INNOVATION & RESEARCH CAUCUS

MAPPING THE INNOVATION AND COMMERCIALISATION INFRASTRUCTURE FOR NON-HEALTH APPLICATIONS OF ENGINEERING BIOLOGY IN THE UK

IRC Report 003

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About the Innovation and Research Caucus

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Executive Summary

Context and study objectives (Section 1)

Engineering Biology is one of five priority technologies identified by the UK Government in its Science and Technology framework[1]. Engineering Biology is *'the application of rigorous engineering principles to the design of biological systems, with the objective of contributing to economic activity and sustainable and resource-efficient solutions to the societal challenges faced in food, chemicals, materials, water, energy, health and environmental protection*.' (Royal Academy of Engineering, 2019, p.3). Owing to early investments in Engineering Biology research, the UK is now recognised as a global leader in Engineering Biology; it is second only to the US in recorded grant research investment globally (CST, 2023). This research strength lies both in human health applications of Engineering Biology as well as in non-health applications.

The UK has been relatively successful in commercialising outcomes from human health applications, but less so in commercialising non-health applications of Engineering Biology. This has been attributed to various factors, including insufficient access to finance and scale-up facilities, inadequate skills on the part of innovators, low levels of previous commercialisation success, and inadequate or impatient venture capital and other funding. These barriers to commercialisation have placed the UK's longer-term global leadership in the Engineering Biology sector at risk: other countries, such as the United States, Singapore and Belgium, are beginning to move faster in providing resources and support for commercialisation and scale-up.

The primary objective of this study is to understand the landscape of commercialisation infrastructure for **non-health applications of Engineering Biology** in the UK, to identify the gaps in provision, and to identify investment opportunities. We adopt a broad view of 'infrastructure', including not only physical assets and facilities but also organisations providing 'soft' support to Engineering Biology firms, such as funding organisations and industry networks. Our focus here is mainly on open access facilities and assets.

The study has four components:

- First, we **review the existing literature** relating to the state of the UK Engineering Biology sector, the commercialisation barriers, and any recommendations already put forward regarding commercialisation and scale-up infrastructure.
- Second, we undertake an in-depth **analysis of the non-health applications of Engineering Biology business landscape** in the UK. We use novel Machine Learning and Web Scraping techniques to identify UK firms in four strategic applications: Agri-food, Chemicals, Materials, and Environment[2].
- Third, we undertake an **analysis and characterisation of the infrastructure landscape for non-health Engineering Biology firms in the UK**, identifying both 'soft' infrastructure, such as networks, as well as physical facilities and assets serving different Technology Readiness Levels.
- Fourth, we **conduct in-depth interviews with 18 companies** in three applications of Engineering Biology (Agri-food, Materials and Chemicals) as well as experts in major

[1] https://assets.publishing.service.gov.uk/media/6405955ed3bf7f25f5948f99/uk-science-technology-framework.pdf

[2] The identification of these firms is done using The DataCity's patented Real Time Industrial Classification (RTIC) Machine Learning algorithm methodology.

Engineering Biology support organisations to understand their perspectives on the gaps in infrastructure provision and the strengths and weaknesses of the UK relative to other countries in terms of commercialisation and Scale-up support[3].

In its recently published National Vision for Engineering Biology, DSIT (2023) set out seven key objectives that will help achieve a robust Engineering Biology Ecosystem. One of these was to invest in UK infrastructure: *'to reduce the costs of both the early stages of engineering biology innovation and its scale-up. We will develop a plan for UK facilities supporting start-ups and scale-ups'*. (DSIT, 2023, p9). Insights and interim findings from our research formed part of the evidence base that informed this National Vision, and this research will continue to inform plans for infrastructure delivery.

Our approach (Section 2)

Our approach to understanding commercialisation infrastructure is outlined in detail in Jibril et al. (2023). To understand and map the commercialisation infrastructure landscape for non-health applications of Engineering Biology and to identify gaps and investment opportunities, we follow a sequential process consisting of three key areas of activity: literature review, evidence gathering (including company interviews), and expert consultation exercises. Together, these allow us to identify future investment opportunities.

Prior evidence (Section 3)

A number of recent studies have considered weaknesses in the UK eco-system supporting commercialisation and scale-up in Engineering Biology (see Table 1 for details of these studies). Specific issues identified have been:

- Commercialisation and Scale-up infrastructure can be expensive to access for SMEs
- Collaboration between firms and between industry and academia can be difficult due to IP constraints
- Large economies of scale may be required for profitability, but costs are often too high for SMEs
- High risk and low benefit public perception of non-health applications
- Insufficient Venture Capital and other patient funding beyond seed stage
- Lack of a dedicated funding stream and a fragmented finance landscape
- Low levels of commercialisation success which deters private investors
- Lack of commercialisation skills on the part of innovators
- Unclear regulatory frameworks

Many of these issues are reflected in the recent National Vision for Engineering Biology, particularly around infrastructure, talent and skills, regulatory frameworks and business finance (DSIT, 2023). The Engineering Biology Leadership Council (2021) report detailed research into the specific commercialisation barriers and facilities for Engineering Biology applications in Agri-food, Materials and Chemicals. Gaps identified here focused mainly on the need for application-specific innovation centres.

[3] We have not yet been able to interview businesses with Environmental applications of Engineering Biology.

Understanding the business landscape of non-health applications of Engineering Biology (Section 4)

Based on a new, focused analysis conducted in partnership with DataCity and DSIT, this section provides an overview of the geographical landscape of firms in the non-health applications of Engineering Biology on which we focus. Our sample represents a specific subset of the wider pool of Engineering Biology companies identified by DSIT in its recently published National Vision for Engineering Biology. In this study, our focus is on four non-health applications each of which may have a different geographic distribution and inter-relationship with related infrastructure:

Agri-food - We identified 41 firms with Engineering Biology applications in the areas of Agriculture and Food. These firms are located across the country in London and the South East, Scotland and the North as well as Greater Manchester areas. Most of the Engineering Biology firms in Agri-food are start-ups (37%) or small scale-ups (32%), with relatively fewer established firms (15%), and SMEs (12%).

Chemicals - 23 firms are identified which have Engineering Biology applications in Chemicals. Chemicals firms are located across the country with particular concentrations in London and the South East. Firms here are relatively more established with only 22% start-ups, 4.3% small scale-ups and 13% larger scale-ups; 35% are SMEs, 26% are established firms. 13% of firms are university spinouts.

Materials - We identified 19 firms applying Engineering Biology to Materials, with a particular concentration of firms in London and the South East. This application of Engineering Biology is dominated by small scale-ups (42%). SMEs account for 26% of firms and 21% are established businesses.

Environment – We identified 17 firms with environmental applications of Engineering Biology. As with Agri-food, these firms are located across the country with significant concentrations in the North West, Scotland and the North, London and Oxford. This is an emerging application of Engineering Biology, with the vast majority of firms being start-ups (41%), small scale-ups (35%), or large scale-ups (18%).

Infrastructure for commercialisation of non-health applications of Engineering Biology (Section 5)

Overall, we identified a total of sixty-one open-access organisations and facilities serving as soft and physical infrastructure that support the non-health Engineering Biology innovation system in the UK. Around 44% of these are ‘soft’ infrastructure (see Figure below).

We take a spatial view of the infrastructure we identify. This is important in light of the wider evidence reflected in the Government’s National Vision for Engineering Biology, which suggests that industry participants express a preference for an infrastructure model where *'facilities and infrastructure are distributed across the UK and serve specific technical requirements'*. Our findings here represent an initial exploration of the spatial distribution of existing infrastructure and the Technology Readiness Levels (TRLs) TRL levels they serve. Going forward, this can help inform considerations of the relative merits of a distributed versus a centralised model of infrastructure provision (DSIT, 2023).

Most of the physical infrastructure we identify are proximally located with the seven clusters of Engineering Biology with two exceptions- Yorkshire and Teesside appear to have a vibrant support ecosystem but no identified cluster of businesses with *non-health* applications of Engineering Biology, and Oxford and South East appear to have an established cluster of businesses, but no open-access facilities supporting non-health applications. In both cases this seems to reflect a concentration of businesses emphasising pharmaceutical applications which are outside the scope of the current project and which may be using open access and privately held support infrastructure.

A key feature of the infrastructure landscape is that it is constantly evolving and is in flux. During the course of our research from July 2023 to December 2023, some organisations were dissolved (for instance, the Engineering Biology Leadership Council), and new pilot facilities were launched (such as the Centre for Process Innovation's Novel Food facility and Extracellular). The establishment of new Engineering Biology Mission Hubs is also underway. A key consideration therefore is to ensure that businesses are able to navigate such a fluid infrastructure system, and that they have access to up-to-date information of the support available.

Below we detail our findings relating to the spatial distribution of the facilities we identify:

Scotland - In Scotland, there are a number of facilities supporting Research and Translation (TRL1 to TRL 3), as well as Translation and Demonstration (TRL 3 to TRL 5), but there is gap in Demonstration and Commercialisation (TRL 5 to TRL9), and in Commercialisation and Scale-up facilities. This evidence thus suggests a gap in provision at TRL 5 and above for most applications of Engineering Biology in Scotland. IBioC provides a geo-specific industry network here.

Yorkshire and Teesside - We identify numerous Engineering Biology facilities in Yorkshire and Teesside although we do not identify a cluster of firms with *non-health* applications; it may be that pharmaceutical applications of Engineering Biology are dominant here. Yorkshire and Teesside not only have good Research and Translation and Translation Demonstration facilities but also some of the UK's best Demonstration and Commercialisation facilities (CPI which supports on Biotechnology and Novel Foods). Yorkshire and Teesside area is also well networked (for example through BioYorkshire). Yorkshire and Teesside, therefore, appear to have strong innovation and commercialisation infrastructure for Engineering Biology businesses.

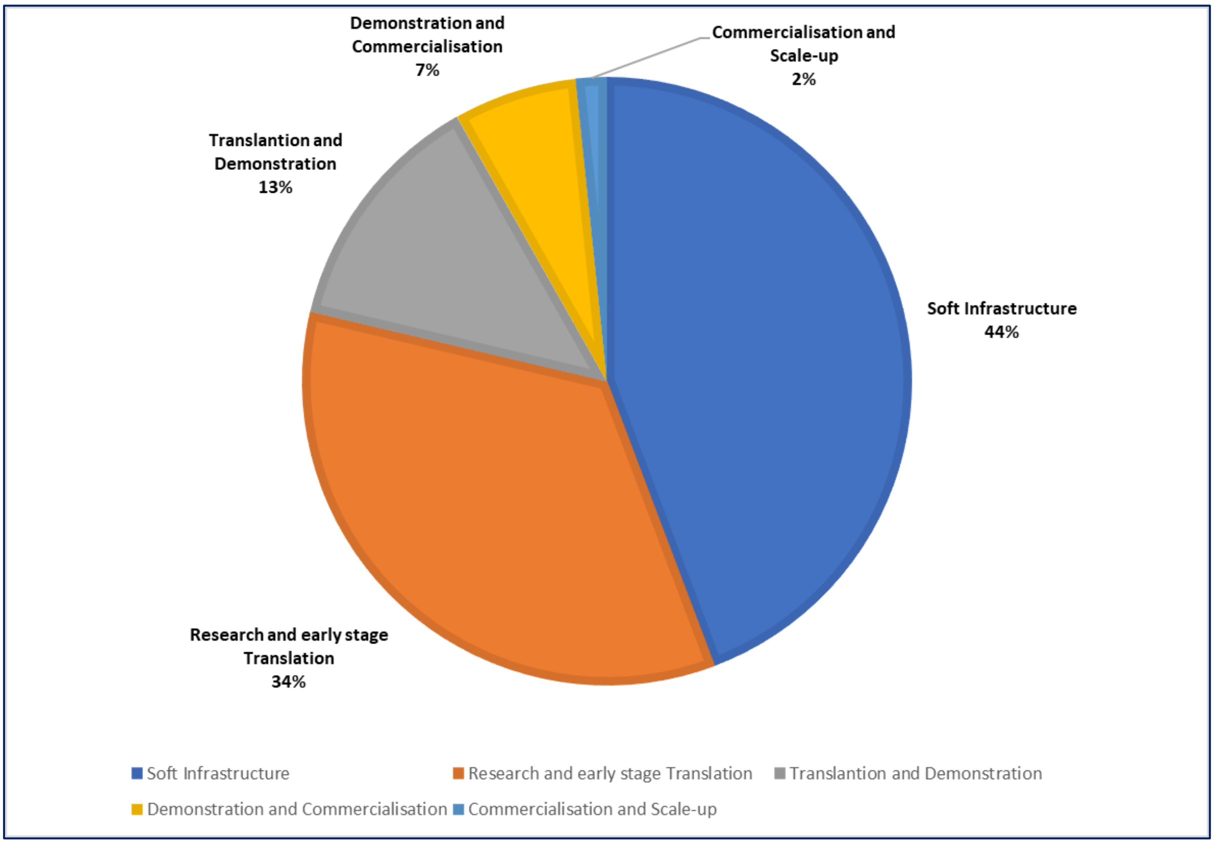

Figure 1: Proportion of soft and physical infrastructure supporting UK non-health applications of Engineering Biology

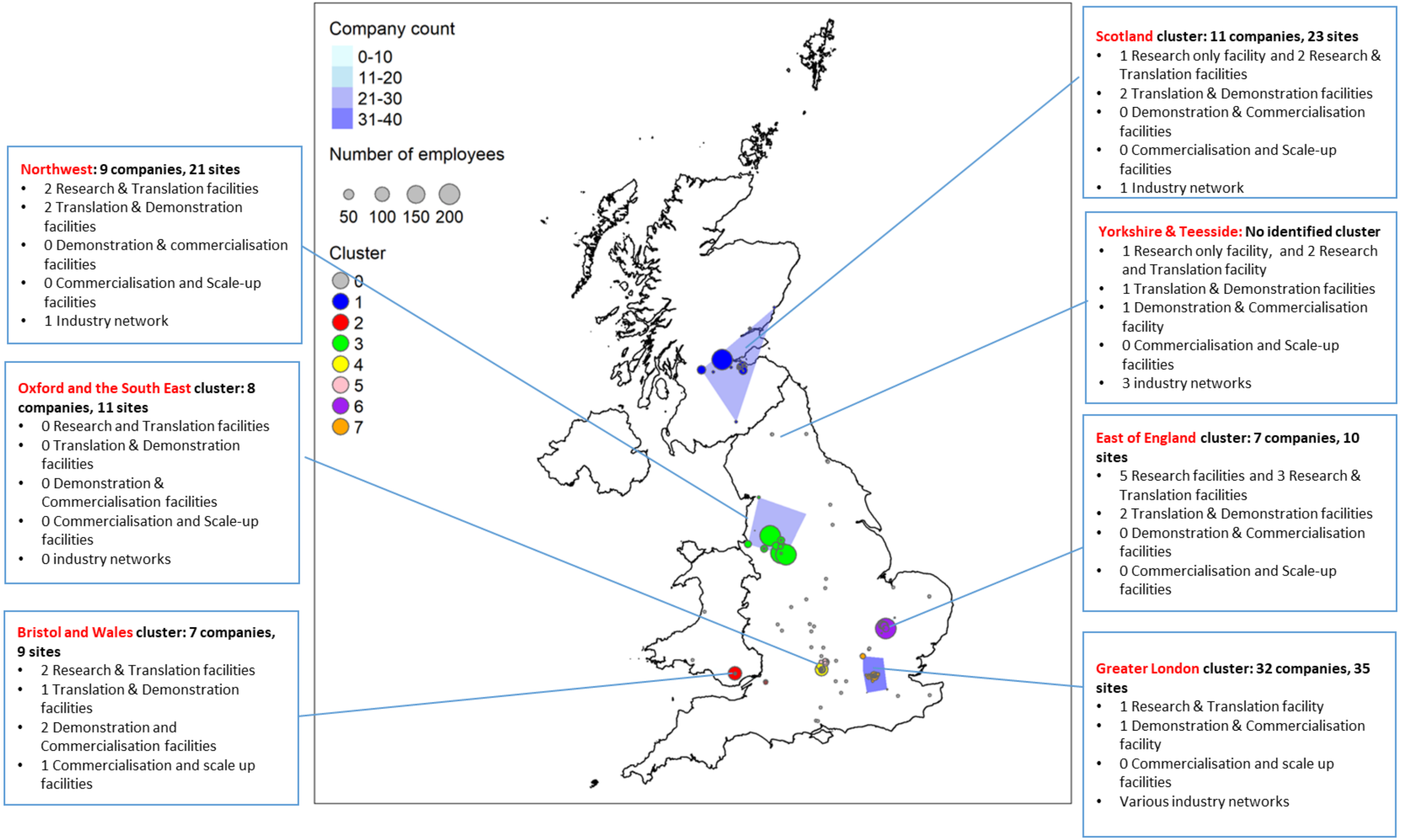

Figure 2: Locations of focal Engineering Biology companies and open-access support organisations

Greater Manchester/ Northwest - Greater Manchester is also well served by Research and Translation and Translation and Demonstration facilities and has 1 industry network (BioProNET) but has no Demonstration and Commercialisation facility and no Commercialisation and Scale-up facility. Similar to Scotland, this suggests a gap in provision facilities serving TRL 5 and above in the Northwest.

East of England - The East of England has various Research and Translation as well as Translation Demonstration facilities supporting non-health applications of Engineering biology, located mainly in Cambridge and Norwich. There are, however, no Demonstration and Commercialisation facilities and no Commercialisation and Scale-up facilities dedicated to Engineering Biology, although Cambridge University spinouts have the opportunity to receive much needed investment funding from Cambridge Enterprise, the University-affiliated seed funding organisation. Overall, the East of England appears to have a vibrant support ecosystem at low and mid-TRL levels. However, as with Scotland and the Northwest, lacks larger commercialisation and scale up facilities that can cater to a broad range of non-health applications of Engineering Biology.

Greater London - Similarly, Greater London has facilities supporting Research and Translation and Demonstration and Commercialisation (including SynbiCITE), but no (open-access) Commercialisation and Scale-up facility. Again, there appears to be a gap in the provision of commercial scale facilities even in London.

Oxford and the South East – As indicated earlier, the picture is somewhat different in Oxford and the South East. Here, despite a significant business cluster, we found no open access facilities supporting non-health applications of Engineering Biology. As in Cambridge, Oxford University spinout companies in Engineering Biology have the opportunity to receive investment funding from Oxford University's seed funding organisation, Oxford Seed Fund.

