysts could potentially drive much of the future fine chemicals, polymers and nutrients businesses. They have the ability to catalyse reactions with high product selectivity, utilise a broad range of substrates and maintain activity at low temperature and pressure. Therefore, they represent a renewable, environmentally friendly alternative to conventional catalysts (Smith, M. R. et al., 2015).

UK policy context – key actors

Government departments

- Department for Business, Energy & Industrial Strategy
- Department for Environment Food & Rural Affairs
- Ministry of Defence
- Cabinet Office

Government agencies

- HSE Health & Safety Executive
- dstl The Science Inside
- Innovate UK
- UK Research and Innovation
- bsi.
- NPL National Physical Laboratory
- Food Standards Agency

Government-supported research institutes

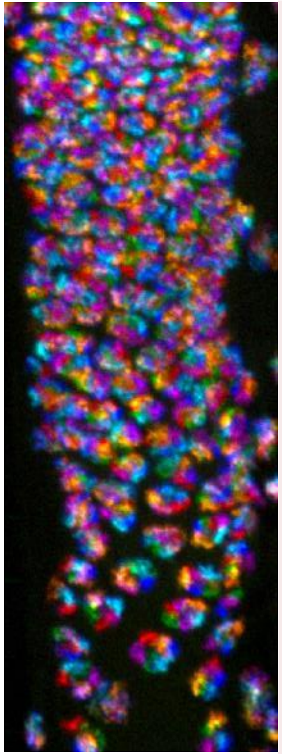
- Earlham Institute
- cpi
- John Innes Centre
- SynbiCITE
- Roslin
- Quadram Institute Science • Health • Food • Innovation
- Future BRH
- The Pirbright Institute

Networks

- Engineering Biology Leadership Council
- Industrial Biotechnology Leadership Forum
- IBioIC

Cambridge Industrial Innovation Policy (2022). *Life Sciences beyond human health: modern industrial biotechnology in the UK.*

UK policy context over the past 2 decades



The industrial biotechnology sector received strong early government support from the mid-2000s, particularly in the areas of genetic editing and synthetic or engineering biology. Over time, the United Kingdom, like the United States, has placed great emphasis on synthetic biology in its bioeconomy strategies (Philip, 2021)

Between 1997 and 2013, the UK's industrial biotechnology and bioenergy sector grew by 5% (Capital Economics, 2016); however, this is likely to have been due to an increase in biofuel use resulting from government support. Between 2004 and 2014, the productivity of the sector fell by 1.8% per year (CAGR).

In 2011 NESTA assessed that within the industrial biotechnology sector, the "total number of significant and active UK participants in all components of the IB value chain comprises fewer than 100 organisations" (NESTA, 2011). This has changed dramatically. The Innovation Caucus for BBSRC has recently conducted a mapping of the biotechnology and bioscience industry by mapping spatial and sectoral data on a sample of over 10,000 biotechnology and bioscience start-ups in the UK.

The bioscience and biotechnology industry received strong government support, particularly in the period from 2005 to 2015. Following this, the focus has shifted primarily onto the human health-related aspects of the life sciences, although institutions with bioscience and biotechnology missions have continued to advance developments in this area, particularly the BBSRC.

Today, the UK is seen as having excellent, world-leading research in this area, albeit with lower success in the commercialisation and scale-up of this technology. This is in part attributed to infrastructure, skills and the availability of venture capital – an assessment that has remained relatively consistent across the past decade.

UK policy context over the past 2 decades

	Funding	Reports
2003	○ £4 million for UK Innovation & Science Seed Fund started for public research organisations, with a focus on synthetic biology (~one-third activity)	
2006	○ £6.5 million for the National Industrial Biotechnology Facility (NIBF), at CPI	
2007	○ £900,000 for Networks in Synthetic Biology ○ £12 million for the National Industrial Biotechnology Facility (NIBF) at the Centre for Process Innovation (CPI)	○ Industrial Biotechnology Innovation and Growth Team established
2008		○ Balmer and Martin (2008) report for the BBSRC
2009	○ £4.7 million for EPSRC Centre for Synthetic Biology and Innovation ○ £2 million in BBSRC and EPSRC Synthetic Biology grants ○ £6 million ESPRC and NSF Synthetic Biology Sandpit funding	○ BERR (2009). Maximising UK Opportunities from Industrial Biotechnology in a Low Carbon Economy. ○ RAEng (2009). Synthetic Biology: scope, applications and implications
2011	○ BBSRC large strategic grants call includes synthetic biology priority	▪ HM Government (2011). UK Life Science Strategy.
2012	○ £2 million from BBSRC, EPSRC, MRC and Dstl for Joint Synthetic Biology Initiative ○ £10 million from BBSRC, EPSRC and TSB to establish an Innovation and Knowledge Centre (IKC) in Synthetic Biology ○ Government capital investment of £50 million in synthetic biology in the 2012 Autumn Statement, for six Synthetic Biology Research Centres by BBSRC, EPSRC and MRC	○ HM Government (2012). Synthetic Biology Roadmap for the UK

UK policy context over the past 2 decades

	Funding	Reports
2013	○ £1 million each for two BBSRC and EPSRC Centres for Doctoral Training (CDT) in synthetic biology ○ £10 million capital funding for investment through the UK Innovation and Science Seed Fund	
2014	○ £75 million in Industrial Biotechnology Catalyst Programme for acceleration of commercialisation	○ House of Lords (2014). Waste or resource? Stimulating a bioeconomy
2015		○ HM Government (2015). Building a high value bioeconomy. Opportunities form waste
2016	○ Industrial Biotechnology Catalyst ended	○ HM Government (2016). UK Synthetic Biology Strategic Plan.
2017		○ House of Lords (2018). Life Sciences Industrial Strategy: Who's driving the bus? ○ Bell J. (2016). Life sciences: industrial strategy. A report to government from the life sciences sector
2018		○ HM Government (2018). Growing the Bioeconomy (withdrawn in 2020) ○ IBLF (2018). Growing the UK Industrial Biotechnology Base
2019	○ £170 million BBSRC investment for 1,700 PhD researchers over 5 years in doctoral training partnerships	

UK policy context over the past 2 decades

	Funding	Reports
2020		○ EBLC (2021). Engineering Biology for the UK a Resource to help Build Back Better
2021	○ BBSRC has £252 million invested in biotechnology-related grants through its current routine funding	○ HM Government (2021). UK Innovation Strategy: leading the future by creating it. names 'Bioinformatics and Genomics' and 'Engineering Biology' as two of the seven technology families of UK strength and opportunity.
2022	○ £37 million additional patient capital in UK Innovation & Science Seed Fund ○ **Health-related announcements, examples:** ➢ British Business Bank launched the £200 million Life Sciences Investment Programme (health-focused) ➢ £60 million to help expand life sciences manufacturing in the UK (vaccine- and health-focused)	○ UK Parliament (2022). Genetic Technology (Precision Breeding) Bill

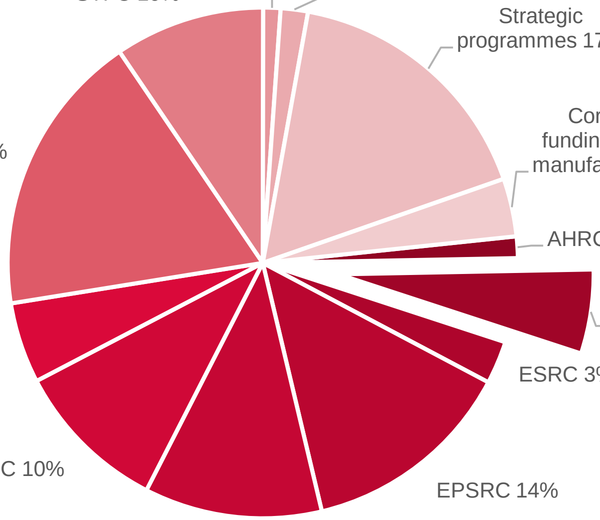
3. UK International Benchmarking

Life sciences beyond human health: modern industrial biotechnology in the UK

UK research strength in modern industrial biotechnology-related fields

UK public R&D investment in modern industrial biotechnology

UKRI R&D budget allocations 2021 to 2022 (total ~£8,580m)



Note: **AHRC** – Arts and Humanities Research Council; **BBSRC** – Biotechnology and Biological Sciences Research Council; **ESRC** – Economic and Social Research Council; **EPSRC** – Engineering and Physical Sciences Research Council; **IUK** – Innovate UK; MRC – Medical Research Council; **MRC** – Medical Research Council; **NERC** – Natural Environment Research Council; **RE** – Research England; **STFC** – Science and Technology Facilities Council

Source: BEIS (2021). BEIS research and development (R&D) budget allocations 2021 to 2022.

- In the UK most of the public R&D expenditure is performed by the Department of Business, Energy and Industrial Strategy (BEIS), which allocates funding to several programmes and organisations, including UK Research and Innovation (UKRI).
- The total UKRI R&D funding is then allocated to different programmes and councils, including the Biotechnology and Biological Sciences Research Council – BBSRC, which can be used as a proxy for public R&D expenditure in biotechnology.
- In the UKRI R&D budget allocations 2021 to 2022, BBSRC has been allocated **£429 million**, equivalent to 5% of the total UKRI budget.
- Between 2009 and 2017 the R&D budget allocation to BBSRC was, on average, £458 million per year. During the same period, BBSRC was the fourth research council by R&D budget allocation, after the Engineering and Physical Sciences (EPSRC), Medical Research Council (MRC) and the Science and Technology Facilities (STFC).[a]
- For the BBSRC research spend **2016–17**, the last year where data is available, **56% of the total budget** was spent on research topics related to modern industrial biotechnology. [b]

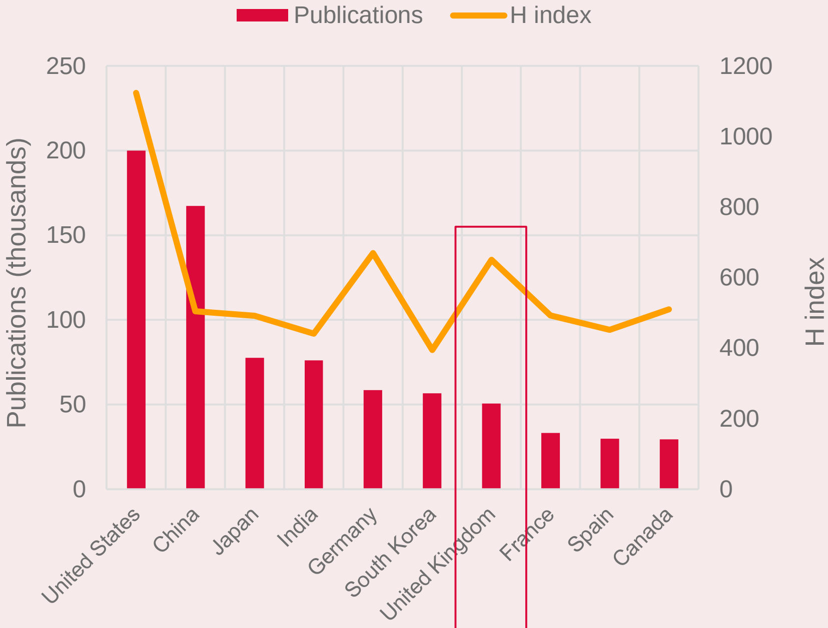
a) BEIS (2021). BEIS research and development (R&D) budget allocations 2021 to 2022.
b) BBSRC (2018). Research spend by research topic and investment mechanism

UK research strength in modern industrial biotechnology-related fields (1 of 6)

The United Kingdom ranked fifth in the world in terms of research productivity (measured by number of publications) in biotechnology and seventh for productivity seen between 1996 and 2021. During this period the United States, China and Japan led the biotechnology field (SCImago, 2022).

In terms of research impact (measured by the H index), the United Kingdom ranked fourth in 2021 and third in the period of 1996–2021. During this period, the United States and Germany, and the United Kingdom, were the top three performing countries in biotechnology (SCImago, 2022).

Countries with the highest research productivity and impact in biotechnology, 1996–2021



Number of publications

Ranking 1996–2021	1	2	3	4	5	6	7	8	9	10
Ranking 2021	2	1	7	3	4	6	5	14	11	13

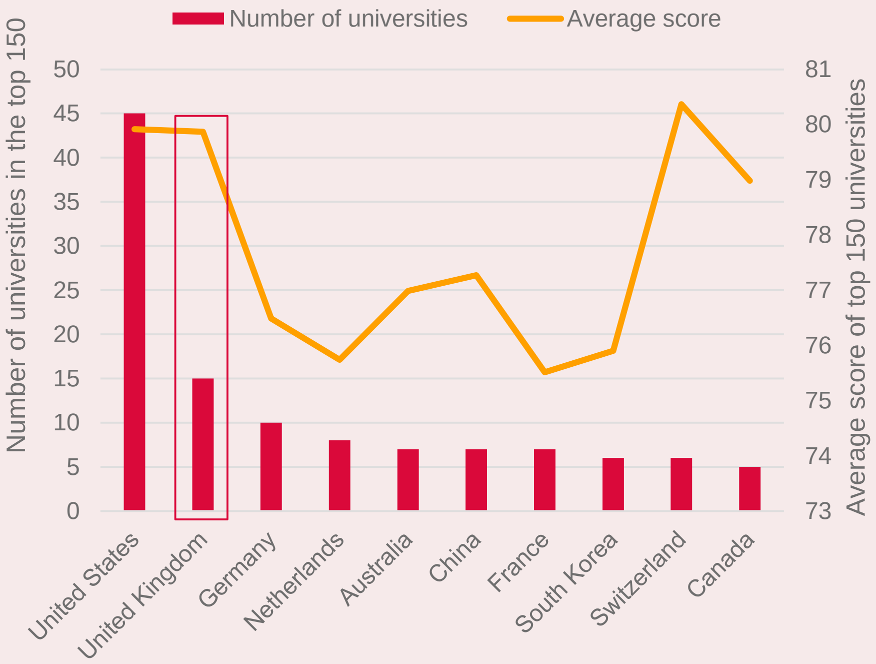
Note: subject categories: applied microbiology and biotechnology and biotechnology.
Source: SCImago Country Rankings.