Bristol and Wales - Bristol and Wales have numerous Research and Translation and Translation and Commercialisation facilities as well as two Demonstration and Commercialisation facilities. These include the recently launched (commercial) pilot scale facility dedicated to cultivated meat (Extracellular) as well as the UKRI funded Engineering Biology Accelerator delivered through Science Creates. Bristol is also home to the only Commercialisation and Scale-up facility we identified- Biocatalysts. This is also a commercial facility going beyond pilot scale to deliver commercial scale upstream and downstream processing capabilities. Bristol and Wales thus appear to have strong support for both lower and higher TRL activities and for scale up.

Business perspectives on current Engineering Biology infrastructure provision (Section 6)

Interviews with firms in Agri-food, Chemicals and Materials applications emphasise the critical nature of the support eco-system for businesses in these Engineering Biology sectors. Many firms in the start-up and scaling phases draw intensively on external support – technological, financial and strategic – to facilitate their development. Gaps in the support eco-system can, therefore, be a critical break on their innovation journey. This may be particularly critical in Agri-food, and Materials applications, given the dominance of early-stage businesses in these applications.

Firms in each of the three sectors recognise the strength of the UK eco-system in Engineering Biology at lower TRLs. This recognition of the strength of the early-stage eco-system contrasted with more critical views of the facilities and funding available for commercialisation. Here, firms often contrasted the UK poorly with other countries, both in Europe and elsewhere, which provide better (and/or lower cost) facilities and greater financial support. The availability of facilities elsewhere is also actively promoted to UK Engineering Biology start-ups to encourage them to move their activity abroad.

Investment opportunities (Section 7)

Our analysis suggests a series of five investment opportunities, which could strengthen the commercialisation ecosystem for Engineering Biology in the UK. Each of these reflects the triangulation of evidence from previous reports on the sector, our own industry and infrastructure mapping, and discussions with Engineering Biology firms and industry experts. The key investment opportunities we have identified are as follows:

(1) ***Targeted development of commercialisation and scale-up capacity*** - our infrastructure mapping and firm cluster analysis suggests some clear limitations in the availability of physical infrastructure, particularly that which can support commercialisation and scale-up, in Scotland, Greater Manchester, South East and the East of England business clusters. In addition, enhancing scale-up facilities in London may also be valuable. However, these potential place-based investments in infrastructure will need to consider the relative importance of infrastructure proximity for different elements of innovation and commercialisation activities, including for example the extent of business mobility to access relevant infrastructure. The development of required skills and expertise is also a key requirement for the effective delivery of any infrastructure.

(2) ***Integrating soft infrastructure for collaborative delivery*** – The Engineering Biology sector is supported by a rich constellation of soft infrastructure. Incentivising collaborative delivery and co-ordination of services and support between organisations to support firms better will help ensure consistency and transparency of support for firms, and can enable more effective signposting between support organisations. Collaborative delivery could be organised by sector, spatial cluster, or specific commercial pathways and could provide a focus for international marketing of UK infrastructure. A previous attempt at providing such collaborative delivery was through BioPilots UK, an alliance of open access facilities across the UK to facilitate signposting and interconnectedness between pilot scale facilities.

(3) ***Commercialisation Infrastructure portal -*** The infrastructure mapping exercise undertaken here could provide the basis for a UK-specific web-based resource which may be useful both for industry and commercial uses. This would contribute to the transparency of commercialisation support available to firms and provide an international showcase for UK support for commercialisation of non-health applications of Engineering Biology. This is in line with wider views of industry participants as reflected in the National Vision of Engineering Biology, where the evidence suggests the need for a directory of the full range of available

facilities and equipment as well as the recommendations of the recent Spin-out Review[4]. The value of this type of investment would need to be carefully assessed and a detailed business case developed. Any directory must be regularly updated to reflect the rapidly evolving nature of Engineering Biology infrastructure landscape.

(4) ***Enabling SMEs' access to existing infrastructure*** - Engineering Biology firms made a range of persuasive arguments for the importance of enabling access to existing infrastructure. Other countries were said to provide greater incentives for SMEs to access infrastructure facilities, particularly at the demonstration and commercialisation stages. Small demonstration grants of £50k-£200k were seen as potentially useful by a range of stakeholders. Another company highlighted an innovative French support scheme which helps firms to de-risk commercialisation investment by providing competitive finance and brokered contacts with potential commercial partners, in return for a royalty payment on subsequent commercial sales.

(5) ***Enhanced international marketing of infrastructure capacity*** – It was clear from our Engineering Biology company interviews that increasingly countries are using aspects of commercialisation infrastructure and related support to attract inward investment at the commercialisation stage. The UK is already regarded as having excellent infrastructure and support organisations at low TRL's. The aspiration, reflected in the recommendations here, is that this excellence should extend to the whole of the commercialisation pathway within Engineering Biology. Supporting future investments in physical and soft infrastructure by enhanced international marketing of the UK ecosystem will help both project the image of the UK as a centre of excellence for Engineering Biology and act as an attractor for inward investment across the sector.

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[4] See https://assets.publishing.service.gov.uk/media/6549fcb23ff5770013a88131/independent_review_of_university_spin-out_companies.pdf

Section 1: Context and report aims

1.1 Introduction

The UK Government's 2023 Science and Technology Framework identified Engineering Biology as one of five critical technologies the UK should focus on to build strategic advantage (CST, 2023). Engineering Biology is '*the application of rigorous engineering principles to biology, enabling the construction of new or redesigned biological systems, such as cells or proteins, with applications across numerous sectors, including food, materials, and health*' (CST, 2023). Engineering Biology has the potential to address important global challenges, such as world hunger and environmental problems while yielding economic benefits. The environmental and sustainability benefits of Engineering Biology also mean that it has the potential to contribute to achieving the UK Government's longer-term vision of achieving net-zero emissions by 2050.

Owing to early investments in Engineering Biology research, the UK is now recognised as a global leader in Engineering Biology research in terms of research quantity, breadth of capabilities and research quality; it is second only to the US in recorded grant research investment globally (CST, 2023). This research strength lies both in human health applications of Engineering Biology as well as in non-health applications. These non-health applications of Engineering Biology can potentially deliver greater commercial value globally relative to human-health related applications (McKinsey Global Institute, 2020). For example, the Agri-food biotechnology sector is estimated to contribute about USD$0.8–1.2 trillion globally by 2030–40, and applications to materials and energy production may contribute USD$0.2–0.3 trillion over the same period (McKinsey Global Institute, 2020). The UK has been relatively more successful in commercialising outcomes from human health applications, but less so in commercialising non-health Engineering Biology applications. This has been attributed to various factors including insufficient access to scale-up facilities, inadequate skills on the part of innovators, low levels of previous commercialisation success which may discourage investors, and inadequate or impatient venture capital and other funding (IBLF, 2018; Parks et al., 2017; EBLC, 2021; CST, 2023).

These barriers to commercialisation have placed the UK's longer term global leadership in the Engineering Biology sector at risk: other countries are beginning to move faster in providing resources and support for commercialisation and scale-up, and the is UK losing businesses to continental Europe where facilities may be more accessible, or to the US where VC funding is more readily available (EBLC, 2021; CST, 2023). Often, Engineering Biology companies may undertake R&D in the UK to take advantage of the strong research base but move manufacturing operations elsewhere for better access to facilities, markets or feedstock (EBLC, 2021). Therefore, recent research has identified a pressing need to address the barriers to accelerating the translation and commercialisation of research within the field, helping start-ups grow, and communicating confidence to investors and consumers (EBLC 2021; CST, 2023). This will require a range of policy and regulatory interventions; within these, recent research has been consistent in highlighting the need for infrastructure that can accelerate the commercialisation of Engineering Biology innovations at higher Technology Readiness Levels:

'*Substantial Scale-up of existing infrastructure, skills and the availability of business finance will be needed to exploit the potential fully [of Engineering Biology], focussed on building capacity at higher technology readiness levels. There is a pressing need for strategic investment to create a continuum of innovation facilities*' (CST, 2023, p. 1)

'*Today, the UK is seen as having excellent, world-leading research in [Engineering Biology], 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*.' (CIIP, 2023, p. 6)

'*Current infrastructures are inadequate…… The need exists to facilitate feasibility and manufacturing scale-up studies by providing demonstration and support facilities that are more affordable and flexible to the breadth of needs and limited resources of growing and adapting companies*' (EBLC, 2021, p. 6)

1.2 Study objectives

The primary objective of this study is to understand the landscape of commercialisation infrastructure for non-health application of Engineering Biology in the UK, to identify the gaps in provision, and to provide recommendations relating to investment in new infrastructure or strategies to maximise the value from existing infrastructure. We adopt a broad view of 'infrastructure', including not only physical assets and facilities but also organisations providing 'soft' support to Engineering Biology firms, such as funding organisations and industry networks.

The rest of the report is organised as follows: Section 2 provides an overview of our approach. Section 3 provides a synthesis of existing evidence on the barriers to commercialisation of Engineering Biology in the UK and suggestions for infrastructure provision. Section 4 presents our findings relating to the business landscape of non-health application of Engineering Biology. Section 5 discusses findings from the infrastructure landscape analysis, and Section 6 presents results from in-depth interviews with companies. Section 7 provides a summary and conclusion and draws out recommendations relating to investment in new infrastructure and strategies to maximise the value from existing infrastructure.

Section 2: Our approach

Our approach to understanding commercialisation infrastructure is outlined in detail in Jibril et al. (2023). To understand and map the commercialisation infrastructure landscape for non-health application of Engineering Biology and to identify gaps and investment opportunities, we follow a sequential process consisting of three areas of activity: literature review, evidence gathering and consultation exercises; together, these allow us to identify future investment opportunities (Figure 2.1). Here, we provide a brief overview of each stage of the process; detailed methodologies are provided in the relevant sections of the report.

First, we review the existing literature to identify the state of the UK Engineering Biology sector, commercialisation barriers, and any recommendations already put forward regarding commercialisation and Scale-up infrastructure. The literature review also allowed us to develop a typology of innovation and commercialisation infrastructure and define the scope of Engineering Biology applications for the study.

In the evidence gathering phase, we mapped the non-health Engineering Biology business and infrastructure landscapes, and we conducted in-depth interviews with these businesses to understand their perspectives on infrastructure provision. To have a good understanding of the business landscape, we used company level data collected through Real Time Industrial Classifications (RTICs) using Machine Learning and Web Scraping techniques[5]. This allowed us to identify UK firms in four strategic applications of Engineering Biology: Agri-food, Chemicals, Materials, and Environment, to identify geographical clusters of activity in these Engineering Biology applications, and to explore, for the first time, the characteristics of businesses in these clusters. The second aspect of evidence gathering involved an analysis of the infrastructure landscape for non-health applications of Engineering Biology firms in the UK, drawing on our proposed typology for innovation infrastructure to categorise both ‘soft’ infrastructure, such as networks, as well as physical facilities and assets serving different Technology Readiness Levels. We explore the extent to which these infrastructures are co-located with geographical clusters of business activity. Additionally, we complemented the evidence gathering by conducting in-depth interviews with 18 companies in three applications of Engineering Biology to understand their perspectives on the potential gaps in infrastructure provision, as well as any other insights into the strengths and weaknesses of the Engineering Biology sector in the UK relative to other countries in terms of commercialisation and Scale-up support.

We consulted an Advisory Group, an extensive group of policy, industry, and academic stakeholders with expert knowledge of the UK Engineering Biology sector (see Appendix 1 for a list of the Advisory Group Members). This group was consulted at the start of the project to sense-check the research objectives and scope of the research. The group was also convened mid-way through the project to share our approach and initial findings; here, they sense-checked our results and contributed useful insights and context that helped refine our approach. We then followed up with further focussed group discussions, here with a smaller selected group of experts from the wider advisory group, to explore potential future areas of research that could serve as fruitful follow ups to this study. Finally, an initial draft of the report was shared will all

[5] As discussed in Section 4.1, the identification of these firms is done by experts within DSIT using the DataCity’s patented Real Time Industrial Classification (RTIC) machine learning algorithm methodology.

members of the group for comments and suggestions. Overall, these expert consultations provided insights that helped to sense-check our approaches and results, refine our recommendations, and identify potential future research areas. It should be pointed out, however, that this report represents the views of the authors, and responsibility for opinions and findings lies exclusively with the authors.

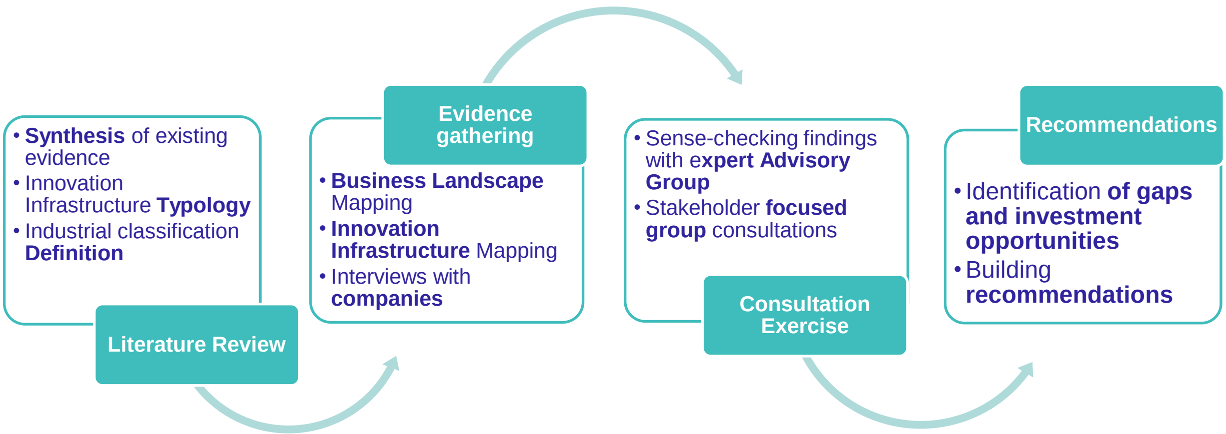

Figure 2.1: Our approach to understanding Engineering Biology innovation and commercialisation infrastructure and identifying gaps

Section 3: Synthesis of existing evidence on the commercialisation of Engineering Biology applications in the UK

Commercialising biotechnology-based products can be challenging in many ways. New products need to be competitive relative to established mainstream alternatives, many of which have already achieved economies of scale in low margin markets such as in agricultural sectors (McKinsey Global Institute, 2020). Several other factors are at play- new business models need to be developed that can combine multidisciplinary expertise in biology, chemistry, data science and automation; the right customers that recognise the value of the products need to be identified; sufficient scale-up infrastructure and viable supply chains need to be developed (McKinsey Global Institute, 2020).

Previous studies have identified various barriers to commercialising innovations in Engineering Biology specific to the UK (see Table 1). At the early stages of innovation, where commercialisation typically encompasses the sale or licensing of IP, target markets (for example, large companies in established industries) may be reluctant to adopt the new technologies, especially where there are long timelines from ideas to commercialisation (estimated to be c.10 years in this sector) (Parks et al., 2017). Once an idea is well developed and translated, and the innovation is at a higher TRL, barriers to commercialisation relate to inadequate scale-up facilities, lack of accessibility and affordability of existing facilities (CIIP, 2023; Parks et al., 2017, CST, 2023), unclear regulatory frameworks (EBLC, 2021), inadequate or impatient Venture Capital and other funding (CFS, 2023, EBLC, 2021) and negative public and societal perceptions of the risks associated with genetically modified products (Parks et al., 2017, EBLC, 2021). The latter barriers are particularly important in inhibiting or significantly delaying large-scale production and market penetration: McKinsey Global Institute (2020) estimates that about 70% of the global impact from the commercialisation of Engineering Biology hinges on consumer, societal and regulatory acceptance.

Previous research has identified gaps in the provision of physical *infrastructure* for commercialisation and scale-up of Engineering Biology in the UK (see lower panel of Table 1). CST (2023) recommends the establishment of multidisciplinary Biomanufacturing Innovation Centres for testing, commercialising and scaling up, tailored to specific Engineering Biology applications, and advocates for more accessible pilot scale facilities for SMEs. IBLF (2018) recommends the collation and promotion of existing facilities to reduce any informational barriers for firms seeking support, as well as subsidising access to expensive facilities. EBLC (2021) conducted detailed research into commercialisation barriers and facilities required for specific Engineering Biology applications in Agri-food, Materials and Chemicals. In Table 2, we summarise their findings related to commercialisation and scale-up barriers as well as application-specific infrastructure gaps; these centre mainly on the need for application-specific innovation centres (Table 2). Many of these issues are reflected in the recent National Vision for Engineering Biology, particularly around infrastructure, talent and skills, regulatory frameworks and business finance (DSIT, 2023).

Despite the numerous barriers to commercialising Engineering Biology and the gaps in infrastructure provision, previous research has also highlighted the UK's strengths and opportunities in Engineering Biology. The strengths include the strong research base and corresponding world-class research infrastructure, a highly networked and geographically dispersed Engineering Biology community connected at both national and local levels and across subsectors, as well as a highly innovative start-up and SME environment (IBLF, 2018). More recent Government investments, for example, in the Engineering Biology Mission Hubs, and increasing recognition of the need to capture value through enhancing commercialisation potential (EBLC, 2021, CIIP, 2023, CST, 2023, DSIT, 2023) also represent an important opportunity for the sector.

There is also a potential opportunity for the UK to attract foreign investment through the provision of effective commercialisation and scale-up infrastructure because, globally, scale-up biomanufacturing facilities are scarce (Synonym, 2023). Capacitor, a global open access directory of over 150 biomanufacturing facilities in over 30 countries, reported in February 2023 that 70% of its users filtered the global directory for commercial scale fermentation facilities that can offer more than 20,000L capacity, but only 20% of the facilities in its directory offered equipment at that scale.