UK research strength in modern industrial biotechnology-related fields (2 of 6)

In 2022 the United Kingdom ranked second in terms of the number of universities classified among the top 150 in the world in biological sciences, and their average scores, behind only the United States (QS World University Rankings, 2022). According to this ranking, the University of Cambridge (3rd), the University of Oxford (5th), Imperial College London (11th), University College London (11th) and the University of Edinburgh (22nd) are the top five universities in biological sciences in the UK.

In the 2021 Research Excellence Framework (REF), an average of 48% of biological sciences research assessed was classed as 4* (world leading) and 41% as 3* (internationally excellent). The top five institutions in biological sciences by proportion of their overall REF rating of 4* were: the Institute of Cancer Research (Royal Cancer Hospital), the University of Dundee, the University of Cambridge, the University of Edinburgh and the University of Manchester.

Top 150 universities in biological sciences by country, 2022



Note: top 150 universities.
Source: QS World University Rankings by Subject.

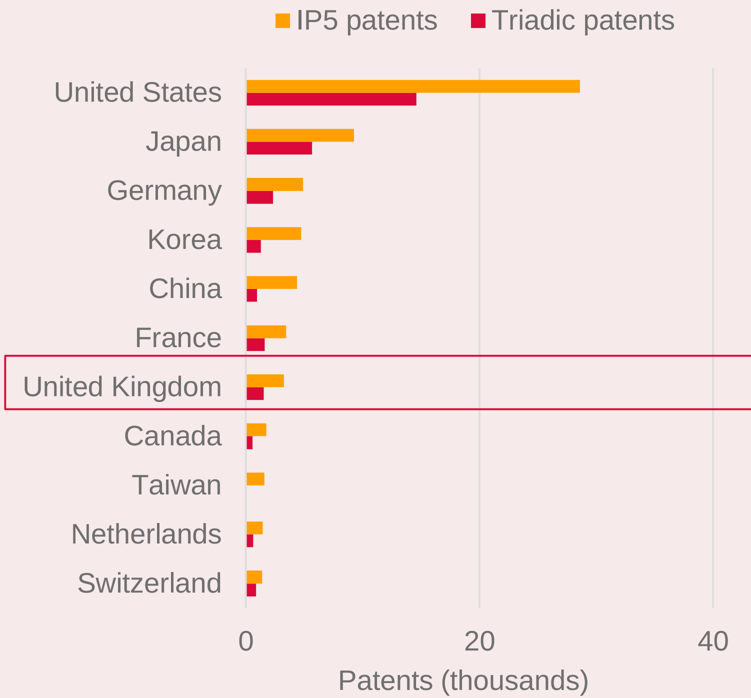
UK research strength in modern industrial biotechnology-related fields (3 of 6)

In 2018 biotechnology patents accounted for 2% of the total patent applications worldwide (WIPO, 2020).

The United States, Japan, Germany, Korea and China are the top five innovators in biotechnology. The United States' patents accounted for 42% of the world's triadic patents in biotechnology and 82% of the world's IP5 patents in the field in 2011–18 (OECD, 2022).

During this period the United Kingdom ranked fifth out of 52 countries according to the number of triadic patents in biotechnology and seventh for the number of IP5 patents. The United Kingdom accounts for 4% of the world's biotechnology triadic patents and 9% of the IP5 patents (OECD, 2022).

Countries with the highest number of patents in biotechnology, 2011–2018



IP5 patents ranking

Ranking 2011–18	Ranking 2018
1	1
2	3
3	5
4	4
5	2
6	8
7	7
8	9
9	6
10	10
11	11

Note: patents by inventor(s)'s country(ies) of residence and priority date.
Source: OECD Stats.

UK research strength in modern industrial biotechnology-related fields (4 of 6)

61

Biotechnology-related university spin-outs founded as a direct outcome of UKRI research grants

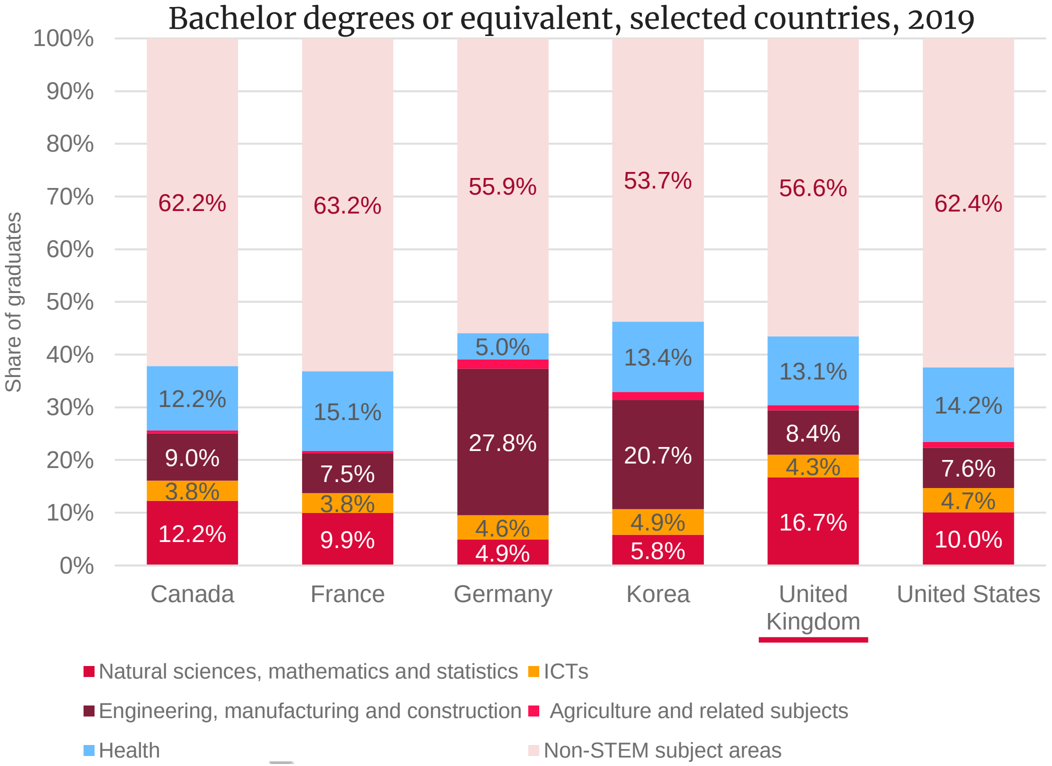
From 2005 to 2021

Source: UKRI research data portal. Accessed October 2022.

University spin-outs

- In 2011 NESTA found that the number of UK SMEs spun out directly from universities was surprisingly small for an advanced technology-based sector, with higher numbers released from large companies to target a particular market opportunity – perhaps because of the requirement for chemical engineering plant skills within biotechnology (NESTA, 2011).
- The technology-transfer offices of universities in this space are sometimes seen as requesting disproportionately high royalties for support for biotechnology companies, as they are used to medicine and health markets.
- In their report for BBSRC, the Innovation Caucus found that various higher education institutions (HEIs) have different preferences for commercialisation pathways. Those with fewer resources prioritise licensing IP, because the risks and costs associated with spin-outs are too great.
- The crucial role of HEI technology-transfer offices (TTOs) raises challenges for resource-poor institutions. The report suggests that it is possible that centralising resources in regional clusters could address weaknesses in TTO provision.

UK research strength in modern industrial biotechnology-related fields (5 of 6)



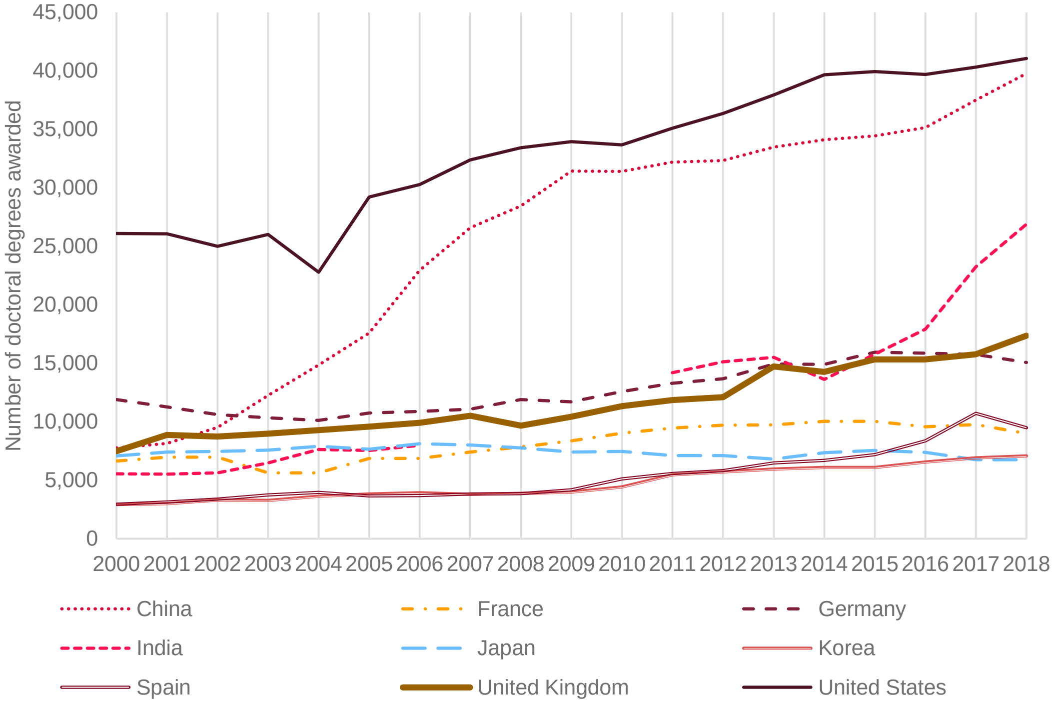
Note: Non-STEM subject areas include: arts and humanities; social sciences, journalism and information; business, administration and law; education; generic programmes and qualification; field unknown.
Source: OECD (2021). Education at a Glance database.

Graduates by subject areas

- In 2019 a total of 431,820 students obtained a Bachelor degree from the UK's higher-education institutions.
- Graduates in STEM disciplines accounted for 43.4% of the total graduates in the UK in 2019. This value was above that for comparator countries such as **France** (36.8%), **Canada** (37.8%) and the **United States** (37.6%).
- The share of graduates in engineering, manufacturing and construction remains relatively low in the UK, at 8.4%, especially compared to countries such as **Germany** (27.8%) and **Korea** (20.7%).
- In 2014 BBSRC and MRC conducted a review of vulnerable capabilities in bioscience and biomedicine. The vulnerable areas identified include: interdisciplinarity; maths, statistics and computation; physiology and pathology; agriculture and food security; and core research and subject-specific skills (BBSRC, 2017). These key vulnerabilities could be usefully updated by UKRI. A number of actions were taken following this review, whose success could be reviewed to inform future strategies.

UK research strength in modern industrial biotechnology-related fields (6 of 6)

Number of STEM doctoral degrees awarded, selected countries, 2000–2018



Notes: STEM PhDs include doctoral degrees awarded in the following fields: natural sciences, mathematics and statistics; ICTs; engineering, manufacturing and construction; agriculture and related subjects; health.
Source: NSF (2022). The State of US Science and Engineering 2022.

STEM PhDs

- In 2018 the UK's higher-education institutions awarded 17,366 PhDs in STEM disciplines.
- The UK is among the countries with the highest number of STEM PhDs awarded per year, even compared to countries with larger populations.
- The **United States** has historically been the country with the highest number of STEM PhDs awarded per year (41,071 in 2018).
- **China** is rapidly catching up with the **USA** in awarding STEM PhDs, from 7,766 doctoral degrees awarded in 2000, to 39,768 in 2018, representing an increase of 412% in 18 years.
- A 2017 study by BBSRC and MRC identified key vulnerable areas in bioscience and biomedicine, primarily around **doctoral** and **post-doctoral** training levels (BBSRC, 2017).
- Interestingly, despite high competition for skills, the UK is seen as better "value for money" for international investors in comparison to the US, where salaries for similar skills and roles are significantly higher. This may have implications for UK-based skills.

Tensions in patenting timing and the implications for the UK

Gaps arise in the post-research but pre-commercial phase because of a drive to patent intellectual property early

The expert workshop identified tensions in the timing of patenting activities – including patenting and spinning out “too early”. This issue arises because it is often seen as sensible or it is encouraged to try to “park” IP in a commercial entity.

However, patenting too early may mean the developer loses years on a patent, which then cannot be used to recoup the value in the market. Patent too late and you may risk being beaten by the competition.

Furthermore, if companies spin out of universities too early by becoming a commercial body to park IP, they risk not doing the important work post-research but pre-commercial, such as testing to destruction and scaling, for which it is hard to get venture capital if the firm has not done the pre-work.

BBSRC can no longer fund spin-outs once they are technically a commercial body. BBSRC does have follow-on funding but only for non-commercial entities. Once a company is formed, it needs money to get to market quite quickly. The difficulty is that investors will not invest in rent and infrastructure. Under EIS rules, investors are actually prohibited from putting money into rent even if they want to.

This creates a funding gap within the commercialisation pipeline. Internal seed funds and incubators within universities are sometimes used during this stage, but the expert workshop attendees identified the potential for the government to support businesses in this stage.