> '*Many users are filtering for demo and commercial facilities and bioreactors larger than 20,000L. The existing infrastructure network severely lacks these pieces, and we need future development to fill these gaps. There are many facilities that make up the existing network, predominantly in Europe and the Americas and at the bench and pilot scales. But … we need more capacity, especially at the larger scales and with larger bioreactors, to help companies produce in quantities big enough to achieve cost parity with legacy products'* Synonym State of Global Fermentation Capacity Report (February 2023)

Table 1: Summary of findings from previous research on Engineering Biology commercialisation barriers in the UK and recommended infrastructure

Previously identified commercialisation barriers
Commercialisation and Scale-up infrastructure can be expensive to access for SMEs (IBLF 2018, EBLC, 2021, CST, 2023) Collaboration between firms and between industry and academia is made difficult due to IP constraints (Parks et al., 2017) Large economies of scale are required for profitability, but costs are too high for SMEs (EBLC, 2021, CST, 2023) High risk and low benefit public perception of non-health applications (Parks et al., 2017; EBLC, 2021) Insufficient VC and other patient funding beyond seed stage (EBLC, 2021, CIIP, 2023) Lack of a dedicated IB funding stream and a fragmented finance landscape (IBLF, 2018) Low levels of commercialisation success which deters private investors (Parks et al., 2017, IBLF, 2018) Lack of commercialisation skills on the part of innovators (IBLF, 2018) Unclear regulatory frameworks (IBLF, 2018, EBLC, 2021)
Previously identified gaps in physical infrastructure
There is a need to collate and promote existing infrastructure (IBLF, 2018) Access to expensive facilities should be subsidised for SMEs by providing financial support (IBLF, 2018, EBLC, 2021) The need to support technical and economic viability testing so businesses can have affordable and accessible pilot scale facilities (CST, 2023) The need to develop scale-up infrastructure specific to biomanufacturing- Biomanufacturing Innovation Centres (CST, 2023)

Table 2: Application specific commercialisation barriers and infrastructure gaps: Summary of Engineering Biology Leadership Council (2021)

Application Sector	Commercialisation and Scale-up barriers	Gaps/opportunities in commercialisation infrastructure
Agri-food	Insufficient research translation into commercial outputs Lack of connection between research and industry Inadequate start up infrastructure Insufficient opportunities to work to scale- many UK companies outsource work at scale abroad	The establishment of an agri-food hub that incubates start-ups, collocated with industrial R&D facilities (estimated to cost £300m per hub) Accelerator programmes and hubs bring academia and industry together. Accessible and discounted Scale-up facilities, including microbial growth facilities, fermenters, bulk plant growth facilities such as vertical farms and hydroponic systems (estimated to cost £50m-£75m per facility)
Materials	VC capital funding is more difficult to access and less flexible than in the US or continental Europe Private investors lack domain knowledge and demand an unrealistically rapid return on investments. Lack of biomass processing facilities such as pulp mills. Inadequate financial support for international patents.	The provision of biomass processing facilities Supporting international patents, which can allow assurance for IP protection in countries like Russia and China
Chemicals	Successful and exceptional research base lacks infrastructure for large scale commercial application. Inadequate UK government investments at low Technology Readiness Levels	The establishment of a Chemicals Biomanufacturing Institute (NCBI) with capabilities at mid-high Technology Readiness Levels (TRL).

Section 4: The UK business landscape for non-health applications of Engineering Biology.

4.1 Introduction

Engineering Biology forms a small proportion of the UK Life Sciences industry. In its 2023 report, BioGate estimated that the UK has around 4,556 companies in the Life Sciences sector. Of these, 1385 companies (30%) were in the Biotechnology subsector. This Biotechnology subsector is, in turn, dominated by firms engaged in R&D services serving both health and non-health applications of biotechnology (51% of firms) and firms with therapeutic and diagnostic applications of biotechnology (34%). *Non-health applications* of Engineering Biology accounted for only 15% of biotechnology firms, comprising around 202 businesses (CIIP, 2023).

Identifying Engineering Biology businesses in the UK using conventional industry classifications is challenging because Engineering Biology is a platform technology applicable to many industries, and application areas continue to evolve. Below, we set out our methodology for identifying these firms and analysing the UK's business landscape.

4.2 Methodology for analysing the business landscape

4.21 Defining Engineering Biology and Identifying Engineering Biology Companies:

We follow the Royal Academy of Engineering in defining Engineering Biology as *'the application of rigorous engineering principles to the design of biological systems, with the objective of contributing to economic activity and sustainable and resource-efficient solutions to the societal challenges faced in food, chemicals, materials, water, energy, health and environmental protection*.' (Royal Academy of Engineering, 2019, p.3). Following policy applications of this definition, Engineering Biology is differentiated here from the broader bioeconomy; we consider Engineering Biology companies strictly as those using genetic modification, non-natural proteins or non-natural growth conditions for cellular culturing[6]. As such, companies using other forms of modifications, such as those engaged in biodegradable plastic packaging, nootropics, or chemical formulations of small molecules, are omitted. In addition, companies in Engineering Biology supply chains are excluded.

As previously discussed, our focus is on four non-health Engineering Biology applications, i.e., Agri-food, Chemicals, Materials and the Environment. These are areas in which the UK has existing strengths or key potential for commercialisation and which align broadly with three of the Four Missions outlined in the *National Engineering Biology Programme* (NEBP): Food Systems, Clean Growth and Environmental Solutions[7]. Annex 1 provides a more detailed background to the choice of these applications. For the purposes of this report, each of these application areas is defined as below:

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[6] This is in line with the criteria and definitions set out by the Department for Science, Innovation and Technology (DSIT).

[7] Recent reports have identified key UK strengths or potential in Agriculture and Food (EBLC, 2021, CIIP, 2023), Chemicals and Materials (EBLC, 2021, CST, 2023), and Biofuels and Renewables (environment) (CST, 2023)

i. *Agri-food:* Firms using Engineering Biology to produce the things we eat. This encompasses sustainable agriculture, eco-friendly agri-chemicals and foods such as alternative meat, protein and fat.

ii. *Chemicals:* Firms using Engineering Biology to produce chemicals for purposes outside of healthcare and farming, encompassing mainly high-value compounds.

iii. *Materials:* Engineering Biology used to produce materials for purposes outside of healthcare and farming, encompassing materials such as biobased or biodegradable products or sustainable fashion.

iv. *Environment:* Firms using Engineering Biology to produce fuels (such as jet fuel. biofuels, or green hydrogen) and firms using Engineering Biology for environmentally friendly purposes, such as removing toxins from the environment and industrial processes. The latter encompasses Engineering Biology firms engaged in bioenergy and carbon capture.

4.22 Developing an Industrial Classification for Engineering Biology

To identify Engineering Biology companies, we collaborated with the Engineering Biology team within the UK Department for Science, Innovation and Technology (DSIT), and with DataCity, a data science company. The DataCity company uses innovative Web Scraping and Machine Learning algorithm techniques to develop Real Time Industrial Classifications (RTICs) based on company data. RTICs are company datasets that classify companies engaged in similar activities, performing similar tasks or using similar technologies based on the information published on their company websites. Based on the DataCity's machine learning algorithms, RTICs use taxonomies and keyword compilations to identify companies in narrow sub-industrial classes beyond traditional SIC or NACE industrial codes. A small group of company websites is used to train the algorithm, which then produces an initial dataset of companies. Quality assurance checks are then conducted to ensure, at most, a 10% margin of error in matching companies to appropriate industry classes.

Taxonomies and keywords to feed the algorithm for identifying Engineering Biology companies were developed by DSIT's Engineering Biology team; this included Engineering Biology scientific experts and incorporated broad cross-government engagement. The Annex 2 lists the core keywords used for identifying Engineering Biology firms in general and the specific keywords used to identify the four applications (Agri-food, Chemicals, Materials and the Environment) considered in this report. Using these keywords, DSIT worked with the DataCity to develop a bespoke Engineering Biology RTIC in July and August 2023. The initial search was conducted on a population of 1.7m UK businesses from Companies House, matched with their website text. This first iteration yielded an initial list of around twenty-one thousand companies. After significant manual checks and quality assurance by DSIT, the DataCity and cross-government stakeholders, the Engineering Biology RTIC resulted in the identification of 1,744 companies.

These companies working in Engineering Biology companies included those in health and therapeutic applications as well as the supply chains of Engineering Biology companies. Out of these, only 86 companies were categorised as one of our four Engineering Biology application areas as defined above. In addition to these 86 companies, we identified 14 companies from the (non-exhaustive) directory of Engineering Biology firms published by the Bio-Industry Association in 2022. Taken together, these formed a total of 100 companies upon which our analysis is based.

It is worth noting the strengths of this approach. The RTIC yields real time data on active companies; this is valuable in the Engineering Biology context where the business landscape is rapidly changing. This approach, therefore, gives us the most up-to-date snapshot of UK Engineering Biology companies, their application areas, their locations and their business characteristics.

4.23 Limitations of the approach

One limitation of the RTIC approach is that it requires website data, meaning that only companies with a website are included in the analysis. It is also possible that some Engineering Biology firms are missed because they may not describe their activities using the keywords specified in the RTIC search. This may lead to an underestimation of the true number of companies in the four applications considered in our analysis. We mitigate this risk by complementing the RTIC data with additional companies from a complementary source, i.e., the BioIndustry Association's 2022 list of Engineering Biology companies. It is worth noting that the BioIndustry Association's list, although non-exhaustive, included only about 46 companies across all four applications of Engineering Biology, and some of these were already included in the RTIC analysis. Moreover, as previously mentioned, CIIP's 2023 analysis found approximately 202 firms covering eight non-health Engineering Biology application areas. Cross-referencing suggests that our selection of 100 firms spanning four of these eight applications capture many of the companies operating in these areas.

A second limitation is that RTIC classifications have the potential to include up to 10% false positives, i.e., companies wrongly assigned to the industry. The extensive scrutiny and quality assurance processes involved in the development of the Engineering Biology RTIC serve to limit this risk, although it does not eliminate it.

4.3 Analysis of the overall business landscape

Figure 4.1 shows the geographical distribution of the companies identified, showing a good spread of Engineering Biology companies across the UK. Table 3 shows that, on average, these firms have around 31 employees. The median number of employees is only around 5, however, reflecting the high proportion of start-ups and SMEs. Average firm growth in 2022 is estimated to be around 30%. Around half of the firms in our sample had some Innovate UK funding. The average IUK funding is estimated to be around £700K, with median funding of around £367k. The top five firms with the highest IUK funding are spread across applications and geographical locations. 13% of the firms we identify are university spinouts, 43% are in Agri-food, 23% in Chemicals, 17% in Environment and 19% in Materials.

Business growth stages are consistent with the emerging nature of Engineering Biology - 28% of firms are early-stage start-ups, 28% are smaller companies that are scaling up, 9% are larger scale-ups, 18% are SMEs, and 17% are established firms (Figure 4.1). The classification of growth stages is based on the DataCity's methodology, which uses specific minimum and maximum boundaries on firms' incorporation date, employee information, turnover, growth potential and investment data to arrive at a growth stage classification for each company. Annex 3 provides further details of this methodology.

Table 3- Descriptive statistics: Full sample

Variable	Obs	Mean	Median	Std, Dev	Min	Max
Employees	100	52	5.00	177	0	1772
Growth	60	0.30	0.13	0.49	-0.56	1.997
IUK Funding	53	696397	367274	865762	0	3973820
Deal Room funding	46	17.44	4.63	28.29	0	150.12
Spinout	100	0.13	0	0.34	0	1
Agri-food	100	0.43	0	0.50	0	1
Chemicals	100	0.23	0	0.42	0	1
Environment	100	0.17	0	0.38	0	1
Materials	100	0.19	0	0.39	0	1

Source: Authors calculations using data from DataCity. Deal room funding is in millions of £.

4.4 Analysis of the business landscape by Engineering Biology applications

This section provides an overview of the geographical landscape of Engineering Biology firms in the four specific applications we focus on (Figure 4.2), the growth stages of these firms (Figure 4.3), as well as descriptive statistics relating to estimated employment, turnover, growth and Innovate UK funding (Table 4).

Agri-food

We identified 41 firms with Engineering Biology applications in the areas of Agriculture and Food. These firms are located across the country in London and the South East, Scotland and the North, as well as Greater Manchester areas (Figure 4.2). Most of the Engineering Biology firms in Agri-food are start-ups (37%) or small scale-ups (32%), with relatively fewer established firms (15%) and SMEs (12%) (Figure 4.3). The average number of employees is 60, with a median of 5 employees, underscoring the predominance of start-ups and scale-ups. 15% of firms are University spinouts. Average Innovate UK funding is estimated to be around £576K with a median of around £227k.

Chemicals

The dataset includes 23 UK firms with Engineering Biology applications in Chemicals. Chemical firms are located across the country, with particular concentrations in London and the South East. Firms here are relatively more established with only 22% start-ups, 4.3% small scale-ups and 13% larger scale-ups; 35% are SMEs, and 26% are established firms (Figure 4.3). 13% of firms are university spinouts. The average number of employees is around eight with a median of three employees, and the average IUK funding is around £800k with a median of £462k.

Materials

We identified 19 firms applying Engineering Biology to Materials, with a particular concentration of firms in London and the South-East (Figure 4.2). This application of Engineering Biology is dominated by small scale-ups (42%). SMEs account for 26% of firms, and 21% are established businesses (Figure 4.3). On average, these firms employ around 15 people, with a median employee count of seven employees. 11% are university spinouts. The average IUK funding is about £990k, with a median level of £721k.

Environment

We identified 17 firms with environmental applications of Engineering Biology. As with Agri-food, these firms are located across the country with significant concentrations in the Northwest, Scotland and the North, London and Oxford (Figure 4.2). This is an emerging application of Engineering Biology, with the vast majority of firms being start-ups (41%), small scale-ups (35%), or large scale-ups (18%).

Table 4: Descriptive statistics by Engineering Biology application

	Number of employees	Growth (%)	IUK funding	Deal room	Spinout
	Agri-food				
Mean	60	0.41	576157	24.28	0.15
Median	5	0.17	227364	5.78	0
Std, Dev	275.4	0.51	710498.3	35.23	0.36
Min	0	-0.1	0	0	0
Max	1772	1.52	2270777	150.12	1
N	41	23	22	23	41
	Chemicals				
Mean	8	0.05	799541.3	16.47	0.13
Median	3	0.04	462418.5	2.6	0
Std, Dev	15.02	0.29	1074425	25.33	0.34
Min	0	-0.56	9876	0	0
Max	71	0.86	3973820	54.31	1
N	23	16	12	7	23
	Environment				
Mean	12	0.48	572625.9	6.7	0.12
Median	6	0.337	314653.5	4.22	0
Std, Dev	18.03	0.6	825253.4	8.18	0.33
Min	0	-0.11	0	0	0
Max	70	2	2582059	21.78	1
N	17	9	10	10	17
	Materials				
Mean	16	0.29	990311.7	10.27	0.11
Median	7	0.14	721576	3.69	0
Std, Dev	22.8	0.51	1010645	18.54	0.32
Min	0	-0.27	309058	0	0
Max	88	1.65	3565026	47.7	1
N	19	12	9	6	19

Notes: Source: Authors calculations using data from DataCity. Deal room funding is in millions of £.

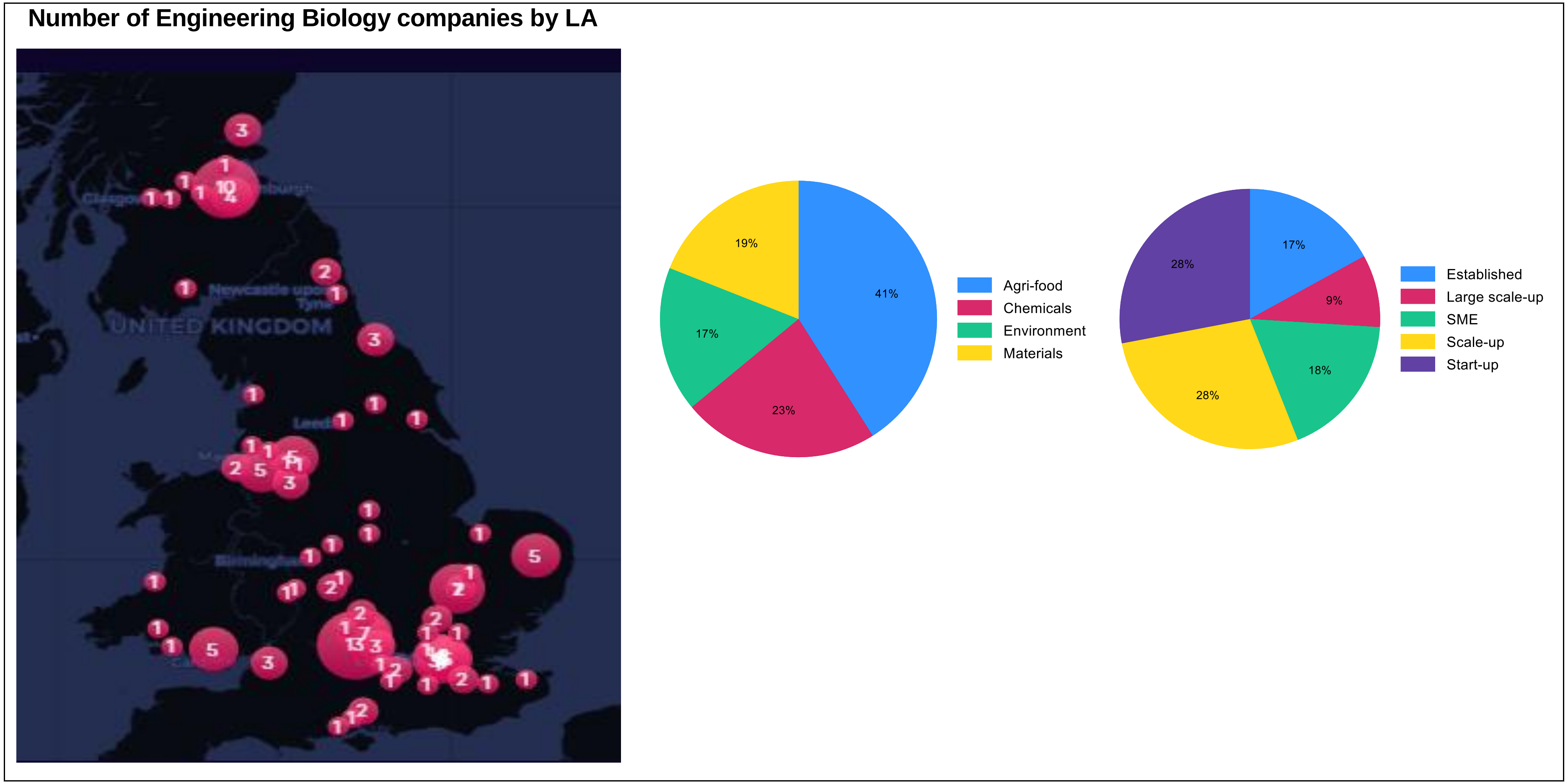

Figure 4.1: Geographical distribution of the four applications of Engineering Biology firms