The importance of intellectual property for SMEs

Key barriers to effective use of the IP system: skills, awareness and cost

- Given the importance of SMEs to the modern industrial biotechnology sector in the UK – they constitute some 94% of all enterprises (as per slide 19) – effective use by SMEs of IP assets is a key factor in the development of the industry.
- As suggested by Sukarmijan and Sapong (2014), and confirmed by the consulted stakeholders in this project, there are various barriers to wider and more effective use of the IP system by SMEs:
  - First, "low awareness of the system limits the exposure SMEs have to the IP system and their ability to use all the elements offered by the IP system effectively, including not just patents but also utility models, trademarks, industrial designs, trade secrets, patent databases, copyright and other IP rights (Saleh, 2008). In addition, poor IP management skills within SMEs reduce their ability to fully benefit from the system and, therefore, discourage its future use" (Sukarmijan and Sapong (2014).
  - "Secondly, limited access to the necessary human resources and/or accessible legal advice makes use of the IP system complicated and decreases the chances of success in the application process for registration/grant of IP rights. Efficient IP management requires an array of skills ranging from the legal to the scientific/technical and the commercial that not all SMEs have in-house. In fact, such expertise is generally lacking in many if not most SME support institutions; this is equally true of SME consultants and business advisors in the private sector" (Sukarmijan and Sapong (2014)).
  - "Thirdly, high costs, not just for acquiring and maintaining but also for monitoring and enforcing IP rights are an additional barrier, particularly for firms that are operating in a number of geographically dispersed markets" (Sukarmijan and Sapong (2014)).

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Cambridge Industrial Innovation Policy

UK business strength in modern industrial biotechnology

UK business strength in modern industrial biotechnology (1 of 5)

Top countries for number of biotechnology companies by sub-sector. Ranked by number of modern industrial biotechnology firms.

Data removed for publication

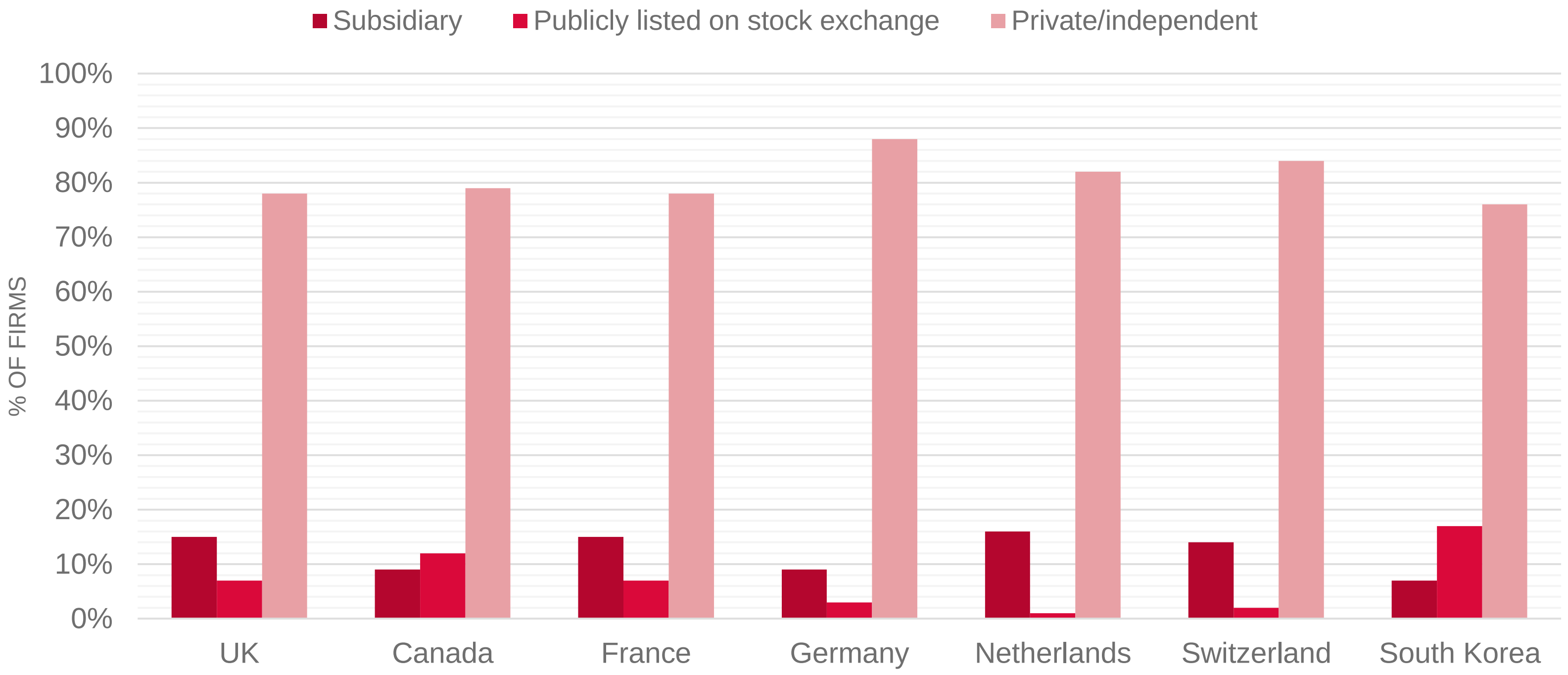
UK business strength in modern industrial biotechnology (2 of 5)

Share of firms by biotechnology sub-sectors for the modern industrial biotechnology category. Selected countries based on data availability.

Data removed for publication

UK business strength in modern industrial biotechnology (3 of 5)

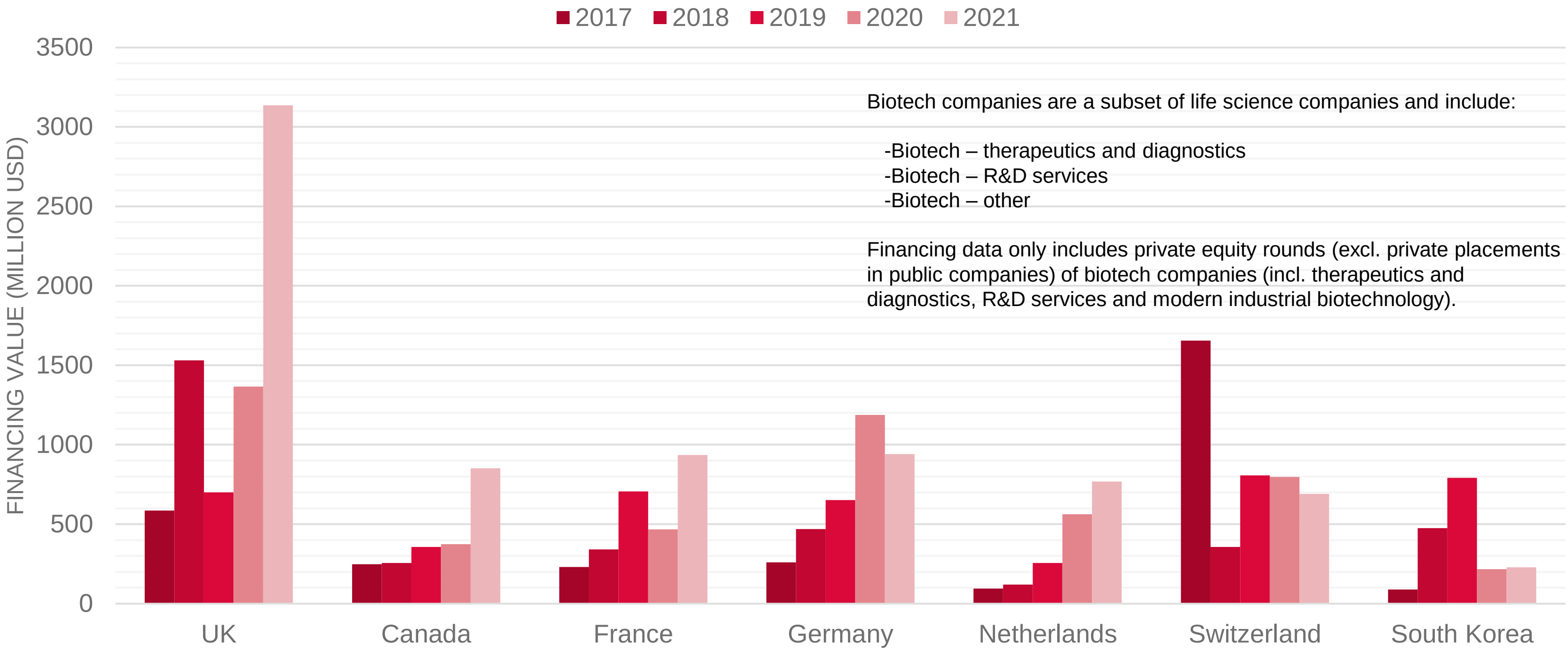
Share of firms by ownership type for the modern industrial biotechnology category (selected countries based on data availability)



Source: BiotechGate (2022). Life Science Trend Analysis. Accessed on October 2022.

UK business strength in modern industrial biotechnology (4 of 5)

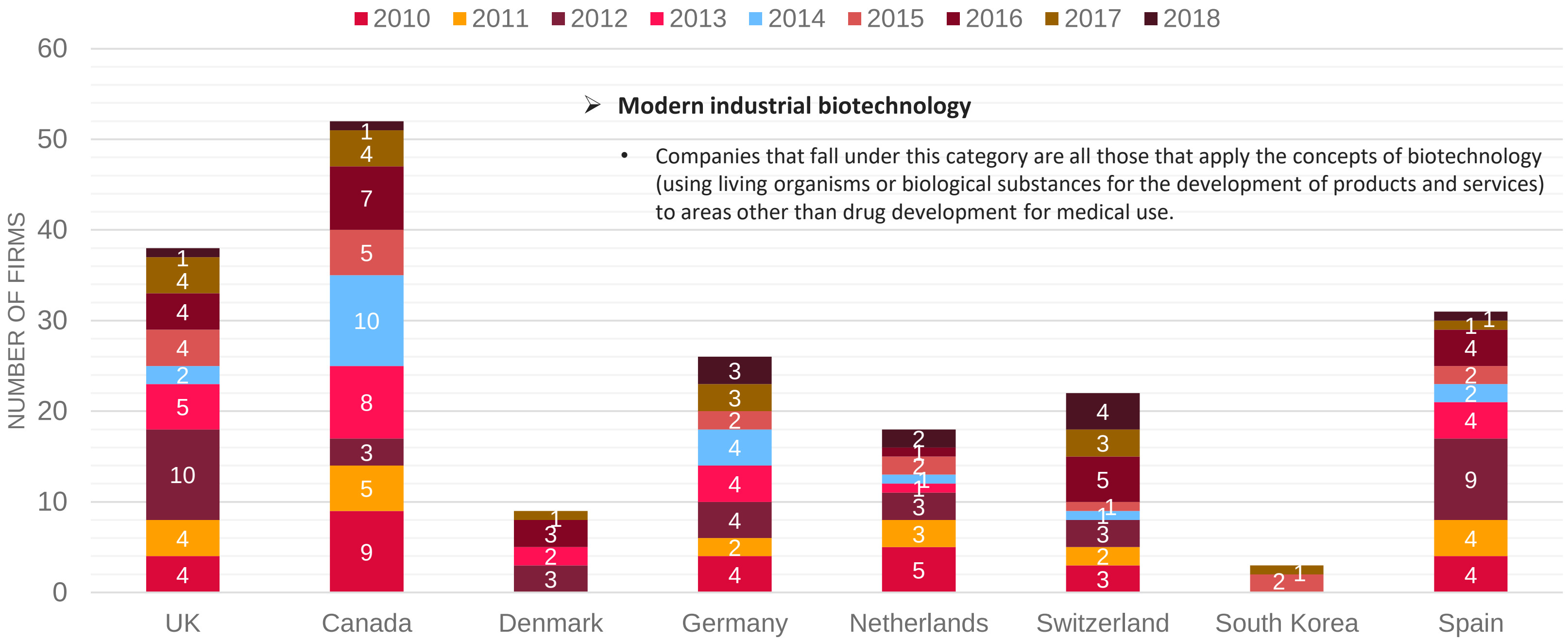
Biotechnology venture financing (private equity – 5-year report). All biotechnology sub-sectors included (selected countries based on data availability)



Source: BiotechGate (2022). Life Science Trend Analysis. Accessed on October 2022.

UK business strength in modern industrial biotechnology (5 of 5)

Number of biotechnology firms founded by year for the modern industrial biotechnology category (selected countries based on data availability)



➢ **Modern industrial biotechnology**

- Companies that fall under this category are all those that apply the concepts of biotechnology (using living organisms or biological substances for the development of products and services) to areas other than drug development for medical use.

Source: BiotechGate (2022). Life Science Trend Analysis. Accessed on October 2022.

Potential issues with VC reliance

- In giving evidence for the House of Lords enquiry, Mike Thompson, CEO of ABPI, suggested that*:*

  "Growing into a reasonable-sized pharmaceutical company is expected to take up to 20 years. Most venture capitalists want to cash out in six to eight years. There has been a gap in the funding available to have that long-term investment" (House of Lords, 2017). This may also apply in the field of modern industrial biotechnology.

- A shrinking venture capital market (as suggested in the Financial Times in August 2022) may negatively affect the UK's biotechnology pipeline. In 2011 NESTA produced a report on *Financing Industrial Biotechnology in the UK* (2011), which identified that:

  "The high degree of uncertainty and technical risk for these companies means they struggle for investment in a shrinking early-stage venture capital market."

- Overall, the experts consulted identified a **lack of deep or patient capital** to invest in start-ups beyond seed or series A funding. While the skills were available, there are perceived to be only one or two large funds investing in this space. Some participants suggested that BBB could play a role in setting up large funds.
- UKRI "investment partnerships" provide hybrid public–private investment in start-ups that are struggling to access private-sector investment. This takes the form of 70% grant and 30% equity and requires both technological and feasibility assessments.