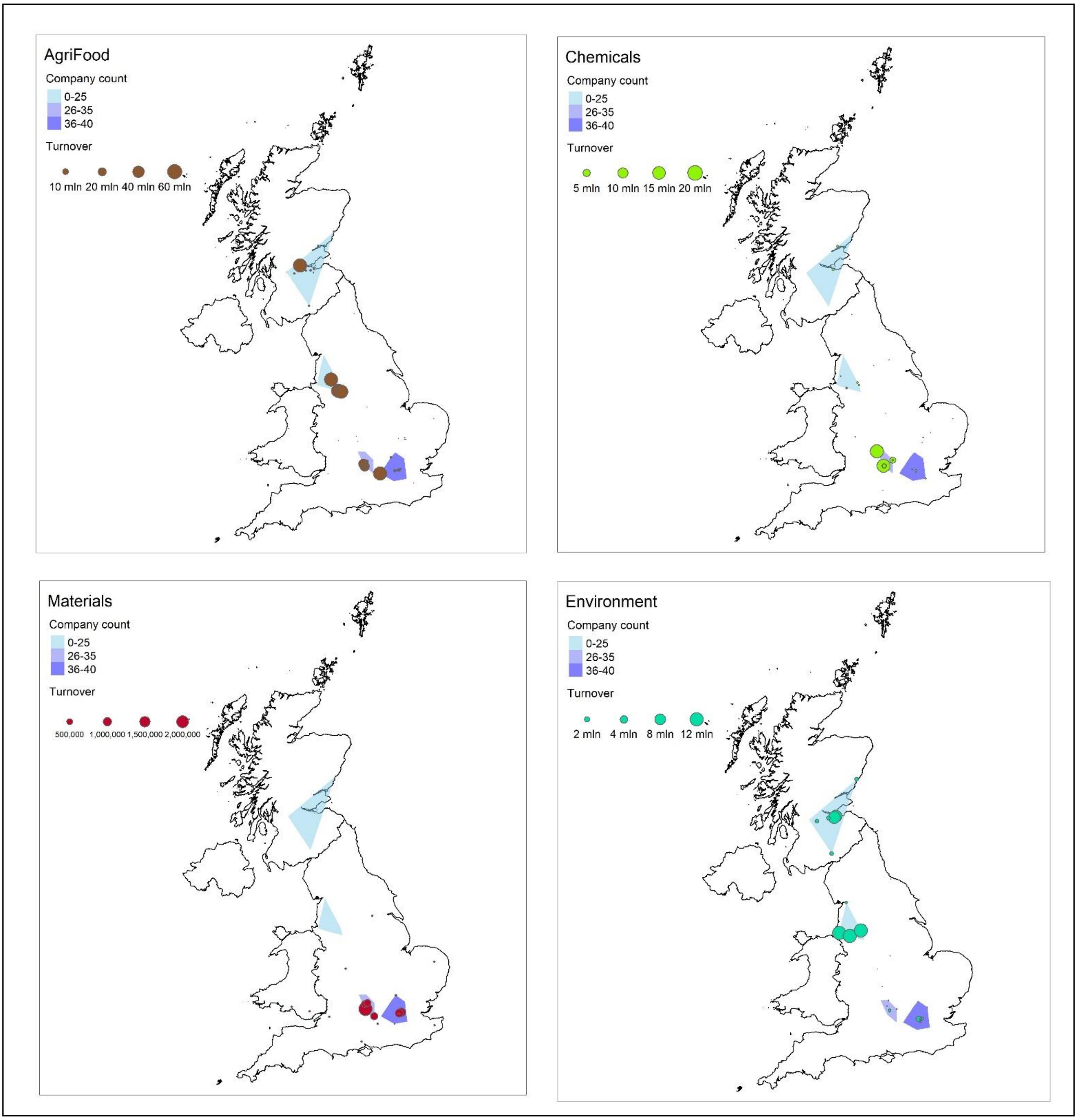

Figure 4.2: Geographical distribution of the four applications of Engineering Biology firms by application

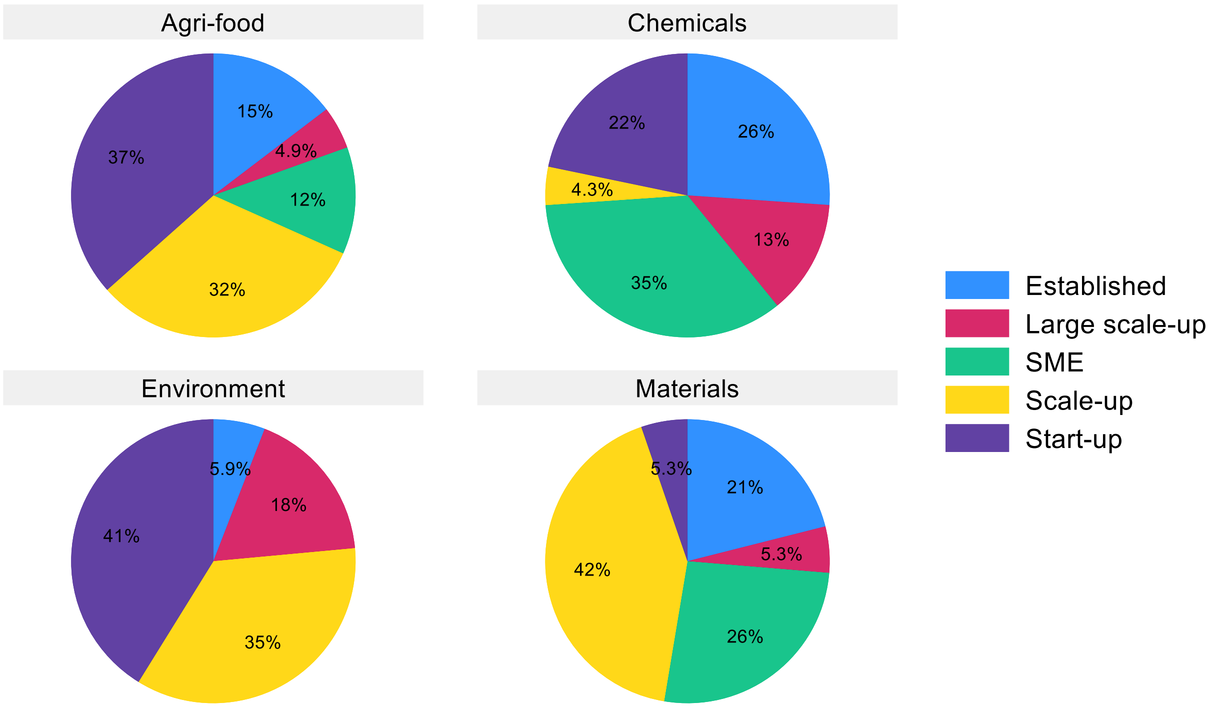

Figure 4.3: Growth stages by Engineering Biology application

Notes: See Annex 3 for a detailed definition of Growth Stages

4.5 Analysis of the business landscape by geographical clusters

Here, we present results from an analysis of geographical clusters of activity aimed at measuring concentrations of Engineering Biology applications that may identify a critical mass in certain areas in the UK. The cluster analysis uses 164 geographical locations for the 100 firms in Agri-food, Chemicals, Environment and Materials. The spatial cluster analysis is done in collaboration with the DataCity, who use the HDBSCAN technique to find clusters of companies across the country. HDBSCAN is a suitable clustering algorithm for this type of geographical distribution because it deals well with clusters with different densities. In particular, it can identify both very dense company clusters -like those in London- and more dispersed clusters. This overcomes the limitations of other clustering techniques that tend to identify cities and dense urban areas as clusters mainly because of their socioeconomically dense networks.

Figure 4.4 shows two maps reflecting the different levels of clustering identified. Figure 4a shows four main clusters of Engineering Biology firms, with each cluster containing at least fifteen companies. The clusters identified here are in Scotland and the North, Greater Manchester/Northwest, Greater London and Oxford and Reading areas. Figure 4b shows seven smaller clusters of Engineering Biology firms, where the criteria for cluster identification is that each cluster contains at least seven firms. This continues to identify the previous four clusters but additionally identifies a cluster in Cambridgeshire and another in Bristol and Wales[8]. In the subsequent analysis, we focus on the four main clusters in Figure 4a as these are more strongly

[8] Due to the small number of firms specified to form a cluster (7 firms), Figure 4b identifies two clusters in the Oxford area.

indicative of the critical mass of Engineering Biology activity. It is noteworthy that around 35 firms are non-clustered, i.e., geographically dispersed and not categorised as forming part of any of the four identified clusters.

Cluster 1- Scotland and the North

This cluster is dominated by Agri-food applications of Engineering Biology (64%), followed by Environmental applications (18%) (Figure 4.5). The cluster has a good mix of firms in relation to growth stages- 27% are small scale-ups, and the rest are evenly distributed across start-ups, large scale-ups, SMEs and established businesses (18% each) (Figure 6). This cluster, therefore, is dominated by Agri-food, and 45% are small or large scale-ups. The average number of employees here is about 15, with a median of 8 employees. On average, firms grew by about 21% in 2022 (Table 5). 18% of firms are university spinouts, and average IUK funding is about £620k with a median of £216k.

Cluster 2- Greater Manchester/Northwest

40% of firms in this cluster are in Chemicals applications of Engineering Biology, 30% are in Agri-food, and 30% are in Environment; there does not appear to be a significant concentration of firms applying Engineering Biology to Materials (Figure 4.5). Figure 4.6 shows that, as with Scotland and the North cluster, firms are well distributed across growth stages, with 30% SMEs, 30% start-ups, 20% large scale-ups, 10% established firms and 10% smaller scale-ups. Thus, this cluster has a good mix of applications excluding Materials and a good mix of growth stages. On average, firms have around 16 employees, with a median employee count of about 5-6 employees. Firms grew on average by about 55% (median growth 16%). 20% of firms are university spinouts. Average IUK funding is about £768k, with a median funding of about £356k.

Cluster 3- Oxford and Reading

This cluster has a good spread of the four applications of Engineering Biology - 33% of firms are in Chemicals, 27% in each of Agri-food and Materials, and 13% in Environment applications (Figure 4.5). There is a similarly diverse distribution of firms across growth stages, although start-ups are not prominent here, suggesting that this cluster is more established. The cluster is characterised by 27% each of SMEs and established firms, 20% small scale-ups, and 13% each of large scale-ups and start-ups (Figure 4.6). This cluster thus has a good mix of applications and is relatively established, with 54% of firms either SMEs or established larger firms. The average number of employees is 16, with a median of 7 employees. On average, firms grew by 23% (median growth of 3%), and about a third (33%) of firms are university spinouts. This cluster has the highest average IUK funding of around £1.1m with a median funding of about £525k.

Cluster 4- Greater London

This cluster is dominated by Agri-food applications of Engineering Biology (45%). Still, there is a healthy proportion of firms in Environment applications (24%), Materials (17%) and Chemicals (14%) (Figure 4.5). This is very much an emerging cluster, with 45% of firms being start-ups and

31% small scale-ups; established firms and SMEs each account for about 10% of firms, and only about 3% of firms are large scale-ups (Figure 4.6). On average, firms have around 6 employees with a similar median of 4 employees, underlying the absence of larger firms. Firms grew by 29% on average, with a similar median growth of 27%. Only about 7% of firms are classified as university spinouts. Its average IUK funding is about £581k, with a median funding of £309k.

Other non-clustered firms

As previously mentioned, many Engineering Biology firms are more geographically dispersed and do not fit into a specific geographical cluster, although they may be proximate to certain clusters. 40% of these firms are in Agri-food, 26% in Chemicals, 26% in materials and 8.6% in Environment (Figure 4.5). 34% are small scale-ups, 23% are start-ups, 20% are established businesses, 17% are SMEs, and about 5% are large scale-ups (Figure 4.6). The average number of employees is 68, with a median of 6 employees, indicating a few very large firms and many smaller ones. Firms grew on average by about 27%, with a median growth of about 14%. Only 5% of firms are university spinouts. The average IUK funding is around £529k, with a median funding of £397k.

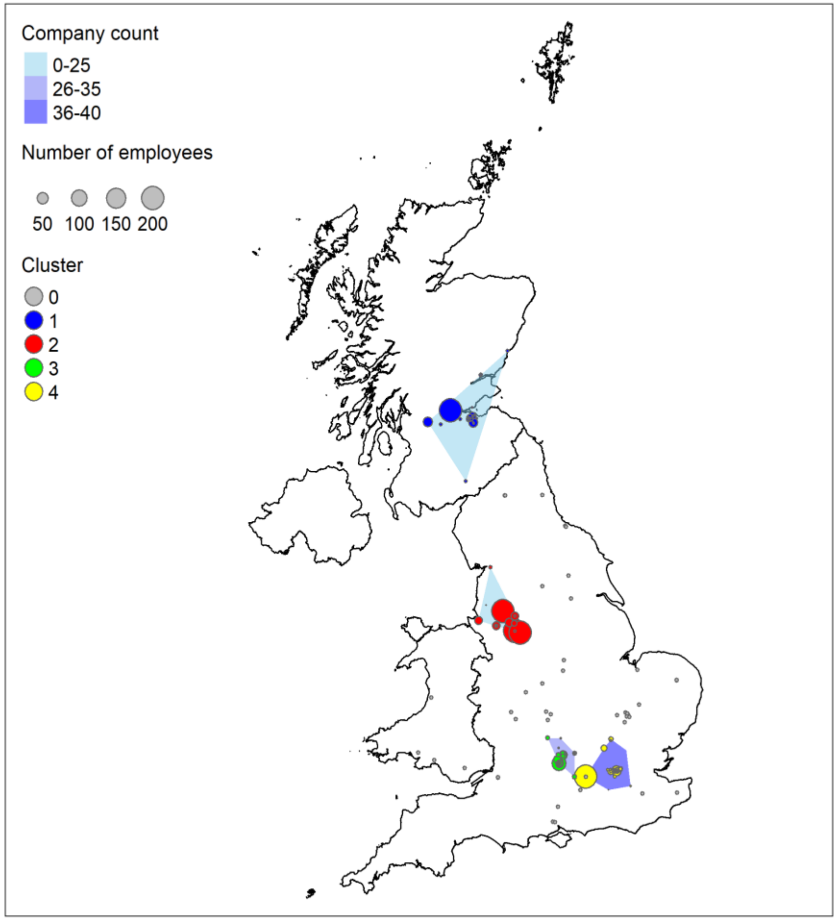

Figure 4a: Four Main clusters of Engineering Biology activity

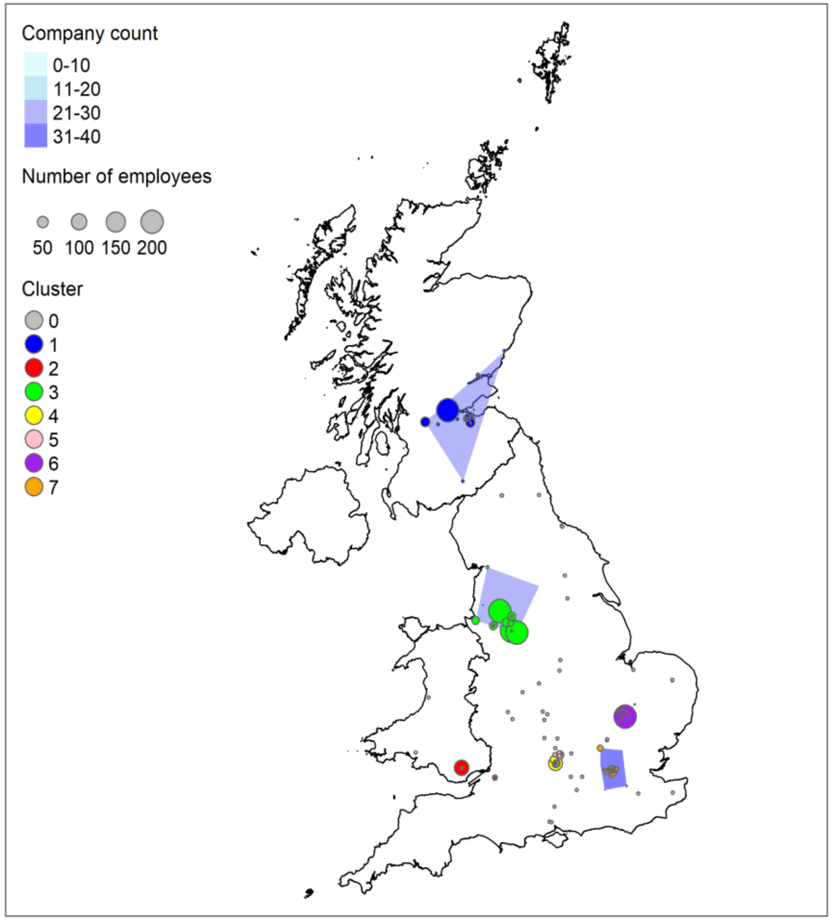

Figure 4b: Seven smaller clusters of Engineering Biology activity

Figure 4.4: Clusters Analysis for Agri-food, Chemicals, Materials and Environment Applications of Engineers Biology in the UK