Intrinsic limitations for the UK: product price and manufacturing scale

Low margins within industries that may purchase modern industrial biotechnology-derived products may limit investment

- A NESTA report in 2011 identified a key shortcoming that the industrial biotechnology sector may face in the UK context (NESTA, 2011), which is still relevant today:
    - "Despite advanced underlying techniques and science, **many of the fuels, chemicals and foodstuffs produced by industrial biotechnology sell for prices in the low single-digit dollars per kilogram**.
    - Typically at this level, to recoup R&D investments, this requires industrial plants manufacturing hundreds of thousands of tonnes of product per year.
    - The capital required to build and operate such plants is usually high (£75–150 million) and the time it takes to develop them to the point when they become commercial (around 4 to 8 years). This is too long for most UK investors, particularly venture capital (VC) funds.
    - This inhibits the development of UK IB companies in large-scale manufacturing processes and puts off international investors, who look for companies and markets with successful track records of growth."
- This was echoed more recent in McKinsey's (2020) report on bio-innovation:
    - "Many potential buyers of biology-based products are in **industries with low margins** such as energy and agriculture, and established products or methods of production have had years to develop ways to improve efficiency."
- While some areas of the UK, such as the North East of England, maintain experience in bulk chemical manufacturing, **over time much chemical manufacturing has moved internationally.** This trend is not unique to the UK and has also been seen in countries across the EU. This is primarily driven by profitability, and when it comes to biotechnology, both labour, feedstock availability and the cost of products derived from non-biotechnology methods may limit the cost competitiveness of the UK in bulk commodity markets with small margins.
- This is perhaps why many suggest that identifying **low-volume, high-value products** may present a better market for the UK to target and a rationale for many companies within the UK targeting health-related biotechnology applications.
- There are, of course, other considerations that may come into play, including **national security and domestic supply chains.** One of the largest producers of agricultural chemicals, Syngenta, is owned by Chinese state-owned enterprise.

4. Capturing value from UK modern industrial biotechnology

Life sciences beyond human health: modern industrial biotechnology in the UK

Policy levers – bioeconomic support measures and regulatory tools

In their study of the bioeconomy strategies of 40 countries, Dietz et al. (2018) created the following taxonomy of political support measures – split into both enabling and constraining (regulatory) governance

	Enabling governance		Regulatory mechanisms
I	**Promoting research and development for a bio-based transformation** -Funding of research projects -Establishment of specific research facilities -Promotion of research networks and strategic partnerships -Promotion of knowledge and technology transfer (science-praxis-nexus)	I	**State regulation of the bioeconomy**
II	**Improving the competitiveness of the bioeconomy through subsidies** -Quotas for the bioeconomy -Promotion of bio-based public procurement -Promotion of sustainable consumption behaviour -Tax benefits	II	**Governmental development of positive incentives** (e.g. payments for environmental services)
III	**Industrial location policies for bio-based industries** -Promotion of industry clusters in the field of bioeconomy -Promotion of knowledge and technology transfer between research and industry -Promotion of labour education in the field -Creation of appropriate intellectual property rights -Promotion of foreign direct investment (FDI) in the field	III	**Government support for private standards and certifications**
IV	**Political support for bio-based social change** -Promote public dialogue to increase understanding of the functioning of the bioeconomy -Promote public dialogue on technological risks in the field of bio-economics	IV	**International cooperation** (through international organisations and regimes)

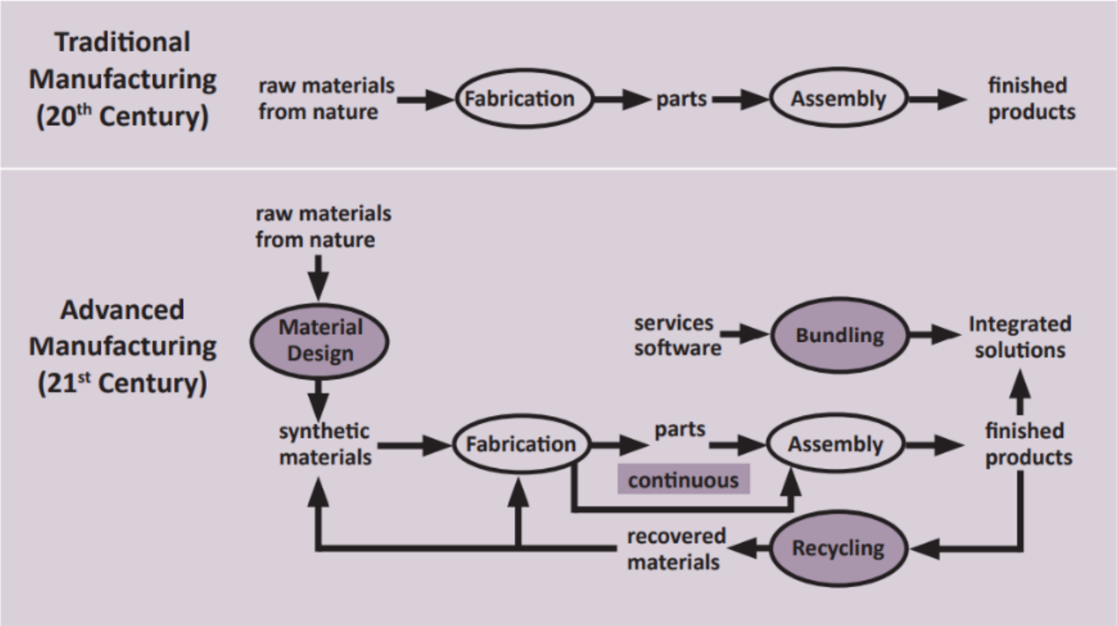
Value chains in modern industrial biotechnology (1 of 4)

Introduction to the concept of value chains

To what ends should these policy levers be applied? **Value chains** provide the framework for understanding, in a globalised world, **how parts of a production network are distributed**, where dependencies and vulnerabilities arise, and in which countries the high-value aspects of a production process fall.

Value chains (a broader but related concept to supply chains) have evolved significantly over the past 100 years, and they continue to develop rapidly with digitally enabled innovation in business models.

Industrial biotechnology value chains will likely involve new raw materials and an increasing focus on recycling and the circular economy.



Source: De Weck, O. and Reed, D. (2014). Trends in Advanced Manufacturing Technology Innovation. In: Locke, R. and Wellhausen, R. (eds). *Production in the Innovation Economy.* Boston: MIT Press, pp. 235–263. Extracted from Hauge & O'Sullivan (2019) Inside the Black Box of Manufacturing.

Value chains in modern industrial biotechnology (2 of 4)

How value chains can be used to identify priority areas for policy intervention, and why the UK cannot just do R&D

- Innovation drives up the level of value-added output per capita in the workforce, which in turn is the basis for improved wages and standards of living.
- Through engaging over eighty SMEs, the Engineering Biology Leadership Council found that many companies consider carrying out R&D in the UK but manufacturing abroad is ultimately the best option (EBLC, 2021).
- The consulted stakeholders mentioned that high rents in specific regions such as Cambridge lead manufacturers to cheaper areas of the country (or abroad) where staff are generally considered to be less skilled.
- From a UK standpoint this is of concern because significant amounts of revenue (and taxation) are derived from manufacturing and not from R&D (EBLC, 2021). Governments typically do not tax R&D – quite the opposite. The UK government offers tax credits for R&D conducted in the UK. On the other hand, company profits are taxed. Therefore, whether the company that derives profits has an office in the UK matters.
- There are also potentially (though not always) more people employed on the “marketing and retail” end of the value chain than in R&D and design. In 2020 R&D employed 283,000 people in the UK (ONS, 2021). In comparison, there were at least three times as many sales and marketing professionals, and around twice as many again in direct customer service roles (ONS 2018), excluding retail.
- There is also an open question as to whether a domestic manufacturing base is required to export “embodied services”. Some argue that for the value of many service industries to be exported and increase the wealth of a nation, these must be “embedded” within the value chains of physical exports.
- Some suggest that an alternative model is to undertake R&D in the UK and then license the technology to companies worldwide, providing a revenue stream back to the UK (EBLC, 2021). It should be noted, however, that this value is likely to be smaller and more localised to individuals or single companies than value added and jobs that are generated in later production stages. This, however, may be an appropriate approach for specific technologies in which the UK does not have the feedstocks or competitive advantage.
- The confluence of these factors contributes to the assessment that “real economic value comes not from funding start-ups but from enabling scale-up” (House of Lords, 2017).

Value chains in modern industrial biotechnology (3 of 4)

How value chains can be used to identify priority areas for policy intervention, and why the UK cannot just do R&D

- The value-added contribution within a value chain is not equally distributed through all steps of the production process.
- Traditionally, value added has been seen as higher at the early (e.g. R&D and design) and later stages (e.g. marketing and add-on services) than within the manufacturing portion of the supply chain.
- In modern manufacturing, these early- and late-stage functions have been enhanced, but there is also **potential for significant value added within high-value manufacturing** elements of value chains. This is particularly applicable when the process is difficult or capital costs are high.
- Note that the graph on the right represents value added per person, per hour. If more people are employed within the manufacturing or marketing and retail stages of production than in R&D and design, or they are employed for a longer period of time, both of which are likely, then the net value added of these segments in an economy may be higher.

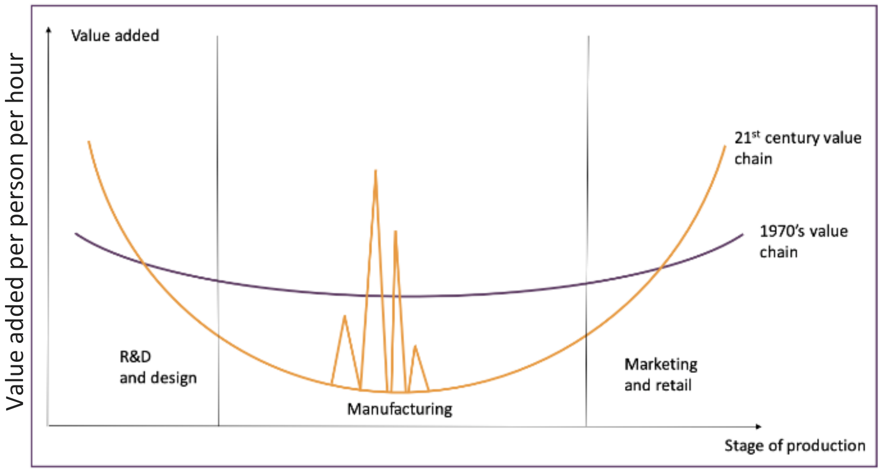


FIGURE 5: The growing smile of value chains (but with 'toothy' parts)

Image: extracted from Hauge & O'Sullivan (2019) Inside the Black Box of Manufacturing.

Value chains in modern industrial biotechnology (4 of 4)

What does this mean for the UK?

- Because the UK has a strong R&D base, it is clear that UK companies must be supported to capture value within the early (e.g. R&D and design) and later stages (e.g. marketing and add-on services). At the early stages, this includes a strong need to capture value through intellectual property, support for patenting and enabling conditions for spin-outs and scale-ups. This includes incentives to keep these innovative firms in the UK. IP should be used to capture value from products that cannot be manufactured locally.
- For manufacturing in biotechnology, products may be incorporated as inputs or materials into traditional value chains, or disruptive new products may be created. Biotechnology may be incorporated in products that have not typically used biotechnology, such as sustainable, low-carbon plastics produced using algae. Biotechnology may provide new services, such as ways to screen imported materials to ensure they are from sustainable and ethical sources.
- There may also be potential to produce high-value, low-volume products where feedstocks in the UK lend themselves to these processes.
- Many value chains in biotechnology, for high-volume products, will be determined by feedstock availability. Depending on the process, these feedstocks may be distributed (which may require production networks) or available on seasonal cycles (e.g. annual crop waste), presenting potential challenges to traditional business models.

For example, the value chain for cultured meat and seafood is significantly shorter than the breeding, feeding, slaughtering and processing of livestock, and activities of sampling and cultivation may be performed within a single company (McKinsey, 2020).

Case study: support from the US government for modern industrial biotechnology

There are interesting US examples of support for modern industrial biotechnology from work done by Baker (2017):

- "Among the leaders in this effort are the nation's biofoundries, including both public and academic efforts, such as Agile BioFoundry (DOE), the MIT-Broad Foundry (DARPA), and iBioFAB (University of Illinois)."
- "The DOE has set aside $5 million for companies to write proposals to obtain $500,000 to $2 million over 2 years for product development. Companies put in competitive proposals, as well as commit to a 30-percent in-kind cost-share toward labor costs, materials, or software."
- "The Advanced Biofuels and Bioproducts Process Demonstration Unit at the Berkeley Lab is a related effort, also funded by DOE. It's a competitive process where companies will apply for vouchers to be spent at the national labs. Companies can wholly fund R&D, or they can embed their scientists in the national labs. Companies can learn how the lab is developing its processes and can take all that learning and know-how back to their company."

UK Government support – early-stage R&D (1 of 4)

Key views on early-stage involvement from research councils and government research institutes from the consulted stakeholders and literature

Research councils

- The consulted stakeholders see the work of BBSRC positively, with strategic investment – although there are perceived gaps in funding between the remits of individual councils, and there is a need for mechanisms that utilise the interdisciplinary space of UKRI to work better within these interfaces in practice.
- BBSRC can no longer fund spin-outs once they are a commercial body (i.e. funding to continue to the end of the grant if a team becomes a commercial entity during an award). BBSRC does have follow-on funding but only for non-commercial entities. MRC has a "proof in confidence" fund for this sort of early-stage translation piece. This gap could be addressed through internal UKRI policy changes.
- Grants from respected agencies such as UKRI are seen to provide reputational and financial leverage, which can combine into a virtuous circle (NESTA, 2011).
- Regarding early-stage funding, the consulted stakeholders see that there could still be more coordinated funding in this space between research councils, particularly for cross-disciplinary or platform technologies and issues.
- It is argued that more could be done to join up UKRI and Innovate UK funding pathways.

Facilities

- "SMEs cannot afford expensive equipment – they need to get access to equipment and expertise" (EBLC, 2021).
- In 2013 BBSRC (acting as the coordinating partner for other research councils) funded a number of foundries around the UK – in Earlham, Edinburgh, Liverpool, London (Imperial College) (Synthetic Biology Leadership Council, 2019). There is some support for the idea of further, or expanded, government-supported biofoundries and scale-up facilities in the UK (Philip, 2021; EBLC, 2021).
- The Engineering Biology Leadership Council's report this year has recommended that the government "consider establishing a National Chemicals Biomanufacturing Institute" (Engineering Biology Leadership Council, 2022).