Notes: Spatial cluster analysis using HDBSCAN

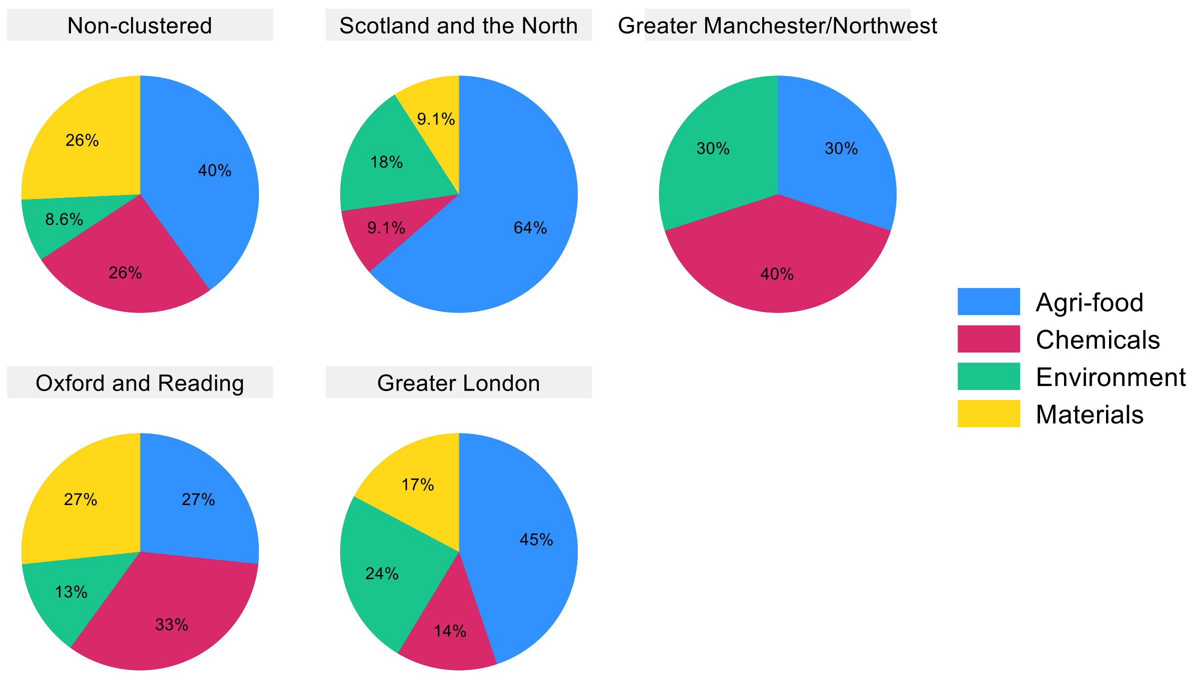

Figure 4.5: Distribution of Engineering Biology applications by Spatial Cluster

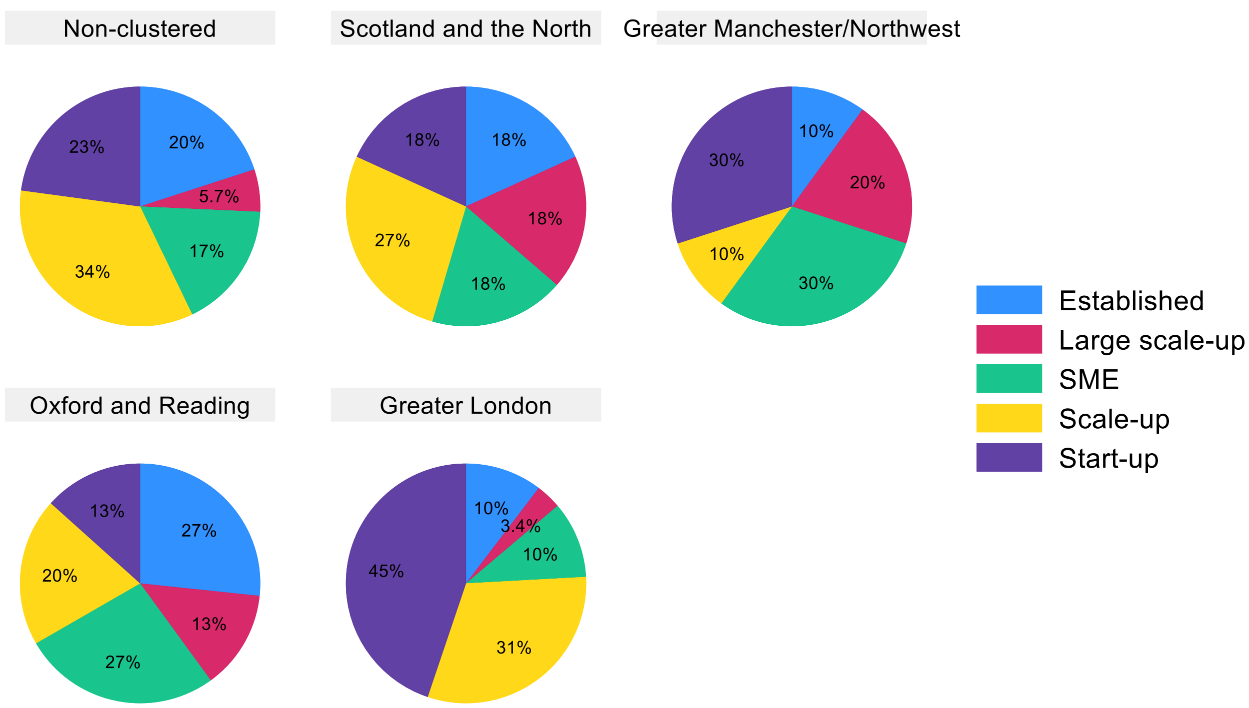

Figure 4.6: Growth stages of firms by spatial cluster

Table 5: Descriptive statistics by spatial cluster

	Number of employees	Growth (%)	IUK funding	Deal room	Spinout
Scotland and the North					
Mean	16	0.21	620393	18.71	0.18
Median	8	0.03	216415	6.1	0
Std, Dev	14	0.36	807685	25.72	0.40
Min	2	-0.27	0	0	0
Max	39	0.80	2270777	72	1
N	11	10	8	9	11
Greater Manchester/Norwest					
Mean	16	0.55	768128	7.37	0.2
Median	6	0.16	356275	0.25	0
Std, Dev	25	0.78	918900	13.62	0.42
Min	0	-0.07	193269	0	0
Max	70	2.00	2582059	31.4	1
N	10	8	6	5	10
Oxford and Reading					
Mean	16	0.25	1131026	25.67	0.33
Median	7	0.03	525889	24.51	0
Std, Dev	22	0.71	1439732	25.54	0.49
Min	0	-0.56	9876	0	0
Max	80	1.65	3973820	54.31	1
N	15	10	10	6	15
Greater London					
Mean	6	0.29	581942	5.76	0.07
Median	4	0.27	309058	3.91	0
Std, Dev	8	0.24	652610	6.68	0.26
Min	0	0	18280	0	0
Max	39	0.65	2264645	22.52	1
N	29	12	13	15	29
Non-clustered firms					
Mean	69	0.27	528850	32.43	0.05
Median	6	0.14	397510	20	0
Std, Dev	298	0.39	505706	45.44	0.24
Min	0	-0.19	0	0	0
Max	1772	1.52	1741701	150	1
N	35	20	16	11	35

Section 5: The infrastructure landscape of non-health applications of Engineering Biology in the UK

5.1 Introduction

In line with our framework for innovation and commercialisation infrastructure in emerging technologies (Jibril et al. 2023), infrastructure which supports commercialisation includes both physical assets and 'soft' infrastructure. In this context, 'soft infrastructure' includes institutions and organisations that provide resources, services and networks which support innovation and commercialisation. Our focus is on organisations and facilities that are open access.

The research and commercialisation value chain can be thought of as having different stages - early-stage research, industrial translation and demonstration, the commercialisation of new products and scaling up. Both physical and soft infrastructure can support different stages of the innovation and commercialisation process.

To accommodate the types of organisations supporting Engineering Biology in the UK, we adapt our original infrastructure framework to delineate three broad categories of soft infrastructure and four categories of physical infrastructure.

Soft infrastructure:

Research and Innovation Ecosystem Enabling Organisations (EEOS) are organisations that fund Research and Innovation in Engineering Biology. They include funding organisations such as UKRI, IUK, BBSRC, EPSRC MRC, and DSTL. Together with key policy actors such as Government departments, these organisations provide a 'System Guidance' function to the innovation system (Bergek et al., 2008); they provide targeted and strategic organisational investments in Engineering Biology to support knowledge creation, knowledge diffusion, or both.

Strategic Coordinating Organisations (SCOs) include organisations such as sectoral bodies, trade organisations and Knowledge Transfer Networks that are regarded as credible integrators of knowledge in the Engineering Biology field. They include organisations like the (former) *Engineering Biology Leadership Council, the Industrial Biotechnology Leadership Forum* and the *Innovate UK Knowledge Transfer Networks*. These organisations often work closely with R&I ecosystem enablers to develop and implement the strategic direction for Engineering Biology. They may also function as thought leaders, widely recognised as key players in the innovation system and may hold considerable convening power within the sector. They enable 'Knowledge Diffusion through Interaction' (Bergek et al., (2008) by facilitating knowledge flows within the innovation system, identifying and integrating useful knowledge from outside the system, and by serving as intermediaries for collaboration.

Industry and Research Networks also include organisations such as sectoral bodies and trade organisations, but unlike strategic coordinating organisations, they typically have a narrower research, industry or geographical focus, and they are further away from the strategic activities of R&I ecosystem enablers. Nevertheless, they provide important soft support to their members, including providing networking opportunities, bringing together research and industry actors, making introductions to potential investors, signposting members to funding opportunities, etc. These include organisations such as the *Bio-Industry Association*.

Physical infrastructure:

Research and Translation (R&T) infrastructure refers to facilities and assets that support basic Engineering Biology research as well as research aimed at proving the feasibility of the technology, for example through experimental proofs of concepts. These are usually laboratory or bench scale facilities with very small fermentation capacities (typically less than 10L) and with little or no downstream processing capabilities. This infrastructure tends to support Technology Readiness Levels (TRL) 1 to TRL 3.

Translation and Demonstration (T&D) infrastructure encompasses facilities and assets that support the industrial translation of research, moving beyond lab validation to validation in the relevant environment, enabling, for example, the development of prototypes in Engineering Biology. These facilities typically operate at semi-pilot scales with medium-scale fermentation capacities and limited down-stream processing capabilities, mainly supporting TRL 3 to TRL 5

Demonstration and Commercialisation (D&C) infrastructure are larger scale facilities, typically operating at pilot and demonstration scales, with larger fermentation capacities and well-developed downstream processing capabilities. These facilities may support up to TRL 9.

Commercialisation and Scale-up (C&S-up) facilities tend to be similar to Demonstration and Commercialisation facilities, except they focus more on products that have already achieved a degree of market penetration, supporting these to produce at levels that deepen market penetration or enable scale-up. This category may also include seed funding organisations that direct significant investment to Engineering Biology start-ups and scale-ups.

There is, of course, considerable overlap in functions across different categories of infrastructure. The classification above recognises this, and the categories represent the *highest* TRL levels each facility supports. It is also worth clarifying that for both T&D and D&C infrastructure, we use ‘Demonstration’ in the sense of *technology readiness* as opposed to the scale of biomanufacturing facilities offered.

5.2 Characterising the UK infrastructure landscape for Engineering Biology

To identify soft and physical infrastructure that supports Engineering Biology in the UK, we searched the UK and international repositories of Engineering Biology facilities, reviewed previous Government and other stakeholder reports on Engineering Biology, and consulted numerous stakeholders. For the physical infrastructure, we additionally obtained data from i) *Capacitor,* a directory of global fermentation facilities; ii) Pilots4U, a European database of biotechnology semi-pilot, pilot and demonstration scale facilities; and iii) *Infraportal*, a UK database for research and innovation infrastructure. We also conducted broad web searches with key terms such as ‘bioreactors’, ‘downstream processing’, ‘biomanufacturing facilities,’ ‘fermentation capacity,’ and so on.

We identified a total of twenty-seven organisations providing soft support, including: seven Ecosystem Enabling Organisations, five Strategic Coordinating Organisations, nine Research Networks and six Industry Networks. For physical infrastructure, we identified twenty-one Research and Translation facilities: of these, five are purely research facilities, and three are digital databases supporting biotechnology research. Not included here are the Synesthetic Biology Research Centres, which closed down in 2022, although the underlying research infrastructure likely remains; it is anticipated that these SBRCs will be replaced with new UKRI Engineering Biology Mission Hubs[9]. We identified thirteen facilities that support both research and early-stage translation (these include bio-foundries and similar facilities). Additionally, we identified eight Translation and Demonstration facilities, four Demonstration and Commercialisation facilities, and only one Commercialisation and Scale-up facility- Biocatalysts, a commercial facility located in Wales.

Overall, therefore, we identified a total of sixty-one open-access organisations and facilities serving as soft and physical infrastructure that support the non-health Engineering Biology innovation system in the UK. 44% of these are 'soft' infrastructure, 34% of the organisations are focused on research and early-stage translation, 13% support Translation and Demonstration at a semi-pilot scale, 7% support demonstration at a pilot scale and commercialisation, and one organisation (2%) supports commercialisation and scale-up activities (Figure 5.1). This pattern is consistent with the premise that the UK has a strong research base with numerous facilities at lower TRLs and fewer at higher TRLs. As we will show later, however, there are geographical variations in this pattern, with a few areas having particular strengths in higher TRL support.

[9] https://www.ukri.org/opportunity/engineering-biology-missions-hubs-and-mission-awards/

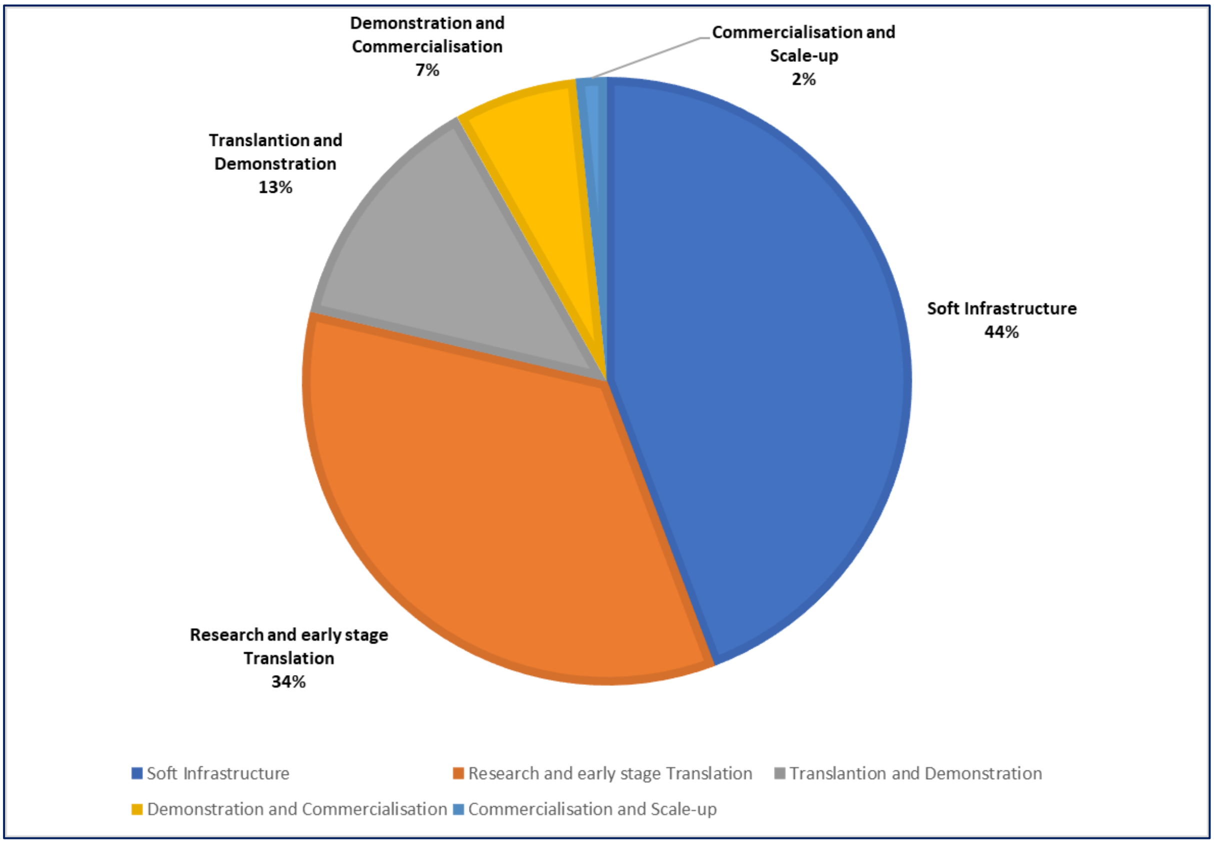

Figure 5.1: Proportion of soft and physical infrastructure supporting UK non-health applications of Engineering Biology

Table 6 shows a list of all the elements of infrastructure we have identified, their category within our infrastructure framework, and their geographical location. Figure 5.2 maps these infrastructures onto our infrastructure framework, indicating whether these organisations are privately owned (PV) or publicly funded (PB). Many physical facilities offer soft business support such as market research, connecting businesses to investors or other funding opportunities, and Techno-Economic Assessments.

Looking specifically at the seven Demonstration and Commercialisation facilities, two new pilot scale facilities, both launched in the last quarter of 2023, offer services specific to Agri-food applications. These are Extracellular, located in Wales and serving firms working in Cultivated Meat and the CPI's Novel Food Innovation Centre in Wilton. Both of these facilities have a capacity of up to 10,000L bioreactors and appropriately scaled Downstream Processing facilities. Non agri-food applications are supported at this scale by the CPI's Industrial Biotechnology facility (Wilton) and SynbiCITE, the UK's Innovation and Knowledge Centre for Synthetic Biology (London).

For Commercialisation and Scale-up, Biocatalysts represents the only open-access organisation we identified which goes beyond pilot scale to offer businesses commercial scale biomanufacturing services. Their services appear to cover food, pharmaceutical and Industrial Biotechnology, with 20,000L fermentation capacity, including onward capabilities of 63,000L and full downstream processing capabilities.

Although not focusing on Engineering Biology, it is worth noting the role of Crop Health and Protection (CHAP) and the National Institute of Agricultural Botany (NIAB); these organisations support the broader agricultural technology sector and, as part of this, provide support for some Agri-food applications of Engineering Biology, including crop transformation services, incubation services and large facilities that can allow commercial cropping or field trials. They are excluded here because agricultural *biotechnology* is not the main focus of these organisations, and their services are distinct from those offered by dedicated biomanufacturing facilities.

Table 6: List of Soft and Physical UK Infrastructure for Engineering Biology

Infrastructure	Framework position	Location
Soft infrastructure		
Ecosystem Enabling Organisations (EEOs)		
1. Biotechnology and Biological Science Research Council (BBSRC)		Cross cutting
2. Defence Science and Technology Laboratory (DSTL)	EEO	Cross cutting
3. Engineering and Physical Sciences Research Council (EPSRC)	EEO	Cross cutting
4. Research England	EEO	Cross cutting
5. Innovate UK	EEO	Cross cutting
6. Medical research Council (MRC)	EEO	Cross cutting
7. UK Research and Innovation (UKRI)	EEO	Cross cutting
Strategic Coordinating Organisations (SCOs)		
8. Engineering Biology Leadership Council*	SCO	Cross cutting
9. Industrial Biology Leadership Forum (IBLF)	SCO	Cross cutting
10. Royal Academy of Engineering	SCO	Cross cutting
11. Innovate UK Knowledge Transfer Network (KTN)	SCO	Cross cutting
12. National Non-Food Crops Centre (NNFCC)	SCO	York
Research and Industry Networks		
13. Biomass Biorefinery Network (BBNet)	Research Network	Cross cutting
14. E3B: Elements of Bioremediation, Biomanufacturing & Bioenergy:	Research Network	Cross cutting
15. Algae-UK	Research Network	Cross cutting
16. Carbon Recycling NIBB	Research Network	Cross cutting
17. EBNet: Environmental Biotechnology Network	Research Network	Cross cutting
18. HVB: High Value Biorenewables Network	Research Network	Cross cutting
19. Royal Academy of Engineering	Research Network	Cross cutting
20. Royal Society of Biology	Research Network	Cross cutting
21. Royal Society of Chemistry	Research Network	Cross cutting
22. Chemical Industry Association	Industry Network	Cross cutting
23. IBioIC- Engineering Biology Innovation Centre	Industry Network	Scotland
24. Bio-Yorkshire	Industry Network	York
25. BBIA- Bio based and Biodegradable Industries Association	Industry Network	Cross cutting
26. BIA- Bioindustry association	Industry Network	Cross cutting
27. BioProNET	Industry Network	Manchester
Physical infrastructure		
Research only and Research and Translation (R&T) facilities		
28. MRC lab for molecular biology foundry	Research	Cambridge
29. Hub for Biotechnology in the Built Environment (HBBE)	Research	Newcastle
30. The Sainsbury Laboratory	Research	Norwich

Infrastructure	Framework position	Location
Soft infrastructure		
Ecosystem Enabling Organisations (EEOs)		
31. The James Hutton Institute	Research	Scotland
32. Quadram Institute	Research	Norwich
33. EMBL-EBI- Bioinformatics and data	Research (database)	Cambridge
34. Agrimetric	Research (database)	Hertfordshire
35. Bio-FAIR	Research (database)	Crosscutting
36. BrisSynBio	R&T	Bristol
37. Liverpool Gene Mill foundry	R&T	Liverpool
38. DNA synthesis and construction foundry	R&T	London
39. Future Biomanufacturing Research Hub	R&T	Manchester
40. Earlham Biofoundry	R&T	Norwich
41. Genome Analysis centre (foundry)	R&T	Norwich
42. Edinburgh Genome Foundry	R&T	Scotland
43. Roslin Institute	R&T	Scotland
44. Activatec Biobased Ingredients**	R&T	Nottingham
45. Teesside University's National Horizons Centre	R&T	Teesside
46. IBERS- Institute of Biological, Environmental and Rural Sciences	R&T	Wales
47. Fera Science	R&T	York
48. Rothamsted Research	R&T	Hertfordshire
Translation and Demonstration (T&D) facilities		
49. Centre for Biochemical Engineering (ACBE).	T&D	London
50. Henry Royce Institute	T&D	Manchester
51. John Innes Centre	T&D	Norwich
52. BioComposites Centre	T&D	Wales
53. Isomerase Therapeutics**	T&D	Cambridge
54. IBioIC - FlexBio and Rapid Bio	T&D	Scotland
55. Biotech Business Incubation Centre (Bio BIC)	T&D	Liverpool
56. Biorenewables Development Centre (BDC)	T&D	York
Demonstration and Commercialisation (D&C) facilities		
57. SynbiCITE	D&C	London
58. Centre for Process Innovation (CPI)	D&C	Wilton
59. Extracellular**	D&C	Bristol
60. Science Creates (Eng Bio Accelerator) **	D&C	Bristol
Commercialisation and Scale-up (C&S-up) facilities		
61. Biocatalysts**	C&S-up	Wales

Notes:
*At the time of writing, the Engineering Biology Leadership Council is winding down
**These organisations are commercial but open access facilities offering contract facilities.

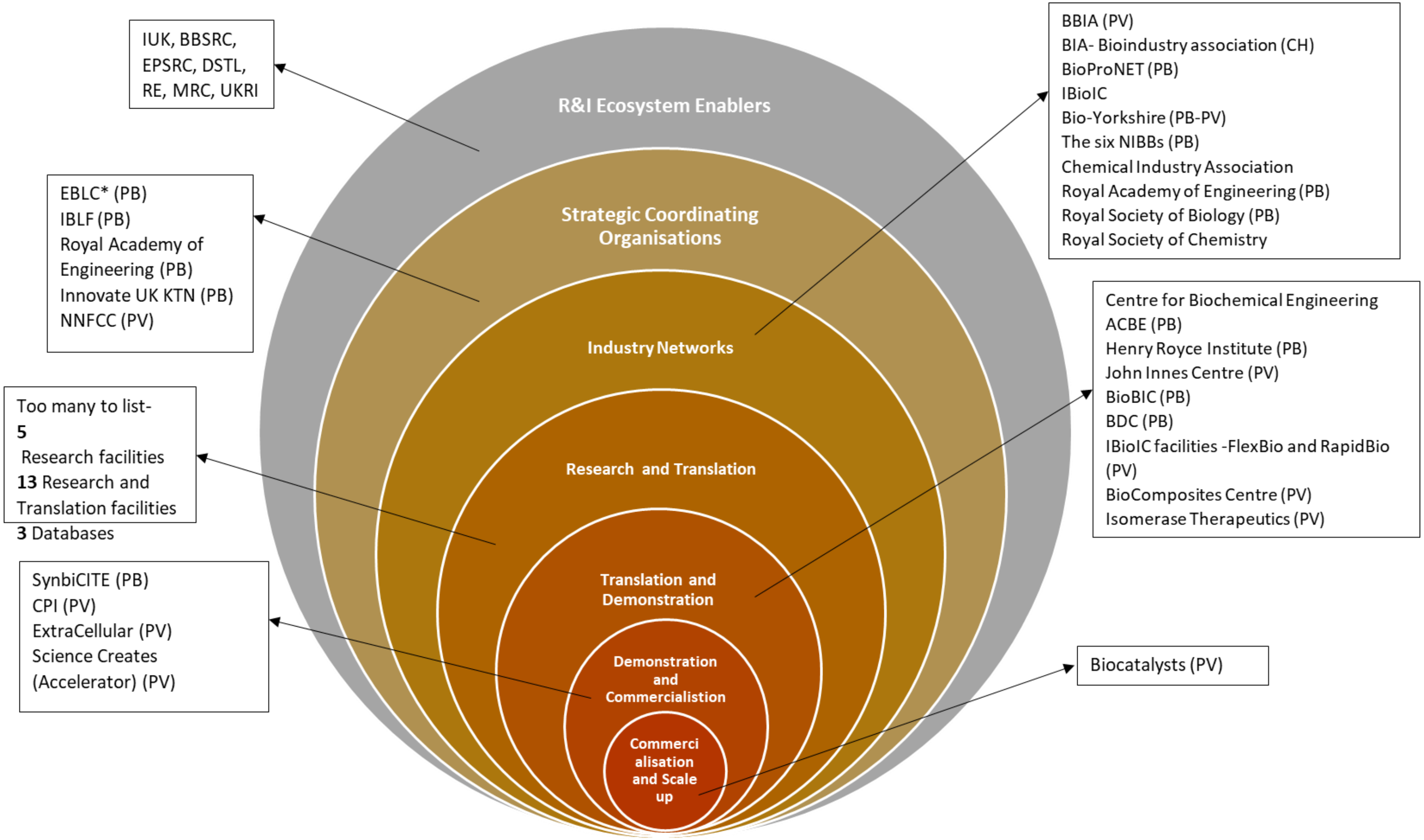

Figure 5.2: The Infrastructure landscape for Engineering Biology in the UK

Notes: * At the time of writing, the EBLC is winding down.

5.3 Geographical Distribution of Engineering Biology UK Infrastructure

Many of the elements of soft infrastructure we identified have a national presence, including all of the Ecosystem Enabling Organisations (See Table 6). Figure 5.3 shows the geographical distribution of the infrastructure we identified relative to the seven clusters of Engineering Biology applications identified in Section 3.13. With the exception of Yorkshire and Teesside, most of the physical infrastructure we identify is proximally located within the seven clusters of non-health applications of Engineering Biology[10].

[10] Many companies in Yorkshire and Teesside tend to focus on pharmaceutical and health applications.

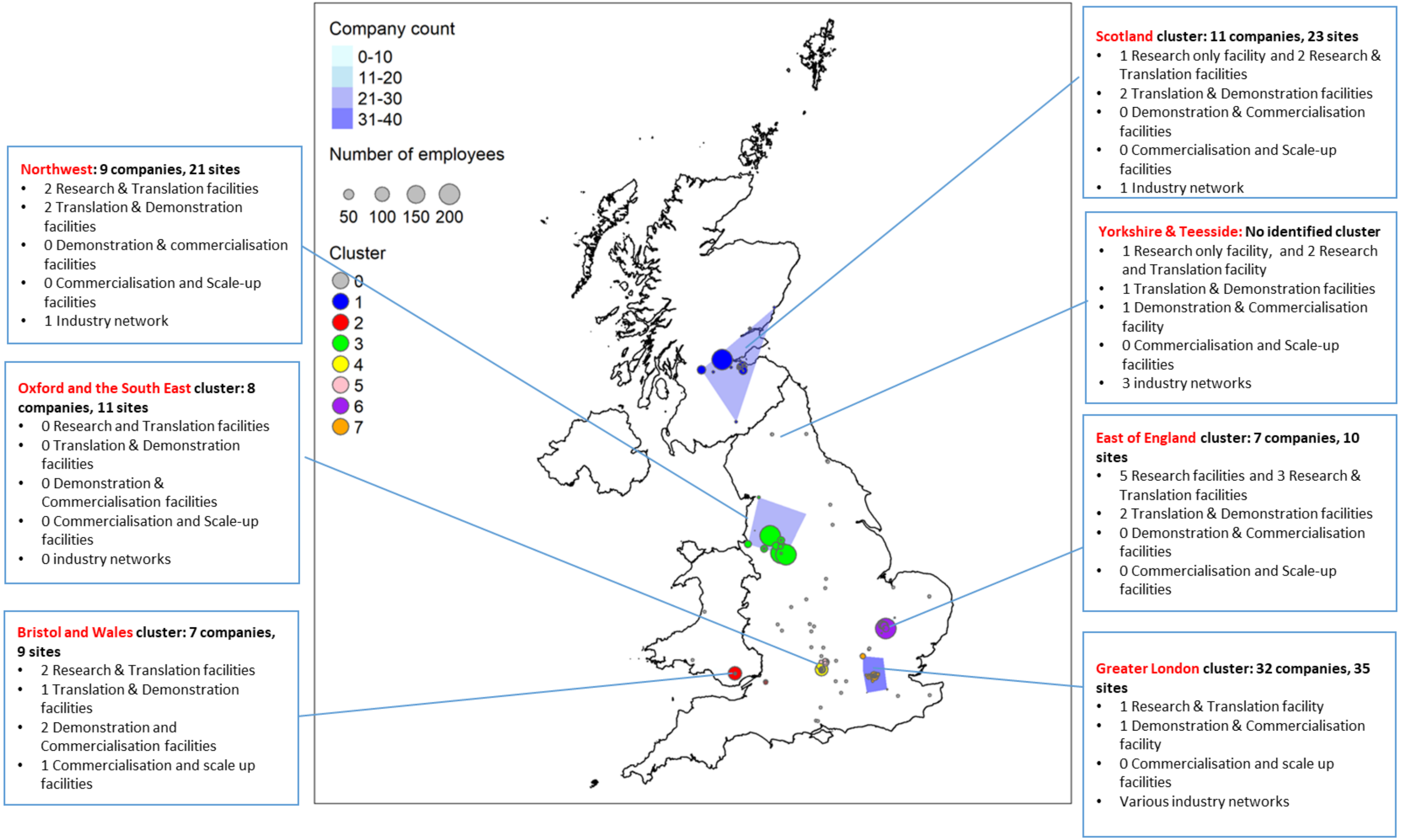

Figure 5.3: Locations of focal Engineering Biology companies and open-access support organisations

Scotland

In Scotland, there are number of facilities supporting Research and Translation and Translation and Demonstration, but there is a gap in Demonstration and Commercialisation and Commercialisation and Scale-up facilities (Table 7). This evidence suggests a gap in provision at TRL 5 and above for most applications of Engineering Biology in Scotland. IBioC provides a geo-specific industry network here.

Table 7: Infrastructure supporting non-health Engineering Biology in Scotland

Type of infrastructure	Organisation and location
Research	The James Hutton Institute
Research & Translation	Edinburgh Genome foundry Roslin Institute
Translation and Demonstration	IBioIC facilities- FlexBio and Rapid Bio
Networks	IBioC

Notes: FlexBio and RapidBio are the physical infrastructure elements of IBioC

Yorkshire and Teesside

We identify numerous Engineering Biology facilities in Yorkshire and Teesside although we do not identify a cluster of firms with *non-health* applications; it is possible that this area is dominated by pharmaceutical applications of engineering biology. Yorkshire and Teesside not only have good Research and Translation and Translation Demonstration facilities but also some of the UK's best Demonstration and Commercialisation facilities (CPI which supports on Biotechnology and Novel Foods). This region also houses Crop heath and Protection Innovation Centre (CHAP) (York) which, although not dedicated to Engineering Biology, supports some activities of businesses with Agri-food applications. Yorkshire and Teesside area is also well networked (through BioYorkshire) as well as NIBB research networks and the NNFCC which are headed out of York but serve cross-cutting locations (Table 8). Yorkshire and Teesside, therefore, appear to have strong innovation and commercialisation Engineering Biology business infrastructure.

Table 8: Infrastructure supporting non-health Engineering Biology in Yorkshire and Teesside

Type of infrastructure	Organisation and location
Research Only	Hub for Biotechnology in the Built Environment (HBBE)
Research & Translation	Teesside University's National Horizons Centre (Teesside) Fera Science
Translation and Demonstration	Biorenewables Development Centre (BDC) (York)
Demonstration and Commercialisation	Centre for Process Innovation (CPI) (Wilton)
Networks	BioYorkshire (York) National Non-Food Crops Centre (NNFCC) (York, but services are cross cutting) NIBBs (York, but services are cross cutting)

Greater Manchester/ Northwest

Greater Manchester is also well served by Engineering Biology Research and Translation and Translation and Demonstration facilities and has one industry network (BioProNET) but has no Demonstration and Commercialisation facility and no Commercialisation and Scale-up facility. Similar to Scotland, this suggests a gap in the provision of facilities serving TRL 5 and above in the Northwest.

Table 9: Infrastructure supporting non-health Engineering Biology in Greater Manchester/ Northwest

Type of infrastructure	Organisation and location
Research & Translation	Future BHR Liverpool Gene Mill foundry
Translation and Demonstration	Henry Royce Institute BioBIC (Liverpool)
Networks	BioProNET

East of England

The East of England has various Research and Translation as well as Translation and Demonstration facilities supporting non-health applications of Engineering biology, located mainly in Cambridge and Norwich. Translation and Demonstration facilities are provided by the John Innes centre as well as Isomerase therapeutics, a commercial but open access facility supporting applications in pharmaceutical, as well as agricultural and consumer product applications. There are no Demonstration and commercialisation facilities and no Commercialisation and Scale-up facilities dedicated to non-health Engineering Biology, although Cambridge University spinouts in Engineering Biology have the opportunity to receive much needed investment funding from Cambridge Enterprise, the University-affiliated seed funding organisation. The National Institute of Agricultural Botany (NIAB) in Cambridge provides incubation and field trail facilities for agri-tech businesses and so may be relevant for some agri-food applications of Engineering Biology, but this is not its main focus. Overall, the East of England appears to have a vibrant support ecosystem at low and mid-TRL levels. However, as with Scotland and the Northwest, lacks larger demonstration, commercialisation and scale up facilities that can cater to non-health applications of Engineering Biology.

Table 10: Infrastructure supporting non-health Engineering Biology in Cambridge and the East of England

Type of infrastructure	Organisation and location
Research	MRC lab for molecular biology (Cambridge) The Sainsbury Laboratory (Norwich) Quadram Institute (Norwich) EMBL-EBI and Agrimetrics databases (Cambridge and Hertfordshire)
Research & Translation	Genome Analysis Centre (Norwich) Earlham Biofoundry (Norwich) Rothamsted Research (Hertfordshire)
Translation and Demonstration	Isomerase therapeutics (Cambridge) John Innes Centre (Norwich)

Greater London

Similarly, Greater London has some Research Translation Demonstration and Commercialisation facilities (including SynbiCITE) but no (open-access) Commercialisation and Scale-up facility (Table 11). Again, there appears to be a gap in the provision of commercial scale facilities even in London. Note, however, that privately held biomanufacturing facilities may exist at higher TRL levels but may not be open access (such as Tate and Lyle), and so are out of the scope of this study.

Table 11: Infrastructure supporting non-health Engineering Biology in Greater London

Type of infrastructure	Organisation and location
Research & Translation	DNA synthesis and construction foundry (London)
Demonstration and Commercialisation	Centre for Biochemical Engineering (London) SynbiCITE (London)
Networks	Various Networks Headquartered in London

Oxford and the South East

The picture is somewhat different in Oxford and the South East. Here, despite a significant business cluster, we found no open access facilities supporting non-health applications of Engineering Biology. Here, as in London, private biomanufacturing facilities exist but may not be open access (such as Rebio or GSK, although the latter may focus more on pharmaceutical applications). As in Cambridge, Oxford University spinout companies in Engineering Biology have the opportunity to receive investment funding from Oxford University's seed funding organisation, Oxford Seed Fund. Our business landscape analysis suggests that over half of the companies here are established, with a low proportion of early start-ups, and over a third of the companies are University spinouts. This suggests that non-health Engineering Biology activities may be predominantly carried out by larger embedded organisations or spinouts with access to University facilities. More research is needed into the activities of firms in this cluster and the facilities that support them.