UK government support – early-stage R&D (2 of 4)

Key views on early-stage involvement from research councils and government research institutes from the consulted stakeholders and literature

Translation incentives for early-stage researchers

- "The UK is home to many scientific discoveries; however, there is a gap in research translation" (EBLC, 2021).
- There is seen to be a gap in funding for R&D that is close to government or policy-focused, which may not be supported by research councils, but is not always funded by government departments, historically because of decreasing departmental R&D budgets (HM Government, 2019).
- The UK's public research institutes do not necessarily have the experience, support or avenues for securing external funding outside grant funding or core budgets. Innovate UK does not necessarily fill this gap. There needs to be a mechanism for maximising the potential from UK public laboratories and research establishments. There are also often low or no incentives for the development and launch of start-ups at government research organisations.

UK government support – later-stage R&D (3 of 4)

Key views on later-stage innovation support from the consulted stakeholders and literature

Innovate UK

- The workshop participants expressed a perception that more funding for industrial biotechnology is needed through Innovate UK, while more efforts are also required to provide connected funding.
- There are some tensions in this, including at what stage companies benefit from external investment and whether companies that require continued grant funding are more likely to be non-competitive in the marketplace.
- Despite these concerns, the workshop participants expressed a clear call for increased investment in later-stage TRLs and translational research.
- The expert workshop participants identified that other countries are seen as easier for investors, or that support for and funding for scale-up and translation R&D were more generous in other countries.
- Some suggest that Innovate UK funding does not guarantee investment continuity because of the amounts of funding/capital needed from company partners.
- The consulted experts also indicated that even within Innovate UK funding schemes, there can be large gaps in costs for companies to fill – for Smart Grants, for example, funding is available for project costs of up to 50–70% for feasibility studies, or 25–45% for projects closer to market, depending on the organisation size.

ARIA

- The consulted experts expressed a perception of uncertainty regarding the potential impact of the newly formed ARIA, because of the limited budget size and competing priorities.
- More information would be needed to assess whether ARIA can catalyse significant change within industrial biotechnology in the UK alone.

UK government support – later-stage R&D (4 of 4)

Key views on later-stage innovation support from the consulted stakeholders and literature

Other funding

- Relative to early-stage equity funding, grant funding in the UK is seen as more abundant, easier to access, easier to manage and highly attractive because it is non-dilutive (NESTA, 2011).
- The UK Innovation & Science Seed Fund (UKI2S) is an early-stage investment fund for synthetic biology (one-third of the fund) and research out of UK government laboratories or catapults. This is backed by UKRI, Dstl, BEIS, UKAEA and other public bodies. UKI2S is managed by a private fund and has a portfolio of 57 companies. UKI2S was set up in 2002/03 with £4 million in funding from the UK government to help Public Sector Research Establishments (PSREs) exploit the commercial value of their research by filling a perceived gap in the provision of early-stage risk capital. Created with just £15 million of public capital, these companies have attracted over £500 million of later-stage investment and have a combined market value of over £750 million. The fund is positioned at the very earliest pre-seed and seed stages, earlier than venture capital funds, and it provides patient capital. Return on investment is high – for every £1 of investment from UKI2S there has been a return of £7 of GVA and £6 of R&D spend attributable to UKI2S (SQW, 2020).
- The cyclical nature of spending reviews has created issues in being able to sustain some quite successful programmes.

Tax credits

- The Venture Capital Trust (VCT) and Enterprise Investment Scheme (EIS) allow access to tax relief for individual investors in early-stage companies, up to £12 million in total, although this can be higher for R&D- intensive companies (HM Government, 2018).
- The Patent Box tax credit encourages IP commercialisation within the UK by allowing companies to access a lower rate of corporation tax (10% instead of 19%) for profits earned from patented inventions (HM Government, 2018).
- The R&D Expenditure Credit is a tax credit that large companies can access to work on R&D projects (13% of qualifying R&D expenditure) (HM Government, 2018).

Contributing to the SDGs using modern industrial biotechnology

Governments have the potential to use policy levers to promote uses of biotechnology that support progress towards the SDGs

In his 2019 *Nature Sustainability* paper, French gives examples of ways to harness synthetic biology to contribute towards the United Nation's Sustainable Development Goals (SDGs). These are reproduced and expanded upon below, together with other examples from the Synthetic Biology Leadership Council (2019), Engineering Biology Leadership Forum (2022) and UKRI (2021).

Innovate UK funding is supporting a large agrimanufacturing company with operations across Africa looking for innovative solutions to prevent crop damage caused by migrating birds.

UK company Oxitec engineered non-breeding mosquitos to arrest the spread of tropical diseases including Zika, Dengue Fever, Chikugunya and Yellow Fever.

A water filter made of wheat proteins and potato starch incorporates bacterial monoxygenases to remove benzene from contaminated wells after an oil spill.

UK company C3 Biotechnologies, is commercialising the world's first fermentation route to bio-propane using biomass propagated from bioengineered bacteria.

Colorifix to fix dyes to textiles, reduces water use by 90%, energy by at least 20% and dyes released by 99%, via a process that is significantly less toxic to the workers.

UK company Green Biologics uses engineered strains of Clostridia to ferment biofeedstocks, converting them at commercial scale to sustainable alternatives to petro-chemicals, such as 100% renewable n-butanol and acetone.

Biome Technologies has developed and supplies innovative biodegradable natural polymers that replace and enhance products previously made from oil-based materials.

Plants and microbes can be engineered to fix CO2 with increased efficiency. In addition, using photosynthetic organisms (plants/microbes) in manufacturing processes helps to reduce waste and carbon emissions.

UK company CustoMem has applied synthetic biology to develop absorbents that can remove persistent hazardous micropollutants from treated water.

Bacteria and plants are engineered to remove polyaromatic hydrocarbons and polychlorinated biphenyls from polluted land.

5. Regulation and innovation in UK modern industrial biotechnology

Life sciences beyond human health: modern industrial biotechnology in the UK

Risks associated with modern industrial biotechnology (1 of 2)

It is important for any approach to biotechnology to acknowledge and account for the risks involved

It is incredibly important, in any government approach to biotechnology, to be cognisant of the risks associated with these approaches, and to engage in good public dialogue, where risks are acknowledged and trust is built over time and supported by proportional regulation. It is estimated that up to 70% of the total potential impact of biotechnologies could hinge on consumer, societal and regulatory acceptance, based on an analysis of areas where regulations exist today in major economies (McKinsey, 2020).

Environmentally, many concerns are influenced by the complexity of ecosystems and the linked potential for unintended consequences, where clear parallels can be seen in the negative consequences of the introduction of non-native species into environments globally. Crops that are genetically engineered to be better adapted to certain conditions will more easily out-compete native species. This raises the risk of monoculture in an era that increasingly acknowledges the importance of biodiversity.

There are risks associated with biotechnology in both the health and non-health fields, but health applications have progressed along different paths. The potential benefits of applications of biotechnology in health and non-health fields are significantly different – compare, for example, saving lives with increasing crop yields – and the difference in the proportionality of risk versus reward influences differences in the discourse between these applications that must be acknowledged.

What does this mean for the UK government's actions within biotechnology regulation? The UK has very high awareness of biological risk (Dietz et al., 2018), which puts it in good stead to tackle these issues. There are some learnings from the GMO debate, the success of the Human Fertilisation and Embryology Authority (HFEA) and some parallels with current regulatory issues around AI, which should be explored further by the government in the context of non-human health biotechnology.

Risks associated with modern industrial biotechnology (2 of 2)

Examples of identified risks associated with biotechnology

Six key risks related to bioinnovation (McKinsey, 2020):

1. "Biology is self-replicating, is self-sustaining, and does not respect jurisdictional boundaries.
2. The interconnected nature of biology can increase the potential for unintended consequences.
3. Low barriers to entry open the door to potential misuse with potentially fatal consequences.
4. Differing value systems make it hard to forge a consensus, including on life-and-death issues.
5. Privacy and consent issues are fundamental.
6. Unequal access could perpetuate socioeconomic disparity, with potentially regressive effects."

Some examples of the key risks associated with biotechnology

- "The reduction of global biodiversity through the introduction of genetically modified organisms into the environment as crops, bioremediation tools or forms of bio-control" (French, 2019).
- The WHO (2022) identifies that "many countries do not have laws or regulations to govern biosecurity or biorisk management practices more broadly, and many scientific institutions (both public and private) lack biological risk management governance tools (instruments or apparatus) and mechanisms (a process, technique or system)".
- With increased digitisation and automation of biotechnology production processes and R&D, the need for cyber-biosecurity emerges (Philip, 2021).
- While biotechnology has the potential to eradicate disease vectors (such as mosquito carriers of malaria and Dengue), this could also disrupt local food chains in unforeseen ways (French, 2019).

Many risks are associated specifically with synthetic or engineering biology

In 2014 the EU Scientific Committee produced a report on the risk assessment of synthetic biology (EU Scientific Committee, 2014), which identified risks including:

"1) the integration of protocells into/with living organisms,
2) future developments of autonomous protocells,
3) the use of non-standard biochemical systems in living cells,
4) the increased speed of modifications by the new technologies for DNA synthesis and genome editing; and
5) the rapidly evolving DIYbio citizen science community, which may increase the probability of unintentional harm", as well as intentional harm, security and bioterrorism issues.

Regulation and innovation in modern industrial biotechnology

For many technologies, regulation will be a key mechanism by which government can manage the risks from biotechnology. The implications of regulation on innovation are complex: while disproportionate regulation may impede innovation, **regulation can also drive innovations**. In addition to regulation, there is also a role for **standards** and similar guidelines.

Innovation driven by regulation

There are a number of examples of innovation that are driven by regulation, and there is evidence that policy interventions can and do influence the renewable energy sector (Cross et al., 2021). The UK has had success in using policy to drive economic trends in related areas before, and the UK's approach to promoting biopower achieved a successful step change in generation (Cross et al., 2021). This regulation does not need to specify biotechnologies to employ them. For example, regulation controlling pollutant and contaminant levels in residual waste streams identifies a problem to be solved, which can be used to drive challenge-driven innovation in technologies for resource recovery (Resource Recovery from Waste, 2018).

Standards

There is much work underway in the regulation of biotechnology. In 2015 the British Standards Institution (BSI) published guidelines for the use of standards relating to synthetic biological systems (PAS 246). Released in 2019, ISO 35001 is a standard for bio risk management for laboratories that work with dangerous pathogens. The UK has strong standards institutions, and there is a potential international leadership role to be played in setting international standards if there is a strong knowledge base that has developed these domestically, in the British Standards Institution (BSI) first (EBLC, 2021).

Devolution

Current policy differences among devolved administrations have to be considered in any future discussions on biotechnology regulation in the UK. For example, the Scottish government has a long-standing opposition to the cultivation of GM crops in the open environment on the premise of protecting the clean and green branding of Scotland's food and drink sector (Dietz et al., 2018), while Northern Ireland is currently employing the EU's rules for the control and marketing of GMO post-Brexit (Defra, 2019).

Future regulatory discussion points

- Moving forward, there may be issues associated with "naturalness".
  - For example, acetic acid produced by fermentation is a "natural" product, while chemically synthesised but otherwise identical acetic acid requires designation in a product with an E number (i.e. the code for substances used as food additives).
  - A likely scenario when industrial biotechnology becomes more prominent is that products will be produced partly by "biological" processes and partly by "chemical" processes.
  - The question of how will these be classified is yet to be answered.
- Land use might be another source of future regulatory discussion, that is, what proportion of land (and fresh and sea water) is devoted to food production (food security), industrial production (industrial security), rewilding (environmental and biodiversity security) and urban development (housing security).

Case study: genetically modified crops

FIGURE 1. GLOBAL AREA OF BIOTECH CROPS, 1996 TO 2019 (MILLION HECTARES).

Image source: ISAAA, 2019

- The European Court of Justice has ruled that plants obtained by precise genome editing are to be classified as GMOs and have to be regulated as GMOs (European Commission, 2021). However, plants obtained by precision breeding cannot always be distinguished from those obtained by traditional breeding methods (Siksnys, 2021), presenting a challenge for regulation. At the time, the Synthetic Biology Leadership of the UK issued a statement including the position that "the impact of the ruling is entirely negative at a time of multiple threats to global food security" (Synthetic Biology Leadership Council, 2018). There is an opportunity for the UK to follow the US regulatory approach in this space, away from that of the EU, to gain market entry.
- A total of 29 countries planted 190 million hectares of biotech crops in 2019, and the top 5 countries by area were the USA, Brazil, Argentina, Canada and India (ISAAA, 2020). The US is the dominant player in this space, with 30% of the global market share (Turnbull et al., 2021), although developing nations account for 53% of all GM crops by area. As of 2021, the UK is still only conducting trials of genetically modified crops.
- The Synthetic Biology Leadership Council's statement (2019) proposed a regulatory system that:
    - is based on the properties of the final product rather than focusing primarily on the technique used to modify the organism;
    - considers and balances the potential benefits and risks of the product;
    - considers the risks of not developing the product;
    - is informed by scientific experience and understanding gained from the adoption of GM crops and animals worldwide since the original GMO regulations were put in place; and
    - reflects technological advances in the ability to measure and monitor the impact of new products in the field and marketplace.

Case study: cultured meat – UK regulatory framework

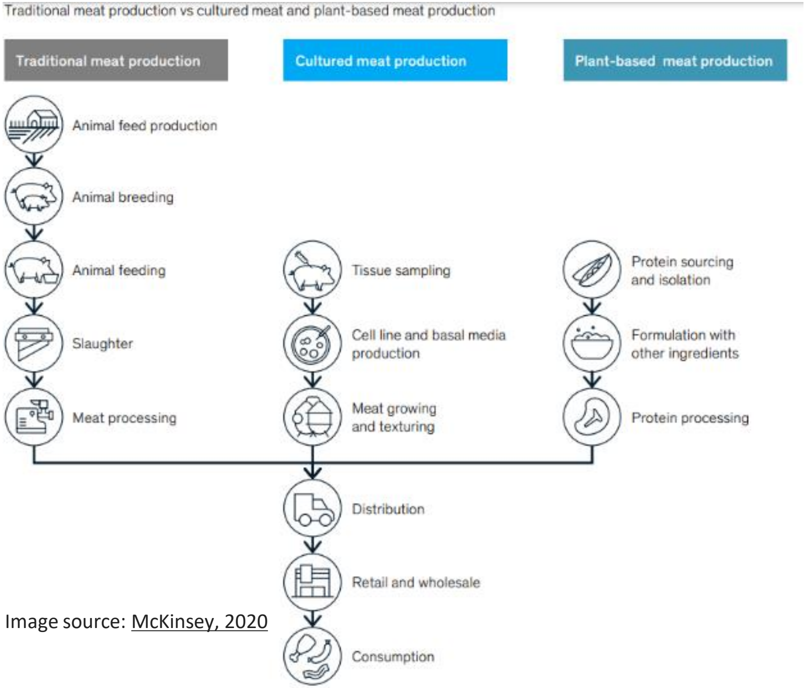


Image source: McKinsey, 2020

- "The agrifood sector is also a highly regulated sector, making the introduction of innovation not straightforward as it needs to comply with existing regulations" (European Commission, 2020).
- In the UK, "there is no distinct regulatory pathway for cell-cultured meat. For a cell-cultured meat product to be placed on the market, it would need to be authorised as a 'novel food'. The novel foods regime derives from EU law that has been retained in the UK post-Brexit" (Stevens & Bolton, 2022).
- Novel foods are those that have not been widely consumed by people in the UK or EU before May 1997.
- "In January 2022, the UK government published a policy paper called 'The Benefits of Brexit: How the UK is taking advantage of leaving the EU'. It sets out proposed reforms to regulatory systems in a number of different areas including industry, climate, health and infrastructure" (Stevens & Bolton, 2022).
- "The paper describes cultivated meats as a 'new and exciting area with significant innovation' and commits to creating a distinct regulatory framework for cultivated meats in the UK. However, there is not currently any detail on what this new regulatory framework will look like and when it will be introduced" (Stevens & Bolton, 2022).

6. Sectoral futures in UK modern industrial biotechnolgy

LIFE SCIENCES BEYOND HUMAN HEALTH: MODERN INDUSTRIAL BIOTECHNOLOGY IN THE UK

Sectoral futures in UK modern industrial biotechnology

- Biotechnology in general – and industrial biotechnology in particular – represents a key tool to resolve some of humanity's future challenges in a timely fashion and is a natural evolution of classical agricultural and plant and animal breeding practices to create goods that are useful for mankind (see figure on the right) without plundering fossil fuels and using bio-based feedstocks and biological rather than chemical methods for product development.
- Modern industrial biotechnology is one of the fastest-growing and most innovative areas of modern science combining biological, design, engineering and software disciplines to shape, improve and create entirely new products and systems de novo.
- This biological era represents one of humankind's great transformations, following on from the agrarian, industrial and digital revolutions, and will impact all aspects of human health and well-being, agriculture, food, the environment, bioenergy and "green" industrial processes.

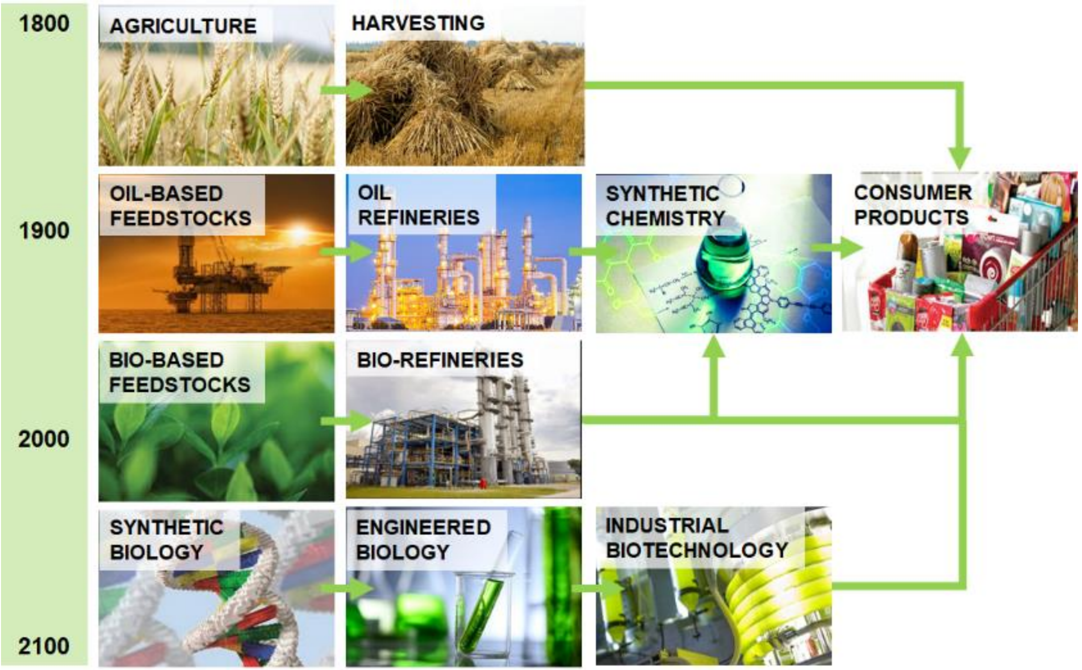


Fig.1 The evolution of modern industrial biotechnology
Source: Professor Chris Lowe OBE, FREng, FInstP, FRSC (2022)

The current landscape will influence future development

Path-dependency may lock in certain trends that are already emerging into the future

- **Lock-in effects of fossil fuels**. Dietz et al. identify that "many existing value chains are specialized in an efficient use of fossil-based resources and pre-biotechnological production processes […] Naturally, this leads to lock-in effects. […] current economic systems that have been shaped through the utilization of fossil-based resources and pre-bioeconomy production techniques are not yet able to provide the necessary incentives to leverage comprehensive bio-based transformations" (Dietz et al., 2018).
- **Certain sectors are already emerging within the UK's bioscience industry.** The consulted experts suggested that new industrial biotechnology start-ups in the UK are trending towards three major sectors – health, food and energy – encompassing sub-activities such as innovative foods, transportation, sustainability, agritech, wellness and beauty, and sports.
- **There will be specific international lessons for the adoption of industrial biotechnology in the UK**. For example, in 2019, the genetically modified crops with the highest acreage globally were: soybeans (48%), maize (32%), cotton (14%) and canola (5%). Other crops grown included alfalfa, sugar beets, sugarcane, papaya, safflower, potatoes, eggplant, squash, apple and pineapple (ISAAA, 2019). In 2020 the most popular crops grown in the UK were wheat, barley, canola (oilseed rape), maize, oats, field beans and sugar beets (Defra, 2020), indicating potential for overlap in crop types that may have demonstrated use-cases in other countries.
- **The capabilities of existing industries may influence development pathways.** For example, despite increased internationalisation of manufacturing (seen also in the EU), the UK is still around the 10th largest chemical producer in the world (Cefic, 2022). Three UK-headquartered companies made the top 50 largest chemical firms in 2021: Ineos was the largest UK company and the 4th largest company in the Global Top 50 Chemical Firms for 2021, while Linde came 9th and Johnson Matthey 32nd (C&EN, 2021).
- **Potential to over-promise**. Writing in 2015, Peterson and Krisjansen noted that "the process of technological innovation typically involves cycles of hype and disappointment", and that the industrial biotechnology industry is not immune to this. "History proves that it doesn't take too much for capital markets to lose faith in life science companies" (PWC, 2014).

Trends and drivers for modern industrial biotechnology

It is already being seen that wider societal and economic trends may drive focus areas for biotechnology innovation

- **Non-health biotech has significant room to grow.** In its 2020 report McKinsey estimated that more than half of the impact from applications of biotechnology will lie outside healthcare, with the most significant proportion of this in agriculture aquaculture, and food ($0.8–1.2 trillion USD globally 2030–40), followed by consumer products and services ($0.2–0.7 trillion USD globally 2030–40), and materials and energy production ($0.2–0.3 trillion USD globally 2030–40) (McKinsey, 2020).
- **Costs and the sustainability agenda will play a significant role.** One of the barriers to the development of biotechnology-based biofuels has been low petroleum costs, with manufacturers shifting to higher-value molecules and materials (Baker, 2017). If the price of petroleum increases significantly in the future, countries with a well-functioning biotechnology industry and circular economies may be well placed to capture this value. This may also be driven within-countries using pricing for environmental impacts (e.g. CO_2e).
- **National security may also be a factor.** This will be particularly relevant in the case of shortages or withholding of the supply of critical materials, for example, shortages of fertilisers. The UK needs to identify where the location of critical materials and confluence with political conflict have the potential to cause issues. In some instances, domestic development informed by biotechnology techniques may help to address these.
- **Governments can create a pull for modern industrial biotechnology.** Governments can use procurement as a driver of innovation. The US government, in particular, has a long history of mandating and incentivising US-manufactured or US-sourced materials in this way. Similarly, the UK could create targets for innovation content, or clean energy content, for government-procured items. There is already an established route for this for health biotech through NICE approvals, which will provide access to a revenue stream through use in the NHS.

Challenges that modern industrial biotechnology could address

There are particular economic, environmental and societal challenges that biotechnology may be well placed to address

Examples of economic, environmental and societal challenges that modern industrial biotechnology is well placed to address include the following:

- **Unsustainable use of fertilisers**, particularly nitrogen and phosphorous, will become an issue in the future, which biotechnology may assist in addressing – for example, through cereal crops that can access the nitrogen they need from the air, or through novel fertilisers that use microbiomes to affix nitrogen in the soil, rather than the current mineral options (Phillip, 2021).
- **The use of antibiotics in farmed animals**, such as salmon, may be avoided through vaccination programmes – which has already been demonstrated in Norway (Phillip, 2021).
- **Mitigation of climate change,** particularly in the areas of carbon capture and storage, and of low-carbon feedstocks and biodegradation of materials and chemicals.
- **Climate change will increase the risk of cross-species transmission of viruses** (Carlson et al., 2022), and biotechnology can support the detection, prevention and treatment of these. Biotechnology can support the detection, prevention and treatment of diseases within key crops and livestock, and within protected environments for key ecosystem services.
- Biotechnology may also have to react to correct for the risks associated with **unregulated use of scientific advancements in biotechnology.** This may include bioterror or unintentional harms, as skills and tools become more widely available.

Examples of potential challenge areas for synthetic biological materials, as identified by Scrutton and le Feuvre (2018), include:

- Corrosion-resistant materials.
- Bioelectronics and electro-genetic devices between electronic devices and biological systems.
- Optical materials – microsensors, optical sensors, light-energy conversion, optical plasmonic material.
- Self-healing materials (e.g. for touchscreens, if electricity-conducting).
- Biomolecular programmable robots (e.g. artificial muscle).
- Responsive materials (e.g. turbulent drag reduction, drug delivery).
- Feedstock engineering (e.g. bio-based production of monomers).

Potential avenues for the UK (1 of 4)

Areas of modern industrial biotechnology in which the UK may have competitive advantage

In addition to the areas of biotechnology already identified by UK regions in science and innovation audits, which should be supported, there are a number of broad areas in which the UK may have strengths and may be able to develop competitive advantage. This is not an exhaustive list, but it reflects the insights of experts consulted during the course of this work:

- **Agribiotech**
  - Global market estimated to grow from USD$49 billion in 2021 to USD$114 billion in 2030 (Research and Markets, 2022).
  - Agribiotech consistently arises as one of the key areas in which the UK can be world-leading and capture significant value.
  - Key UK strengths are seen to lie particularly in agriculture-related areas, including microbiology, plant sciences and crop research, and animal sciences, including animal diseases.
  - Sensors and detection systems will also be vital for fully automated field agriculture and both hydroponic and aeroponic horticulture. The UK has strengths in space and satellites, and applications in agriculture offer significant potential value.
- **Food and drink**
  - Bio-based flavours and fragrances represent a potential niche of low-volume, high-value products, with potential EU and US markets. The European Commission estimates that the global market will grow from €20 billion in 2020 to €29 billion by 2026, with a roughly 7% market share for biotech and stronger-than-average growth in this sub-sector (EU Commission, 2020).
- **Commercial genomics for well-being**
  - Applications include direct-to-consumer (DTC) genetic testing, beauty and personal care based on microbiomes, and innovative approaches to wellness and fitness in humans. In some instances, these could also be applied in pets.
  - The global genomics market is projected to grow from USD$27.81 billion in 2021 to USD$94.65 billion in 2028 at CAGR of 19.4% in the forecast period, 2021–28 (Fortune Business Insights, 2022).
- **Animal health**
  - There is a strength in zoonoses, but experts have identified a lack of animal-vaccine-manufacturing facilities in UK, despite previous strengths in this area. This is identified as a weakness in the potential to exploit UK R&D innovation in this space.
  - The global animal biotechnology market size was valued at USD$22.66 billion in 2021 and is expected to expand at a compound annual growth rate (CAGR) of 9.2% from 2022 to 2030 (Grand View Research, 2022).
- **Underpinning technologies and platforms**
  - The UK has key strengths in the platforms, the detection methods and the technologies (e.g. sequencing) that underpin advances in this field. For example, the UK is well organised in high-throughput sequencing, longitudinal cohorts and population genetics. Gene editing is also a research strength.
  - Robotics is an area of UK advantage – Bristol is one of the best places for this in Europe – and there are many potential applications, alongside AI and ML approaches, to optimisation and fast iterative design in biotechnology.

The key insight to be gained in this is the importance of breaking biotechnology opportunities down to the sectoral level, as there are significant differences in commercialisation pathways and potential based on end-use.