Bristol and Wales

Bristol and Wales have a number of Research and Translation and Translation and Commercialisation facilities as well as two Demonstration and Commercialisation facilities. These include the recently launched (commercial) pilot scale facility dedicated to cultivated meat (ExtraCellular) as well as the UKRI-funded Engineering Biology Accelerator delivered through Science Creates. Bristol is also home to the only Commercialisation and Scale-up facility we identified- Biocatalysts. This commercial and open access facility goes beyond pilot scale to deliver commercial scale upstream and downstream processing capabilities. Bristol and Wales thus appear to have strong support for both lower and higher TRL activities.

Table 12: Infrastructure supporting non-health Engineering Biology in Bristol and Wales

Type of infrastructure	Organisation and location
Research & Translation	BrisSynBio (Bristol) Institute of Biological, Environmental and Rural Sciences (IBERS)
Translation and Demonstration	BioComposites Centre (Wales)
Demonstration and Commercialisation	ExtraCellular (Bristol) Science Creates (Bristol)
Commercialisation and Scale-up	Biocatalysts (Wales)

Section 6: Business perspectives on current Engineering Biology infrastructure provision

6.1 Introduction

We conducted in depth, semi-structured interviews with 18 Engineering Biology companies: Seven companies were in Agri-food, five were in Chemicals and six were in Materials applications. No companies were interviewed that had Environment applications of Engineering Biology. The interviews explored the ways in which Engineering Biology applications are commercialised, the main target markets, the barriers companies face in commercialising and scaling up, and their view on the gaps in infrastructure provision. The interviews were recorded, transcribed and analysed by Engineering Biology application. Below, we present a summary of the findings for each application; a more detailed exposition is given in Annex 4.

6.2 Agri-food

Firms interviewed.

Here, we interviewed seven firms with 3 to 50 employees. Three had spun-out of universities or university research centres, and a fourth was located near a university for access to talent. One firm is head-quartered in the US with a UK piloting facility. The oldest was established in 2013, and the youngest was established in 2022. They are engaged in various activities, including bio-manufacturing of food waste, protein ingredient development from natural and microbial fermentation, meat cultivation from animal cells and antibiotics and development of seeds for sustainable protein crops.

Commercialisation Pathways in Agri-food applications

A range of pathways to market were discussed, including licencing and outsourcing:

> *‘Licencing is something that we're thinking about in the future because we don't intend to be an owner-operator for all our plants, we just don't have the capital or the size of the business to support that.’ Agri-food 2*
>
> *‘(If we outsource), we wouldn't have to fundraise, wouldn't have to manage the facility, etc. In some ways it's less risky, in some ways it's more risky because you don't control your production process.’ Agri-food 7*

Other options include direct selling, joint ventures with manufacturers, strategic partnerships with producers with joint Intellectual Property and royalties, sales via larger producers (who will pay a royalty in some cases), making available to labs for further testing subject to an evaluation fee, and developing manufacturing facilities. Firms are also exploring commercialising products which emerge through the R&D process, such as growth factors or bioreactor technology, as well as the ‘end’ product.

Although most firms’ current stage of development is in the UK, most are looking abroad for further commercialisation activity, drawn by finance and better commercialisation facilities and prospects. The cultivated meat firm is ‘*proudly British, but there's a lack of capacity and resource to even regulate these types of products*’.

Use of existing infrastructure in Agri-food applications

Some Engineering Biology firms had received R&D funding (e.g., BBSRC or Innovate UK), but most had private investment or were self-funded through their own contract research activities. Most were using their own (sometimes bespoke) equipment and facilities, but some used university research park facilities. One was located at the National Institute for Agricultural Botany (NIAB). Most were contemplating how to develop. One option is the Centre for Process Innovation (CPI):

> *'There are only a couple of facilities in the UK (*including CPI) *that we are aware of that do this outsource manufacturing, tech transfer-type supporting activities, but they're very expensive, ridiculously expensive.' Agri-food 3*

> *'Those places work because they're getting funded from PLCs. They're not a solution for an SME. [CPI is] ...over spec'd because they are looking primarily at active ingredients like pharmaceutical ingredients… and it's not approved for food.' Agri-food 6*

One firm was aware that the CPI is opening a Novel Foods Innovation Centre, which will add to the infrastructure, but is disappointed it did not get funding:

> *'It could have been so much better with a little bit of foresight from whoever is making the decisions about where funding goes.' Agri-food 2*

Some facilities which firms suggested they might progress to were at capacity (John Innes Centre and Rothamsted), and others had facilities but were considered unsuitable (FERA). One firm had found ICURE helpful. No facilities are available for some sectors (e.g., meat cultivation).

All Engineering Biology Agrifood firms had networks which were considered useful for promotion, finding customers and keeping abreast of government thinking. Network membership costs were an issue for some. The Good Food Institute is a thought leader in the sector on alternative protein. Networks are useful in early-stage development, but approaching launch, people tend to '*keep their cards close to their chest'*.

Barriers to commercialisation in Agri-food applications

A number of barriers were cited, including:

- Access to Scale-up fermentation equipment, e.g., from demonstration facilities to larger scale:

  > *'We've scaled up in our small fermentation pilot plant here, we've scaled in another site, and we're now talking with CMOs. We've had samples out to commercial customers in the product kilogrammes range, but they want us to be making tonnes. And it's the tonnes bit that is the stumbling block at the moment in terms of the a) cost and b) finding manufacturers to do that.' Agri-food 6*

- Access to food grade drying facilities; those available often prioritise pharmaceutical clients, the prohibitive cost of available equipment, and lack of space for the development of R&D investment:

  > *'If you look at the investment happening in biotech, Innovate UK is supporting so many companies, and then if you look at facilities available to execute those, you'll see that there's a gap.' Agri-food 4*

- Lack of access to finance, particularly outside London and for demonstration activities, attributed to investors' requirement for more certainty around the market and product.

- UK regulatory uncertainty for novel foods like cultivated meat, unlike in the US, Singapore & others.
- Insufficient public funding opportunities were also cited:

> *'Smart awards are so competitive, and you tend to lose out to Pharmaceuticals, tech gadgets, sensors, those sorts of things. Sexy stuff. We've applied for two smart awards over the last few years and we've got scores in the 80 to 85% range and not got funded.' Agri-food 6*

- Requirement to collaborate for Innovate UK funding which is costly & '*doesn't seem worthwhile'.*
- Shortage of skilled people necessitating recruitment from abroad, for example:

> *'There's a limited number of the right types of scientists for this emerging industry. So, we have to look not just in the UK, but out with to get some of the capability and skills that we need.' Agri-food 1*

- Rural location making it problematic to attract scientists.
- Difficulty getting results data back on Scale-up because '*in a very secretive emerging sector, not everybody wants to share everything'*.
- Technical challenges of complex processes, e.g., cultivating meat.

Infrastructure requirements in Agri-food applications

There was broad agreement that the UK requires specialised biomanufacturing innovation centres. A need for larger scale fermentation facilities and large-scale bioreactors was also cited by a number of firms:

> *'… precision fermentation, which is a big emerging theme, for instance expressing recombinant proteins in yeast to replace dairy, milk or of albumin to replace eggs - that's a big investment area at the moment. It requires food grade fermentation space. Sometimes there's going to be nuances on how you actually separate out those proteins and what you're going to do with them. But, it's food grade fermentation scale piloting early stage. It's a little bit of a bridge between our level of food grade, which is just a whole cell ingredient which is really simple, to almost like a pharmaceutical aspect in terms of a little bit more technically challenging to get the proteins out.' Agri-food 6*

Kit, which enables process improvements, such as automated cell counters and electronic equipment, and ancillary equipment, such as preparation facilities for mixing, were also identified. Also, a step-change is needed to move from R&D to commercialisation support:

> *'The number of potential small businesses that could be created out of our universities is huge. But they need to gravitate towards somewhere. We need to model what's been done in Oxford and Cambridge, with the tech sensors, in biotechnology. We seem a little bit disparate, spread out and lacking that critical mass and that vision.' Agri-food 2*

> *'If Innovate UK were to follow businesses all the way through their journey, it's only at that TRL 5 to 9 where the impact can be so big it outweighs anything else that was done before that. A couple of big companies making thousands of tonnes of product from 10,000, 50,000 tonnes of*

> *biomass is going to have a significant impact compared to supporting a business for £150,000 on a lab-based project.' Agri-food 3*

Equipment should be accessible through fast-track funding through a non-competitive, expert assessed basis or through vouchers of £50,000-£100,000, as is available on the continent. Open-access research is also desirable:

> *'What I don't want when I speak to organizations is 'Let's come up with a 2-year project plan that we can deliver together'. And I'm like, 'that just sounds like bureaucracy'. Agri-food 7*

> *'What would be really spectacular to see is some of these facilities also doing their own research and making it public, which you could argue is what academic Institutes do, but they're just very slow. They're aiming for perfection. What we're aiming for is practical solutions and we need a bridge between those two.' Agri-food 7*

Developing a hub in an efficient and effective way would put the UK on par with competitor nations. This efficiency could be achieved by having:

> *'A very clear strategy (based on) the markets where the UK has an opportunity. How does that relate to the infrastructure that we currently have? If the research suggests that we should put between 4 and 5 of these hubs throughout the UK, around science clusters, with a high degree of collaboration, linking up sources of investment with needs for investment…. it's just a well thought through strategy and plan.' Agri-food 1*

Practically, however, *'each company will have slightly different requirements for these sorts of facilities' (Agri-food 5)*

Outsourcing too much activity risks that '*you don't maintain any IP, and really you're not generating any value in the company'*. Technology sharing must be balanced against protecting know-how.

International comparisons of infrastructure for Agri-food applications

The UK is seen as strong in some science clusters and with a good brand. However, Brexit means regulatory uncertainty and has cut routes to investors and skills. Other countries (e.g., Switzerland, Netherlands, Belgium and Germany) are supporting Engineering Biology commercialisation through clearer leadership, investment, a longer-term vision and critical mass. Respondents have been approached to relocate or been offered facilities at a discount. Seeking multi-capacity Scale-up equipment, on one site, with drying facilities and operating at food grade, one firm has:

> *'found a lovely one in Belgium. That's a government facility and even if it's a bit more expensive, having the capability to go through kilogrammes, to a tonne, to 10 tonnes, all in one place, all with one conversation, all with one team of people, I'm paying more for that.' Agri-food 6*

> *'Their (European) understanding of biotech solutions and biotech work is significantly higher because in Europe they do a lot of it. The problem in the UK is we don't do enough of it. It's it feels like sometimes it's a bit of a taboo.' Agri-food 3*

Singapore has a strategic approach to biotech and has approached a firm interviewed:

> *'Singapore are pitching quite hard for us to stop doing what we're doing in (UK) and move it all to Singapore where they give you money, but then you've got to spend your money in Singapore with Singapore universities on Singapore citizens doing the work in Singapore. They also facilitate getting regulatory approval ….and they've got the big Fast-Moving Consumer Goods*

> *corporates …and the big ingredient companies to put a hub base in Singapore as well, which they probably paid for. So, you end up with this real ecosystem. They're being very aggressive because they see next generation food and next generation biotechnology as one of the things to bet on.' Agri-food 2*

One respondent cited European facilities on the continent set up by the milk industry and sugar industry, but with 50% vouchers offered by regional government:

> *'There are industry aligned research places that are set up for start-up or early tonnes. They're probably set up because the bigger businesses want to try different things technically and they didn't want to do it on their main factory plant. And that sort of thing seems to exist more elsewhere than it does in the UK.' Agri-food 6*

Although this firm had received a Joint Development Agreement from a major manufacturer, they seemingly do not invest in this type of equipment which could be utilised sector-wide.

Another respondent was aware of how INRA[11] in France contacted funded organisations at the end of the project to ask about the next steps to introduce them to potential commercial partners, making 100k – 1 million Euros available on a competitive basis to those projects and taking a percentage back from commercial sales.

> *'I think this could be a model for start-up, especially in biology.' Agri-food 4*

6.3 Materials

Firms interviewed

Here, we interviewed 6 Engineering Biology Materials firms, all with fewer than 20 employees. Five are based in the South East region of England and one in Scotland. The oldest was established in 2002, and the youngest was established in 2019. All are founded or led by individuals with specialised scientific backgrounds in chemistry, bioscience and engineering. Only one of the firms interviewed is a university spin-out. Firms are engaged in developing new materials that can be used as end-products or as add-ons to the processing and development of existing materials.

Commercialisation pathways in Materials applications

Early-stage introduction of a new product to the market requires significant personal interaction between the biotech firms and decision-makers in prospective clients. Personal recommendations, trade shows, conferences and network events are predominantly used at this stage.

> *'We've recently launched our website. And now our social media channels have relaunched with lots of different content. But before that a lot of it was word of mouth. Different kind of conferences, networking events. The CEO goes a lot of these and meets lots of people, but also our investors put the company in touch with other companies.'*

More established firms rely mostly on their company website for marketing and maintaining their existing supply chain.

[11] https://www.inrae.fr/en/bioeconomy

> *'People tend to come to us rather than us going to them… mostly, we work via website, we're just doing a new website ... that's probably how most people find us.'*

The majority of firms' commercialisation and R&D activities are located in the UK, near the firm founder.

Use of existing infrastructure in Materials applications

Most respondent firms undertake their core R&D activities in private laboratory facilities. The specialist piloting and testing equipment required is often not available in biotech support centres:

> *'I don't think just adding more centres help necessarily. The issue with some of the centres is that they end-up stagnating. The existing centres need to be pushed to refresh their equipment and services to continue to remain relevant.'*

Where access to equipment is available it is often seen as too costly. Support centres are generally not proactive in supporting firms that come to them. Having a better understanding of what other centres offer would help them direct firms to such places when necessary.

Some firms accessed funding through Innovate UK, the Enterprise Investment Scheme, UKRI through ICAST and other local bodies. However, most grants were secured at the research and development stages of the processes. There is seen as very little help for scaling up and commercialisation and expertise is difficult to access. Complicated application processes are a significant barrier.

Barriers to commercialisation in Materials applications

Consumer confidence and adoption is the main barrier to the commercialisation of innovative products. Prospective customer firms often do not understand the benefits of the products and are concerned about the end users' attitudes to the new products. This can lead to requests for costly and unnecessary testing:

> *'There is still a lot of nervousness from customers to take on the new material that they see is unproven. So, and they put the material through a lot of testing which is over and above what they would traditionally test traditional plastic or glass packaging'.*

The regulatory environment of Engineering Biology is unclear, time-consuming and costly. Different requirements and certification standards in different markets exacerbate this. Inconsistency in government policy delivery means that customer businesses are not clear about the government's commitment and seriousness to certain policies, so they do not see the need to push for specific changes that would pave the way for new and innovative products to be adopted.

The gap between the R&D stage of innovation and the scaling-up stage means that many companies innovate but struggle to upscale their innovations and bring them to the market:

> *'It is not commercialisation that is the challenge but the bridge between lab R&D and scaled up screening which is the bottleneck for biotech companies in the UK. Lab space is scarce in cities like Oxford, London and Cambridge. Moving to rural towns is considerably cheaper but then you have to sacrifice the attractiveness of the location to the pool of young graduate talent in the UK who want to stay in the big cities.'*

Other barriers to commercialisation include a lack of specialised equipment, integrating new products into existing processes, identifying the right application for new products, keeping prices affordable due to the cost of scaling and the lack of financial support, inadequate testing facilities, and less dynamic support centres.

Infrastructure requirements in Materials applications

Some common issues here include:

- Support centres often lack specialized equipment for testing and piloting, and their services are not always dynamic. In order to better serve firms, innovation support centres and hubs should familiarize themselves with the equipment and services available in other hubs so they can direct firms to the appropriate hubs for the services they need. Lack of tailored expert advice to firms on specific issues, such as training on value prepositioning of new products to potential clients:
    - '*Getting technical support where technical advisors really dedicate their time (3h+ / week) would be helpful'.*
- Absence of commercialisation support grants, which would be useful in boosting access to support centres and hiring equipment.

International comparison of infrastructure for Materials applications

The general Engineering Biology innovation infrastructure around the early stages of R&D is seen as very good, and most respondents had received financial support. The availability of reputable research-intensive institutes and universities to support product innovation and development is a strength of the UK, and such institutions also contribute to a skilled workforce. Most respondents had worked with a research institution in developing their products. One noted:

> *'I think where it helps is that we have a certain gravitas in terms of our expertise. The fact that we have a lot of expertise in the field is a real bonus".*

However, respondents pointed to logistical challenges due to increased documentation and bureaucracies post-Brexit as a problem. Government incentives to establish production firms which are present in other countries (e.g., France, Germany, USA) are not available in the UK. Access to relevant raw materials and support industry is another area that makes other countries more attractive than the UK (e.g., Portugal, Italy and Germany). Commercialisation grants or loans may help here. The UK's high labour and material costs put it at a comparative disadvantage, as does its lack of laboratory infrastructure. One respondent noted that it would be helpful to have:

> *'Some kind of centre where companies can access shared facilities and equipment and come in and out without a lengthy onboarding and application process, is what we need to accelerate innovation. But at the moment the modus operandi is extremely bureaucratic, and also the tech infrastructure and sharing structure is completely absent and several years behind hubs in the USA'.*

6.4 Chemicals

Firms interviewed

Here, we interviewed five Engineering Biology Chemicals firms; all were established between 2009 and 2021 and currently employ fewer than 15 people each. Their locations are influenced by proximity to the university, research centre of origin, or the founder's residence. In choosing a location, one firm emphasises tapping into specific expertise and market proximity. Firms here are engaged in product development, process development, or both, serving sectors such as fine chemicals, nutraceuticals and pharmaceuticals.

Commercialisation Pathways in Chemicals applications

Businesses interviewed in the sector either intend to or are commercialising via several overlapping routes:

> *'My customer base has been everything from Small biotech, Virtual biotech, pharma companies, agri-bio companies. Most of what we are doing now, on a client basis, is for consumer products***.'** *Chemicals 5*

One reported they might want to manufacture themselves to attract the investment. All are commercialising in their current location, or if they are moving, it is within the same vicinity. However, partnerships are, in some cases, international and further testing and piloting may be conducted internationally by customers (see also International Comparisons below).

Use of existing infrastructure in Chemicals applications

Three of the five firms made use of the existing innovation infrastructure. They started up in science parks or University business parks, enabling them to use the agile lab space, facilities and equipment. They had conducted extensive research on similar facilities in their vicinity but were attracted by the flexible leases and access to equipment as part of the package. There was a desire to move into their own premises eventually:

> *'You want your own front door, your own office, your own lab, just something a bit bigger that we could call our own rather than lots of shared activity.' Chemicals 1*

In terms of commercialisation support, a spin-out firm from a university was given funding of £3m from the Engineering Biology Catalyst program until 2021. This support was intended to help with translation. However, the program ended before the firm could complete the whole commercialisation process. Nevertheless, the firm found the leadership training from ICURE and Horizon 37 to be helpful.