Potential avenues for the UK (2 of 4)

Key opportunity areas that the UK could address to support modern industrial biotechnology

- **The UK has supported industrial biotechnology in a number of forms over the past 10 years, and essentially it has got in at the start of the curve. This places the UK in an advantageous position from an R&D point of view**. This support has diminished somewhat in the last 5 years, but the opportunity could still be captured.
- One **key area** that could lead to greater success in modern industrial biotechnology in the UK is perceived to lie in the **translation from R&D to commercialisation**. There are twofold issues with not having good scale-up capacity: that inventions will not get scaled up; and also that good companies will leave for more favourable funding or regulatory environments.
- **The UK will need to understand how to capture domestic value from a strong R&D base within a globalised economy**. What this looks like is uncertain. It is likely to involve a combination of IP licensing, strengthening of domestic manufacturing, attracting and growing the HQ of highly innovative companies located in the UK, and understanding the implications for reinvestment and employment if these are acquired by multinationals.
- Capturing of value in modern industrial biotechnology will almost certainly require an **increased volume of patenting** by UK academics, and strategies should be explored to promote this. This may include consideration of a number of incentives that may be connected to funding and promotion within and across UK universities, but also in the technology-transfer offices of universities, the availability of funding or loans for patenting, good examples in this space such as SynbiCITE of Imperial College, and how these can be replicated across the UK.
- **Anecdotally, scale-up facilities in the UK are limited, expensive or not fit for some purposes**. The UK could look to what is being offered by other countries in the scale-up space and whether this represents a threat to the UK ecosystem. There should be a particular focus on Denmark, the Netherlands, Belgium and the US (including national labs).
- **There is a call for clear, long-term support for the sector**. The non-health life sciences sector is seen as having low cross-departmental priority, visibility and understanding. This should exist as a non-partisan issue, about supporting excellence within the UK. Creating a narrative as to why the UK is the best place to invest will require government support and a strong and consistent narrative. This may include active government movement to attract foreign investments (e.g. A*STAR in Singapore).
- One of the key messages arising from the experts within the workshop is that while there is undoubtedly fantastic science in institutions and universities, there is a **need to identify and target where the markets for bioscience are in which the UK has competitive advantage** and could capture value.

Potential avenues for the UK (3 of 4)

Key decision areas in modern industrial biotechnology development, which will require nuanced and balanced solutions

Applied versus basic research

- An increased focus on application-driven biotechnology research could lead to a risk of diminishing funding support for curiosity-driven bioscience, which is currently a strength and will likely provide the basis for future bioscience innovations, highlighting the need to consider a balanced approach to funding of applied and basic research (Ishino et al., 2018).

Skills

- Into the future, the non-health life sciences will be in competition with human health biotechnology and other industries for key STEM skills and highly skilled workers.
- This particularly speaks to the UK economy-wide issue with technician shortages, which T-levels aim to address.

Soil, agriculture, conservation and biodiversity

- There are tensions between the increased need for feedstocks for biotechnology processes and the trends towards increased rewilding and protection of areas (including marine areas) for the preservation of biodiversity and environmental protection.
- Soil is a key resource, and it is important to understand the tensions between land use for materials and chemicals when this is in direct competition with human food. This lesson, learned from biofuel production in the 1990s, means that many modern biotechnology processes are focusing on the utilisation of waste streams.
- In the nascent bioeconomy, plants grown at agricultural scale will provide food and essential nutrients for humans and animals, fuels, fibres, medicines, dyes, perfumes, oils, gums and resins, building materials, pesticides and compost. However, more than 75% of the earths ice-free land is degraded (EC's World Atlas of Desertification), with agriculture being one of the major contributors to soil erosion. Furthermore, 77% of the earth's agricultural land is used for raising animals, even though this supplies only 18% of our food. It is estimated that switching even half the world's population to plant-based meat products would avoid almost 70 gigatonnes of greenhouse-gas emissions.
- Modern industrial agriculture is a volumetric game limited solely by the deficit in soil fertility and, while producing meat, eggs and dairy products from plant-based sources could shrink the ecological footprint of our food supply by an order of magnitude and free land for other industrial purposes, this has to be achieved by restoring soil fertility. Thus, new farming practices that increase soil fertility, water retention and carbon sequestration are essential.
- A key policy issue for the UK would be to determine what proportion of its agricultural land should be devoted to:
    - the food supply of conventional meat/dairy products versus plant-based protein-rich alternatives, such as peas, beans, pulses and legumes, using fertiliser-free procedures;
    - urban and renewable energy development, including on-shore solar farms;
    - reforesting and rewilding to preserve valuable biodiversity; and
    - industrial crops with higher margins designed to reduce the fossil economy.
- This change in farming practices will require recovery techniques for phosphate residues and techniques to reduce or eliminate the dependence on chemical inputs such as herbicides, pesticides and fungicides. Continuous application of these inputs depletes the soil's inherent biological, chemical and structural fertility by disturbing the soil microbiome, disrupting the nutrient cycle and decreasing water-retention capacity.

Potential avenues for the UK (4 of 4)

Key decision areas in modern industrial biotechnology development, which will require nuanced and balanced solutions

Government versus commercial scale-up facilities

- Consulted experts suggested that because of the lack of domestic resources, scale-up facilities in other countries are being used by UK firms. These are often commercially operated facilities. The question as to why the UK does not have the capacity and scale needed could be further explored. It may be the case that demand may not yet be high enough to ensure that scale-up is sustained, and if this is the case, this may be the key point in the produce life cycle when government investment is needed.

Clusters versus distribution

- The success of the "golden triangle", and its perception as a "low-risk place to do high-risk science", gives a clear branding for inward investment. There is clear value in attempting to enhance existing clusters when it comes to R&D, including infrastructural ones. However, there are already tensions in clusters regarding land availability, lab and office space and affordable housing. While the enhancement of clusters should be balanced with place-based considerations, it is worth noting that many biotechnology feedstocks will be distributed across agricultural land and manufacturing regions, and it is likely that these will require dispersed networks for production, which may have positive effects in local areas outside R&D clusters.

Successful acquisition versus domestic capability

- It is seen to be "too easy for innovative biotech to be bought out by non-UK companies and taken overseas" because of a lack of local VC funding. It is argued that increased IPO exits would enhance the domestic base; however, most exits in industrial biotechnology are mergers or acquisitions. What represents success for an individual company (e.g. a start-up being acquired by a multinational) may not be seen as a national benefit. What can the UK do to influence this, and to promote the retention of jobs and skills development within the UK, even when companies are acquired by multinationals?

Bioeconomic transformation pathways

Developed by Dietz et al. (2018), bioeconomic transformation can proceed along one or more of four paths. Note: while this is broader than the focus on biotechnology used in this report, the pathways are still instructive as future scenarios for policy-making

Transformation path 1

Price-triggered transformation

- Transformation is triggered by temporarily increased oil prices, subsidies and environmental policies. For example, biofuel policies in the EU and US have led to increased demand for bioenergy, with direct and indirect effects on land use worldwide.
- These effects vary by country depending on land availability and the effectiveness of environmental and economic governance systems.

Transformation path 2

Increasing productivity-triggered transformation

- If technological innovation increases productivity in agriculture, forestry or fishing, it can open up new production methods or locations.
- In the past this has repeatedly led to an easing in food markets despite increasing population growth.
- However, regional and local boosts in agricultural productivity have also been shown to increase demand for land in ecologically sensitive biomes, leading to losses in globally valued ecosystem services.

Transformation path 3

Supply-triggered transformation

- Innovation in downstream sectors often aims to increase the efficiency of biomass use and waste stream recycling.
- Such innovation can be associated with “rebound effects”, that is, increased demand due to improved provision.
- In the long term, however, the impact depends on supply dynamics, consumer behaviour and the regulatory environment.

Transformation path 4

Technology-triggered transformation

- Biological principles and processes can be used in industrial applications, as in the case of enzymatic synthesis and “biomimicry”.
- Many countries with bioeconomic ambitions have high expectations for this knowledge- and technology-intensive approach.
- Corresponding transformative processes result from providing cheaper and more environmentally friendly production methods or completely new products.

Appendix. Statistical definitions

LIFE SCIENCES BEYOND HUMAN HEALTH: MODERN INDUSTRIAL BIOTECHNOLOGY IN THE UK

Statistical definitions (1 of 11)

Definitions of the available sectors and subsectors from the BiotechGate database

Biotech companies

- **Biotechnology therapeutics and diagnostics**

  Companies categorised as biotechnology – therapeutics and diagnostics are those whose core business is the application of biotechnology to the discovery and development of novel therapeutic compounds and probe molecules for applications in medicine.

  - **Antibodies:** companies whose primary research area is the production of antibodies for therapeutic and/or diagnostic purposes.
  - **Antibody-drug conjugates:** companies whose primary research area is the development of antibodies linked to a biologically active cytotoxic payload or drug.
  - **Anti-infectives:** companies whose primary research area is anti-infective compounds such as antibiotics.
  - **Biosimilars:** companies whose primary research area is biosimilars, also called follow-on biologics, which are officially approved new versions of existing biopharmaceutical products.
  - **Cell therapy:** companies that specialise in the replacement of diseased cells and tissues with a healthy cellular material.
  - **Drug delivery:** companies that specialise in developing compounds that deliver or improve the delivery of medicines to targeted areas in the body.
  - **Gene therapy:** companies that specialise in the treatment of a disease by introducing a new gene into a cell through the use of recombinant DNA technology. The new gene may be used to replace a function that is missing because of a defective gene or to treat a genetic disorder.
  - **Generics:** companies whose primary research area is generic medicines, which are drugs that are chemically equivalent to a particular medicine, innovated by another company, on which the patent has since expired.
  - **Immunotherapy:** companies developing drugs to treat a disease by activating or suppressing the immune system.
  - **Microbiome:** companies active in the development of therapies related to a microbiota (the entire collection of microorganisms in a specific niche, such as the human gut).
  - **Molecular diagnostics:** companies developing new probe molecules whose focus is the discovery and validation of molecules for detection and analysis purposes (e.g. biomarkers), rather than the invention of new medical devices.
  - **Natural compounds:** companies using substances produced by a living organism that is found in nature. Natural products can also be prepared by chemical synthesis and can include cannabinoids and traditional Chinese medicine (TCM) products if clinical trials and standard regulatory pathways apply.
  - **Nucleic acid drugs:** companies that specialise in developing nucleic acids that act as drugs for inhibiting gene expression or protein synthesis.
  - **Peptides:** companies that specialise in developing peptide-based drugs.
  - **Proteins:** companies that specialise in developing protein-based drugs.
  - **Small molecules:** companies that specialise in developing small molecule compounds.
  - **Stem cells:** companies that specialise in the use of stem cells as a therapeutic or to repair specific tissues or to grow organs.
  - **Vaccines:** companies whose primary research area is the development of vaccines either for disease therapy or prevention.
  - **Other:** therapeutic biotechnology companies specialised in an area not mentioned above.

Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

Statistical definitions (2 of 11)

Definitions of the available sectors and subsectors from the BiotechGate database

Biotech companies

- **Biotechnology – R&D services**

  Companies that fall under the biotechnology – R&D services category are those that provide support services such as product development services, analytical services, screening, contract manufacturing and contract R&D to the biotechnology industry.

  - **Analytical services:** companies that provide analytical services, for example, spectroscopy, chromatography, pharmacodynamic assessments or environmental analysis.
  - **Biochips:** companies that produce biochips for other companies to use in their development process.
  - **Bioelectronics:** companies that develop information processing systems and devices based on biological materials, for other companies to use in their development process.
  - **Bioinformatics:** companies that provide bioinformatics services such as the analysis of biological information using computers and statistical techniques.
  - **Cell culture:** companies that culture cells for other companies to use in their development process.
  - **CMO (contract manufacturing organisation):** companies that take over the manufacturing responsibilities for another company.
  - **CRO (contract research organisation):** companies that conduct research for other companies on a contract basis.
  - **Diagnostic instrumentation:** companies that develop diagnostic tests and kits but do not develop new diagnostic molecules.
  - **Diagnostic services:** companies that carry out diagnostic tests for other companies.
  - **Drug delivery:** companies that research and develop methods of drug delivery for other companies.
  - **Fill and finish:** companies that provide fill and finish services.
  - **Genomics:** companies that study and define nucleotide sequences, including genes, regulatory sequences and non-coding DNA segments, for other companies; also, companies running gene banks.
  - **Proteomics:** companies that identify and modify proteins, for other companies to use in their development process; also, companies running antibody and other protein banks.
  - **Screening:** companies that screen potential therapeutic compounds for other companies by performing various test and assays.
  - **Synthesis services:** companies that synthesise molecules for other companies.
  - **Other:** companies that provide other support services to biotechnology companies.

Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

Statistical definitions (3 of 11)

Definitions of the available sectors and subsectors from the BiotechGate database

Biotech companies

- **Modern industrial biotechnology**

  Companies that fall under the modern industrial biotechnology category are all those that apply the concepts of biotechnology (using living organisms or biological substances for the development of products and services) to areas other than drug development for medical use. Examples of areas covered under this category are agrobio companies, cosmetics companies, environmental companies, food technology companies, industrial biotechnology companies, nutraceutical companies and veterinary companies.

  - **AgBio:** companies that apply the principles of biotechnology to agricultural uses such as the production of pesticides or the extension of fruit and vegetables' shelf life.
  - **Cosmetics:** companies that apply the principles of biotechnology to the production of cosmetics.
  - **Environmental:** companies that apply the principles of biotechnology to the protection and restoration of the environment through processes such as wastewater treatment and clean energy production.
  - **Food:** companies that apply the principles of biotechnology to the production and processing of food.
  - **Industrial biotechnology:** companies that apply the principles of biotechnology to industrial processes, for example, using biomolecules instead of chemicals.
  - **Nutraceuticals:** companies that develop natural products for a therapeutic purpose.
  - **Veterinary:** companies whose primary product area is centred on the diagnosis and treatment of diseases and injuries of animals, particularly domestic animals.
  - **Other:** companies that apply the principles of biotechnology in an area not mentioned above that does not involve therapeutic medicine or the provision of a service.

Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

Statistical definitions (4 of 11)

Definitions of the available sectors and subsectors from the BiotechGate database

Pharma (fully integrated)

Fully integrated pharma companies are commercial enterprises that research, develop, produce and sell drugs and other medicines. In today's economy these enterprises are usually large companies that deal both in branded and generic compounds and rely, at least partially, on smaller biotechnology companies for in-licensing of novel compounds for their pipelines.