Other firms had positive experiences with EIS and less so with IUK Edge, mainly due to bureaucratic frictions. The Centre for Process Innovation (CPI) is reported as having credibility, facilities and equipment needed for later stages of development. Still, they are seen as expensive and often only used when there is Innovate UK funding available. Another firm reported they had spoken to CPI, but they '*felt like a contract organisation'* and were not cheap.

One firm cited they had received support to access local Angel Investment. Another had tried to engage with CRODA, who could not help as the firm is not engaged in life sciences.

Firms tended to be part of membership organisations, including the Society of Chemical Industries and the High-Value Bio-renewables network in York. These networks are reported to be useful in broadening reach and exposure to potential customers.

Barriers to commercialisation in Chemicals applications

Private investment was seen as difficult to attract by some of these Engineering Biology Chemicals firms; investors are often not interested in Business to Consumer sales and are more interested in

Business-to-Business sales, are impatient about longer lead times, and tend to be less knowledgeable than US investors.

In terms of government funding:

> *'My own experience, as a businessman dealing with government money, is that by the time I've spent all that time trying to get it, I'll just get on and do it myself anyway.' Chemicals 3*

Another firm also noted these issues with grants:

> *'When I have added up the time it takes to apply for grants, the overall chance of success and the admin needed during execution of the grant, it isn't worth it- for me at least, I'm sure it is ok for other companies with investment or better-established revenues.' Chemicals 4*

On access to facilities, another respondent commented:

> *'I believe there is a probably a whole pool of talent out there that, like me, doesn't have the cushion of access to university labs and a university salary to start companies- but who could, under the right circumstances, commercialise their ideas.' Chemicals 4*

Infrastructure requirements in Chemicals applications

There was broad agreement that the UK needs biomanufacturing facilities for commercialisation and Scale-up. However, Engineering Biology Chemical firms recognise the potential of existing facilities and appear well served by Pharma focused facilities. CPI, Warwick Manufacturing Group, BioServ in Sheffield, the RNA Centre of Excellence in Darlington, and TriRX were cited by respondents as having or potentially having this equipment:

> *'(the UK) needs [biomanufacturing facilities] but whether we need more of them than we currently have, I really don't know.' Chemicals 1*

A more significant issue appears to be the cost of accessing existing facilities. As noted in the section above, two respondents noted CPI as prohibitively expensive. It was also reported that whilst such a new facility could contain fermentation and biotransformation facilities, there are probably existing facilities that are underutilised because of cost:

> *'There's probably a lot of fermentation facilities at the universities that sit around idle for most of the year. They could probably be exploited better.' Chemicals 4*

Respondents suggested that access to existing or new facilities should be facilitated via the grants system. Still, they cautioned that collaboration with universities pushes up costs and collaborative grant applications then become 'undoable'.

> *'Small start-ups or companies with limited cashflow and/or investment need access to full grants- but small to start with to manage the risk to the public purse- then if there is success, this can be followed on until there is enough substance to raise investment, etc. But the key is being able to catalyse this process, which the current system just doesn't achieve.' Chemicals 4*

Respondents also advocated for support with full grants for commercialisation, including support with marketing and networking. They suggested that biomanufacturing hubs should include introductions to Angel investors as well as expertise on regulatory issues. Specific equipment that would be useful to these firms are high throughput screening and molecular biology jet-milling evaporative equipment.

International comparisons of infrastructure for Materials applications

The UK is thought to do well in this arena in early research and start-ups, with a good university science base. The £5,000 Innovation Vouchers were reported as useful. One respondent cited access to Innovate UK grants (albeit very competitive), R&D Tax Credits, EIS and SEIS as positive features to support commercialisation and concluded that the UK is:

> *'not a bad place. I think you'd struggle to find much better.' Chemicals 1*

As a good example of what the UK does well, one firm cited the Cell and Gene Therapy Catapult in Stevenage:

> *'It's a contract facility, and it gets people to the point where they can manufacture some of these therapies at commercial scale. They're so low volume at the moment because it's so expensive. But I think if we're going to stay ahead of that game and continue to punch above our weight globally, we would need to invest in more of that kind of technology as well.' Chemicals 5*

However, a couple of respondents cited a lack of long-termism in Government planning and investment. For example, although the UK is re-joining the Horizon programme, concern was expressed that

> *'… these are fast-paced environments, so, being shut out and then having to try and get back in is complex.' Chemicals 2*

Brexit had created supply chain issues because suppliers are not going to release '*new products or technologies or new drugs*' in the UK- they will go to the EU first.

One Engineering Biology Chemical company is already operating with a factory in Holland, although the IP is held in the UK. Another is committed to remaining in the UK and has become a B Corp business because they want to use local supply chains and not '*shipping everything abroad'*.

One firm also noted that:

> *'… a lot of biotech companies have pivoted their revenue generation strategies recently and become their chemical products companies rather than biotech platforms. Whether that's a sign of how to make money out of this kind of technology or a sign of how investors want to invest in different parts of the world, I'm not sure.' Chemicals 2*

Section 7: Summary, conclusions and recommendations

7.1 Objectives

The primary objective of this study was to understand the landscape of commercialisation infrastructure for non-health applications of Engineering Biology in the UK, to identify the gaps in provision, and to provide recommendations relating to investment in new infrastructure or strategies to maximise the value of existing infrastructure. We adopt a broad view of 'infrastructure', including physical assets and facilities and organisations providing 'soft' support to Engineering Biology firms, such as funding organisations and industry networks. We exclude privately held facilities which are not open access.

The study comprised a review of existing literature relating to the state of the UK Engineering Biology sector, an in-depth analysis of the non-health Engineering Biology business landscape in four main applications (Agri-food, Materials, Chemicals and Environment), an analysis of the infrastructure landscape, and in-depth interviews with 18 companies as well as experts in major Engineering Biology support organisations and academics.

Our analysis of the corporate landscape and infrastructure supporting non-health applications of Engineering Biology in the UK suggests dynamic clusters of activity in specific geographic areas across the country. Reflecting the findings of earlier studies, we also identify some clear Engineering Biology infrastructure gaps which may be limiting commercialisation activity in the UK. Interviews with companies involved in Agri-food, Chemicals and Materials largely support this view. Firms in each sector identified UK Scale-up facilities as either difficult to access or costly to access. Also, they reported active attempts to attract them to use facilities in other countries. Improving firms' ability to access scale-up facilities in the UK seems critical both to maximise the potential innovation across the sector, retain activity in the UK, and support potential inward investment in the sector. This may involve new investment in relevant Engineering Biology support facilities but may also benefit from better signposting offers to existing facilities and potentially providing financial support to enable firms accessing such facilities.

7.2 Key findings

Based on a new analysis conducted in partnership with DataCity and DIST, we explored the geographical distribution of non-health Engineering Biology firms in four applications. This suggests seven diverse and dynamic spatial clusters of Engineering Biology activity across the UK, and these provide the basis for our infrastructure mapping (see below).

We considered four applications in detail: Agri-food, Chemicals, Materials and Environment. Firms exploring Agri-food and Environmental applications of Engineering Biology are widely spread across the UK, with chemicals and materials applications more concentrated in London and the South East. Supporting growth in the more dispersed Agri-food and Environmental applications, therefore, has the potential to contribute to reducing regional disparities. However, Agri-Food, Materials and Environmental applications are dominated by start-ups and younger firms, with relatively few long-established companies. This suggests a need for ensuring firms in these sectors have adequate access to Translation and Demonstration and Demonstration and Commercialisation facilities. Chemical applications present a somewhat different picture, with fewer start-ups and more established firms.

Interviews with firms in Agri-food, Chemicals and Material applications emphasise the critical nature of the support ecosystem for businesses in these Engineering Biology sectors. Many firms in the start-up and scaling phases draw intensively on external support – technological, financial and strategic – to facilitate their development. Therefore, gaps in the support ecosystem can be a critical break in their innovation journey. This may be particularly critical in Agri-food, Material and Environment applications, given the dominance of early-stage businesses in these applications.

Firms in each of the three sectors recognise the strength of the UK eco-system in Engineering Biology at lower TRLs. This recognition of the strength of the early-stage ecosystem contrasted with more critical views of the facilities and funding available for commercialisation. Here, firms often contrasted the UK poorly with other countries in Europe and elsewhere, which provide better (and/or lower cost) facilities and greater financial support. The availability of facilities elsewhere is also actively promoted to UK Engineering Biology start-ups to encourage them to move their activity abroad.

Across the UK, we identified sixty-one organisations and facilities serving as soft and physical infrastructure supporting innovation in firms with non-health applications of Engineering Biology. Around 44% of these are 'soft' infrastructure. Most of the physical infrastructure we identify are proximally located with the seven clusters of Engineering Biology with two exceptions- Yorkshire and Teesside appear to have a vibrant support ecosystem, but no identified clustering of businesses with non-health applications of Engineering Biology, and Oxford and South East appear to have an established cluster of businesses, but no open-access facilities supporting non-health applications.

The key points from the infrastructure mapping are as follows:

- In 'Scotland', 'East of England' clusters, 'Greater Manchester/Northwest' and 'Greater London', there are a number of facilities supporting Research and Translation as well as Translation and Demonstration, but there is a gap in Demonstration and Commercialisation and in Commercialisation and Scale-up facilities. This evidence suggests a gap in the provision of facilities at TRL 5 and above for most non-health applications of Engineering Biology in these clusters.

- Similarly, in Greater London, there are some Research and Translation and Demonstration and Commercialisation facilities (including SynbiCITE), but no (open-access) Commercialisation and Scale-up facility (Table 11). Thus, there appears to be a gap in the provision of commercial scale facilities even in London.

- Although not home to any of the identified clusters of non-health Engineering Biology firms, Yorkshire and Teesside have strong innovation and commercialisation infrastructure with good Research and Translation and Translation and Demonstration facilities, but also some of the UK's best Demonstration and Commercialisation facilities (Centre for Process Innovation). This is supported by strong 'soft' infrastructure networks.

- In the 'Bristol and Wales' cluster, there is a strong infrastructure across Research and Translation through to Commercialisation and Scale-up. This is the only cluster that appears to have the full continuum of support across TRL levels, and beyond pilot- scale facilities to support commercial-scale production (BioCatalysts).

- The 'Oxford and the South East' cluster does not appear to have open-access facilities for non-health applications of Engineering Biology, although privately held facilities and funding sources (such as the Oxford Seed Fund) are available for some businesses.

7.3 Investment opportunities

Our analysis suggests a series of five main investment opportunities which could strengthen the commercialisation ecosystem for Engineering Biology in the UK. Each of these reflects the triangulation of evidence from previous reports on the sector, our own industry and infrastructure mapping, and discussions with Engineering Biology firms and industry experts. The key investment opportunities we have identified are as follows:

(1) ***Targeted development of commercialisation and scale-up capacity*** - our infrastructure mapping and cluster analysis suggest some clear limitations in the availability of physical infrastructure for non-health applications of Engineering Biology, particularly that which can support commercialisation and scale-up, in all business clusters except the 'Bristol and Wales' cluster. This suggests investment opportunities focusing on higher TRLs and building capacity particularly to support commercial-scale production. Any investment should be carefully linked to local supply chains and shaped by long-term needs analysis. For example, Agri-food companies stressed the need for access to food quality scaling facilities, which were often not available or expensive to access. Addressing these limitations in scale-up capacity will help address weaknesses in the commercialisation pathway, contribute to reducing regional disparities and support the ambition to provide an internationally competitive environment for developing and commercialising Engineering Biology technologies.

A key consideration here is the relative importance of geographical proximity to infrastructure for different elements of innovation and commercialisation activities. Insights from our interviews with businesses and consultations with industry experts suggest Engineering Biology firms may be willing to travel or relocate to access critical commercialisation infrastructure; the extent of such business mobility may have implications for spatially based investment decisions around distributed or more centralised infrastructure models. The development of required skills and expertise is also a key requirement for the effective delivery of any infrastructure.

(2) ***Integrating soft infrastructure for collaborative delivery*** – The Engineering Biology sector is supported by a rich constellation of soft infrastructure. Incentivising collaborative delivery and coordination of services and support between organisations to support firms better will help ensure consistency and transparency of support for firms and enable more effective signposting between support organisations. Collaborative delivery could be organised by sector, spatial cluster, or specific commercial pathways and could provide a focus for international marketing of UK infrastructure (see below). A previous attempt at providing such collaborative delivery was through BioPilots UK, an alliance of open-access facilities across the UK to facilitate signposting and interconnectedness between pilot-scale facilities.

(3) ***Infrastructure portal -*** The infrastructure mapping exercise undertaken here could provide the basis for a web-based resource, updated regularly, which may be helpful for both industry and commercial uses. Additional information could usefully be added in terms of accessibility, key target groups, and availability or capacity. This would contribute to the transparency of support available to firms and provide an international showcase for UK support for Engineering Biology commercialisation. This is in line with wider views of industry participants as reflected in the National Vision of Engineering Biology, where the evidence suggests the need for a directory of the full range of available facilities and equipment. The value of this type of investment would need to be carefully assessed, and a detailed business case would need to be developed. In addition, the infrastructure landscape is constantly evolving, and any directory must be regularly updated.

(4) ***Enabling SMEs' access to existing infrastructure*** - During our company interviews, Engineering Biology firms made a range of persuasive arguments for the importance of enabling access to existing infrastructure. Typically, this revolved around the question of cost. Other countries were said to provide greater incentives for SMEs to access infrastructure facilities, particularly at the demonstration and commercialisation stages. Small demonstration grants of £50k-£200k were seen as potentially useful by a range of stakeholders. Another company highlighted an innovative French support scheme that helps firms de-risk commercialisation investment by providing competitive finance and brokered contacts with potential commercial partners in return for a royalty payment on subsequent commercial sales. Such commercialisation loans are in many ways similar to the innovation loans currently provided by Innovate UK.

(5) ***Enhanced international marketing of infrastructure capacity*** – It was clear from our Engineering Biology company interviews that, increasingly, countries are using aspects of commercialisation infrastructure and related support to attract inward investment at the commercialisation stage. The UK is already regarded as having excellent infrastructure and support organisations at low TRL's. The aspiration, reflected in the recommendations here, is that this excellence should extend to the whole of the commercialisation pathway within non-health Engineering Biology. Supporting future investments in physical and soft infrastructure by enhanced international marketing of the UK ecosystem will help both project the image of the UK as a centre of excellence for Engineering Biology and act as an attractor for inward investment across the sector.

7.4 Knowledge gaps and future research

During our research we identified a number of knowledge gaps and research questions which might be useful to address to support future infrastructure investments in non-health applications of Engineering Biology. Some key issues are:

- ***Supply side capacity and quality*** – is there underutilised capacity within the existing physical infrastructure for Engineering Biology? Also, what is the quality of existing infrastructure? How can this be measured?
- ***Demand side mobility*** - To what extent are UK Engineering Biology companies, at different stages of the commercialisation value chain, prepared to travel to take advantage of support and scaling opportunities elsewhere in the UK? Or, to what extent can firms be persuaded to move closer to facilities? To facilitate this type of mobility, is it necessary to extend support organisations' current capabilities? An interesting follow-up to our research would be to explore the relationships that firms in each area have had with their co-located infrastructure, and what other facilities they are accessing. This may help provide insights into infrastructure for which reasonable local access is required versus infrastructure that does not require long-term proximity; the latter can form the basis for larger national or world-class facilities which serve broader geographies.
- ***Clustering -*** Our UK non-health Engineering Biology sector analysis suggests some clearly differentiated spatial clustering. Relatively little is known about the extent to which these clusters are reflected in local network partnerships or collaborative R&D or innovation activity. Are these clusters a source of strength for the businesses involved, or do they simply reflect historical development trajectories?
- ***International benchmarking of infrastructure capacity/quality*** - Are there areas where the UK has a comparative advantage in elements of Engineering Biology infrastructure? More broadly, how does the profile of Engineering Biology infrastructure in the UK compare to that

elsewhere? Understanding this may suggest opportunities for international collaboration and attracting inward investment to the UK to provide infrastructure or extend production capacity.

- ***Commercialisation skills*** - Effective commercialisation of new technologies, such as those involved in Engineering Biology, requires technological and commercial expertise. It is widely recognised that UK universities produce strong technological expertise reflected in the strength of the research base. Our understanding of the origin of those with business skills involved in Engineering Biology commercialisation pathways is more limited but will need to expand if the sector is to develop. How can this be done? Organisations such as the BioIndustry Association and some universities provide entrepreneurship training, but the landscape for such provision appears fragmented.
- ***Responsible Innovation***- Responsible Research and Innovation is emphasised in the newly published National Visio for Engineering Biology (DSIT, 2023); there is a need to better understand how to organise resources to support innovators, firms and communities in embedding responsible and trustworthy innovation in Engineering Biology.
- ***Understanding the landscape of privatively held facilities:*** Our analysis of the infrastructure landscape revealed various high TRL facilities that are privately held by companies but listed in online directories of biomanufacturing facilities. These organisations, such as Rebio and Croda, may choose to work with other businesses, but the criteria to access their facilities are often unclear. Understanding the business models of such facilities may help uncover potential opportunities to avoid duplication of expensive equipment

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Appendix 1: Members of Expert Advisory Group

Name	Organisation
Jillian MacBryde	University of Strathclyde
Philip Shapira	Manchester Institute for Innovation Research
Martin Turner	UK Bioindustry Association (BIA)
Linda Bedenik	UK Bioindustry Association (BIA)
Mark Renshaw	Department for Science, Innovation & Technology
Amy Welch	Department for Science, Innovation & Technology
Jack Weaver	Department for Science, Innovation & Technology
Yvonne Armitage	Centre for Process Innovation
Paul Bello	Innovate UK
Gordon Ford	Innovate UK
Rocky Cranenburgh	Bitrobius Genetics
Nick Bassett	Biotechnology and Biological Sciences Research Council
Lee Beniston	Biotechnology and Biological Sciences Research Council
Noriane Simon	Biotechnology and Biological Sciences Research Council
Ian Lewis	Biotechnology and Biological Sciences Research Council
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