- **Antibodies:** companies whose primary product area is the production of antibodies for therapeutic and/or diagnostic purposes.
- **Antibody-drug conjugates:** companies whose primary research area is the development of antibodies linked to a biologically active cytotoxic payload or drug.
- **Anti-infectives:** companies whose primary product area is anti-infective compounds such as antibiotics.
- **Biosimilars:** companies whose primary product area is biosimilars, also called follow-on biologics, which are officially approved new versions of existing biopharmaceutical products.
- **Cell therapy:** companies that specialise in the replacement of diseased cells and tissues with a healthy cellular material.
- **Drug delivery:** companies that specialise in developing compounds that deliver or improve the delivery of medicines to targeted areas in the body.
- **Gene therapy:** companies that specialise in the treatment of a disease by introducing a new gene into a cell through the use of recombinant DNA technology. The new gene may be used to replace a function that is missing because of a defective gene or to treat a genetic disorder.
- **Generics:** companies whose primary product area is generic medicines, which are drugs that are chemically equivalent to a particular medicine, innovated by another company, on which the patent has since expired.
- **Immunotherapy:** companies developing drugs to treat a disease by activating or suppressing the immune system.
- **Microbiome:** companies active in the development of therapies related to a microbiota (the entire collection of microorganisms in a specific niche, such as the human gut).
- **Molecular diagnostics:** companies developing new probe molecules whose focus is the discovery and validation of molecules for detection and analysis purposes (e.g. biomarkers), rather than the invention of new medical devices.
- **Natural compounds:** companies using substances produced by a living organism that is found in nature. Natural products can also be prepared by chemical synthesis and can include cannabinoids and traditional Chinese medicine (TCM) products if clinical trials and standard regulatory pathways apply.
- **Nucleic acid drugs:** companies that specialise in developing nucleic acids that act as drugs for inhibiting gene expression or protein synthesis.
- **Peptides:** companies that specialise in developing peptide based drugs.
- **Proteins:** companies that specialise in developing protein-based drugs.
- **Small molecules:** companies that specialise in developing small molecule compounds.
- **Stem cells:** companies that specialise in the use of stem cells as a therapeutic or to repair specific tissues or to grow organs.
- **Vaccines:** companies whose primary activity is the development of vaccines either for disease therapy or prevention.
- **Other:** pharmaceutical companies specialised in an area not mentioned above.

Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

Statistical definitions (5 of 11)

Definitions of the available sectors and subsectors from the BiotechGate database

Medical technology

Medical technology companies are involved in research, development, production and marketing of systems and devices for medical applications (i.e. to treat or diagnose diseases or medical conditions) in humans and animals.

- **Active implantable devices:** companies whose primary area of research is medical devices invented to be introduced into the human body and which remain there after the procedure that rely for their functioning on a source of electrical energy or any source of power other than that directly generated by the human body or gravity, for example, cardiac pacemakers, cochlear implants, nerve stimulators.
- **Anaesthetic and respiratory devices:** companies whose primary area of research is anaesthetic and respiratory devices, for example, oxygen masks, anaesthetic vaporisers, nebulisers or inhalers.
- **Biomaterials:** companies whose primary area of research is substances that have been engineered to interact with biological systems for a medical purpose.
- **Coatings:** companies that produce coatings for medication or devices.
- **Delivery devices:** companies whose primary area of research is devices for the delivery of therapeutics to target areas of the body, for example, vaginal rings, syringes or infusion pumps.
- **Dental devices:** companies whose primary area of research is devices intended to treat or reconstruct dental tissue, for example, reusable dental instruments, implants.
- **Diagnostic and therapeutic radiation devices:** companies that produce medical devices that utilise radiation.
- **Diagnostic devices:** companies whose primary area of research is non-radiation devices intended for use in the diagnosis of disease or other conditions; the category excludes molecular diagnostics.
- **Electro-mechanical medical devices:** companies whose primary area of research is electro-mechanical medical devices.
- **Hospital hardware:** companies that engineer and produce hospital hardware, for example, hospital beds, cubicles, examination/operation tables.
- **Imaging:** companies whose primary area of research is technologies for the visualisation of body parts, tissues or organs, for use in clinical diagnosis, treatment and disease monitoring.
- **Non-active implantable devices:** companies whose primary area of research is devices invented to be introduced into the human body and stay there after the procedure that must not have an integral power source, for example, coronary stents or joint replacements.
- **Ophthalmic and optical devices:** companies that develop and produce devices for diagnosis and treatment for eye disorders, for example, glasses, contact lenses, intraocular lenses, implants, lasers or ophthalmology surgical instruments.
- **Regenerative medicine:** companies whose primary area of research is devices applied in the process of replacing, engineering or regenerating human cells, tissues or organs to restore or establish normal function, for example, devices for stem cell administration.
- **Reusable instruments:** companies that produce reusable instruments for medical use, for example, surgical instruments.
- **Single-use devices:** companies whose primary area of research is single-use medical devices, for example, needles, syringes, applicators, catheters.
- **Technical aids for disabled persons:** companies that produce technical aids for disabled persons such as prostheses, hearing aids, colostomy bags or orthoses.
- **Wound care:** companies whose primary area of research is devices for wound care such as dressings or fasteners.
- **Other:** companies that engineer and produce other medical devices.

Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

Statistical definitions (6 of 11)

Definitions of the available sectors and subsectors from the BiotechGate database

Digital health

Companies in this category provide healthcare services or products based on information and communications technologies.

- **Artificial intelligence (AI):** digital health companies that are applying artificial intelligence to their products or services.
- **Doctor networks:** companies providing online communication platforms for physicians.
- **Electronic medical record/electronic health record:** companies providing software products that support physicians and medical practices, including electronic claims management engines.
- **Health and wellness (IoT):** companies developing health-related devices that can connect and exchange data with other devices, such as personal fitness wearables.
- **Health services search:** companies providing information on health services' locations and offerings.
- **Healthcare mobile communication:** companies providing mobile marketing and communication tools for the healthcare sector.
- **Medical big data and analytics:** companies involved in the gathering, storage and exploitation of medical big data.
- **Mobile fitness/health apps:** companies providing mobile fitness and health apps.
- **Online health communities:** communities and forums focused on health education.
- **Patient engagement:** companies offering patient self-management solutions.
- **Payments and insurance:** companies engaged in health-related online financial services.
- **Population health management:** organisations involved in corporate wellness and public health initiatives.
- **Remote monitoring:** companies that provide technologies for monitoring patients outside conventional clinical settings, for example, blood pressure monitors, cardiac monitors, data-storing glucometers and digital weighing scales.
- **Telehealth:** companies providing health-related consultations via telecommunications.
- **Predictive analytics:** companies providing health-related analytical services, including clinical decision support, readmission prevention, adverse event avoidance, chronic disease management and patient matching.
- **Other:** other digital health companies, not covered by any of the categories above.

Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

Statistical definitions (7 of 11)

Definitions of the available sectors and subsectors from the BiotechGate database

Investors

The investor category includes all types of financing sources for life sciences companies. This includes bank funds, public funds, venture capital funds, business angels, corporate investors, institutional investors, private investors, family offices and foundations.

- **Bank fund:** an investment fund owned by a bank.
- **Business angel:** a private investor who invests directly in entrepreneurial companies for equity and provides both finance and business expertise.
- **Corporate investor:** a company that invests in and acquires control of other companies.
- **Foundation:** an organisation supporting newly created companies through financing/grants and possibly in kind as well.
- **Institutional investor:** a financial institution such as a bank, mutual fund, insurance company or pension fund that purchases securities in large quantities.
- **Leasing:** companies providing financing through leasing for equipment and other assets.
- **Private investor/family offices:** an individual or a private investment company, usually held by a wealthy family, that makes a private investment directly into a company.
- **Public fund:** a publicly listed investment fund.
- **Venture capital fund:** a special form of private equity fund, established in the form of a trust or a company, which focuses its investments on companies that are in their early stages of growth.
- **Other:** other potential sources of financing for life sciences companies.

Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

Statistical definitions (8 of 11)

Definitions of the available sectors and subsectors from the BiotechGate database

Other life-sciences-related companies

- **Professional services and consulting**

  Companies in this category provide consulting and services to the life sciences sector in areas such as deal arrangement, event organisation, finance, marketing, law, sales, translation, valuation and others.

  - **Business development:** companies that provide consulting and services in the area of business development; such as finding and assisting with licensing deals.
  - **Communication and PR/IR:** companies that provide consulting and services in the area of communication and public relations, such as writing press releases and handling investor relations.
  - **Deal arranger:** companies that aid in deal arrangement between other companies.
  - **Drug development consulting:** companies that provide services and consulting in the area of drug development, regulatory and clinical affairs.
  - **Due diligence:** companies that perform due diligence for other companies.
  - **Event organisation:** companies that organise events for other companies.
  - **Financial services:** companies providing fundraising and financial consulting services.
  - **Human resources services:** companies that manage human resources duties such as hiring for other companies.
  - **Information provider:** companies that research and provide relevant information to other companies.
  - **IT services:** companies that provide IT services for other companies.
  - **Legal services:** companies that provide legal services and advice to other companies on various matters such as contracts, lawsuits and insurance.
  - **Management consulting:** companies that provide management consulting to other companies in various areas such as strategy and value chain management.
  - **Market access:** companies that provide services to facilitate market entry into specific markets.
  - **Market research:** companies that provide market research services.
  - **Operations/health and safety/purchasing:** companies that provide services in the areas of operations, health and safety, as well as purchasing.
  - **Patents and trademarks:** companies that provide services and consulting in the area of patents and trademarks.
  - **Property management/real estate:** companies that manage the property and real estate of other companies.
  - **Regulatory affairs:** companies providing consulting services to life sciences companies on matters related to compliance with government laws and regulations regarding the development, approval, marketing and licensing of their products.
  - **Reimbursement and pricing:** companies that provide consulting services on the topic of pricing and reimbursement.
  - **Sales and marketing:** companies that provide sales and marketing support.
  - **Technology transfer:** companies that support the transfer of technology from universities or research institutes to the industry.
  - **Translation services:** companies that perform language translation.
  - **Valuation:** companies that perform independent valuations of companies wanting to know their value prior to seeking a licensing agreement or further funding.
  - **Other:** other service or consulting providers in the life sciences industry.

Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

Statistical definitions (9 of 11)

Definitions of the available sectors and subsectors from the BiotechGate database

Other life-sciences-related companies

- **Public/non-profit organisations/medical facilities**

  This category includes government-owned institutions, as well as companies that operate on a not-for-profit basis, such as foundations, hospitals and research institutes.

  - **Foundation:** a non-profit organisation that conducts charitable activities or provides funding for the charitable activities of other companies.
  - **Governmental organisation:** an organisation entirely owned or managed by the government.
  - **Hospital:** an institution where the sick or injured are given medical or surgical care.
  - **Industry association:** an organisation representing the professional, trade or commercial interests of its members.
  - **Institute:** an organisation founded to promote a specific cause such as a research organisation created to perform research on specific topics.
  - **Private clinic:** a privately owned facility, often associated with a hospital, established for the purposes of diagnosing and caring for outpatients.
  - **Research facility:** an entity that operates on a fee-for-service scheme and is either a scientific infrastructure or a technology platform offering access to: sophisticated equipment, training and experimental advice and entire workflows for sample preparation and analysis.
  - **Science /technology park:** a development, usually initiated by the government, comprising highly specified office and laboratory space designed to encourage localisation of high-technology companies.
  - **University:** a higher-education institution with teaching and research facilities that awards degrees at Bachelor's, Master's and doctorate levels.
  - **Other:** any other public or non-profit organisation associated with the life sciences.

Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

Statistical definitions (10 of 11)

Definitions of the available sectors and subsectors from the BiotechGate database

Other life-sciences-related companies

- **Supplier and engineering**

  Suppliers include companies that provide materials, components, products and goods to other companies, and companies that distribute the products of another company to its customers. Engineering companies are those that design, manufacture and operate structures, machines, processes and systems.

  - **APIs (active pharmaceutical ingredients) and excipients:** companies that manufacture active pharmaceutical ingredients (API) or excipients.
  - **Chemicals:** companies that manufacture or engineer chemicals.
  - **Distributors:** companies that distribute products for another company.
  - **Electronics:** companies that manufacture or engineer electronics.
  - **Instrumentation:** companies that provide laboratory and production measurement instruments, for example, thermometers.
  - **Laboratory consumables and reagents:** companies that manufacture or engineer consumable products for life sciences laboratories, for example, disposable pipettes and pipette tips, disposable test tubes, buffers, reagents.
  - **Laboratory engineering:** companies that plan and build laboratories and install the required equipment.
  - **Laboratory equipment:** companies that manufacture or engineer laboratory equipment.
  - **Medical devices:** companies that distribute medical devices but do not develop them themselves.
  - **Packaging and labelling:** companies that provide packaging and labelling.
  - **Precision mechanics:** companies that manufacture precision parts.
  - **Production engineering:** companies that provide production engineering services.
  - **Software:** companies that provide life-sciences-related software.
  - **Synthetic materials:** companies that provide synthetic materials such as special plastics or synthetic rubbers.
  - **Other:** any other companies acting as a supplier or engineer for life sciences companies.

Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

Statistical definitions (11 of 11)

Definitions of the available sectors and subsectors from the BiotechGate database

Other life-sciences-related companies

- **Media**

  Media companies disseminate information to targeted audiences through news casts, newspapers, online publications, television and radio.

  - **News agency:** an organisation that collects and disseminates news to subscribers such as newspapers, periodicals and newscasters.
  - **Newspaper:** a publication, usually issued daily or weekly, containing current news, editorials and featured articles on various topics, as well as assorted advertising.
  - **Online publication:** a publication such as a newspaper or magazine that is distributed over the Internet.
  - **Trade press:** specialist publications aimed at audiences in particular industries or business sectors.
  - **TV and radio:** channels for distributing video and audio information to the public.
  - **Other:** any other organisation focused on gathering and distributing information.

Source: BiotechGate (2022). Industry Sectors Covered. Accessed on October 2022.

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