gfi / Europe

Sustainable proteins in the United Kingdom

An ecosystem review

August 2023

Executive Summary

The UK Government has expressed an ambition to develop and scale-up sustainable proteins in Britain, most clearly in its Food Strategy. The remainder of this decade will be crucial to deliver on this ambition and unlock the environmental and societal benefits of plant-based, fermentation-made and cultivated meat, seafood, eggs and dairy.

British entrepreneurs, food producers and scientists need an enabling environment to make new discoveries, grow innovative businesses and produce sustainable proteins which are affordable and delicious. Forged by a clear vision and decisive action, this ecosystem can foster the rapid growth of a new green industry in the UK, helping us deliver on national priorities for the climate, economy, food, nature, public health and science.

This report reviews the development of the UK's sustainable protein ecosystem to date. It focuses on two key pillars: public investments in research and development (R&D) and private-sector commercial activity. We put forward nine policy recommendations to catalyse the development of plant-based, fermentation and cultivated meat over the remainder of the 2020s - a critical period in the global race to develop and scale sustainable proteins.

Key insights

Public research & development

- UK Research and Innovation (UKRI) is the key public funding agency for investing in sustainable protein R&D. Since 2012, the UK has invested at least £43 million in R&D specifically for plant-based, fermentation and cultivated meat, seafood, eggs and dairy.
- Of this funding, almost two-thirds (65%) was allocated between January 2022 and May 2023, suggesting the UK is beginning to seize the opportunity.
- Cultivated meat has received the largest proportion of funding (£20 million), largely due to the creation of a new cellular agriculture manufacturing research hub (£12 million). Plant-based foods and precision fermentation have been more neglected.
- A diverse range of sustainable protein research is taking place at British universities. However, much more could be done to tap into the UK's latent strengths in relevant fields such as crop breeding, mycology, food science, stem cell biology and bioprocess engineering.

- Public funding is critical for encouraging researchers active in neighbouring fields to apply their expertise to plant-based, fermentation and cultivated meat R&D.

Private sector activity

- Our research identified a total of 138 sustainable protein companies - 100 in the plant-based sector, 23 developing cultivated meat and 15 in the fermentation space. It is very likely that we have underestimated the real total.
- There is a rich diversity in the commercial ecosystem, in terms of business models, geography and scale. Many plant-based brands are headquartered in major cities, but much of the economic potential of the plant-based sector is in the food manufacturing capacity growing throughout the regions.
- The UK private sector has demonstrated a competitive edge in some areas more than others. Quorn operates the world's largest sustainable protein production facility, and UK cultivated meat companies attracted more private investment in 2022 than the rest of Europe combined.
- However, precision fermentation is comparatively underdeveloped, particularly when compared to Israel and the United States.
- It is uncertain whether the UK will develop a strong sustainable protein manufacturing base, but the economic benefits of doing so could be significant. Analysis from Green Alliance indicates that up to 25,000 jobs could be created throughout the UK by 2035, with £6.4 billion added to the economy.
- A critical bottleneck is the lack of pilot infrastructure, particularly for fermentation and cultivated meat, designed to help grow sustainable protein companies from the lab to market.

Future industry clusters

- Our analysis mapped the UK's sustainable protein science and technology and commercial ecosystem to identify areas of regional strength. We found several areas of high potential, including Yorkshire and the North East, the Cambridge-Norwich Corridor, and the Golden Triangle.
- Coordinated action between the public and private sectors could foster the creation of flourishing sustainable protein clusters, as has been the case in other green industries.

Nine policy recommendations to create a thriving UK sustainable protein ecosystem by 2030

Pillar 1: Political leadership

1. Use the forthcoming engineering biology action plan to decisively affirm a cross-government ambition to develop and scale sustainable protein production in the UK.
2. Develop a national plan for sustainable proteins.

Pillar 2: Research and development

3. Between 2025 and 2030, UKRI, DSIT and Defra should together target an average annual spend of £49 million (£245 million total) on public R&D to support plant-based, fermentation-made and cultivated meat, seafood, eggs and dairy. To truly compete internationally, this should increase to a £78 million average annual spend (£390 million) between 2025 and 2030.

Pillar 3: Infrastructure

4. Defra and DSIT should conduct or commission a review of sustainable protein infrastructure and use this as a basis for detailing plans of how the government can derisk the necessary private investment to scale sustainable proteins in the UK.

Pillar 4: Regulation

5. The FSA should focus on 'quick win' reforms that would improve trust and confidence in the novel foods pre-market authorisation process.
6. The FSA should learn from best practices of more innovation-focused regulators, both in the UK and overseas.
7. The Chancellor should give a one-off £30 million injection to the FSA at the 2023 Autumn Statement and the next Comprehensive Spending review should ensure that its budget continues to grow in real-terms over the rest of the decade.

Pillar 5: Fair competition

8. Remove existing restrictions on the use of dairy terminology – provided adequate qualifiers are used.
9. Defra and the FSA should implement a fit-for-purpose framework that allows sustainable proteins to communicate clearly the nature of their products to consumers

Sustainable proteins in the United Kingdom – key statistics

£43 million
Invested by UK Research and Innovation in sustainable proteins between January 2012 and May 2023.

65%
Of the total value of investments made by UK Research and Innovation came between January 2022 and May 2023.

25,000 jobs
could be created by 2035

30 UK universities
Identified who are conducting sustainable protein research and development.

£12 million
Engineering and Physical Sciences Research Council investment in the UK's new cellular agriculture manufacturing research hub – a landmark for cultivated meat.

138 companies
Developing and producing plant-based, fermentation-made and cultivated meat, seafood, eggs and dairy.

£964 million
Spent by UK consumers on plant-based meat and dairy in 2022 – a record. The UK is the second largest consumer market for plant-based foods in Europe.

£143 million
Raised by British sustainable protein companies in 2022. UK cultivated meat companies secured more investment than the rest of Europe combined.

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01 Introduction

"The alternative protein sector provides another opportunity for growth, complementing traditional livestock sectors. The UK has been at the forefront of innovation in protein sources since the development of Quorn products in the 1980s... ***The government will keep the UK at the front of this growing and innovative sector****"*

Government Food Strategy, 2022

Decarbonising the food system, rebalancing land use to achieve climate and nature goals, and bolstering domestic food security are all urgent national priorities for the United Kingdom. To help achieve these goals, the independent Climate Change Committee and Henry Dimbleby's National Food Strategy have recommended significant reductions in meat consumption. Effective enablers to make this shift happen are sorely needed. Catalysing the development of sustainable proteins – plant-based, fermentation-made and cultivated meat, seafood, eggs and dairy – is one of the most promising solutions, helping us to tackle climate change, take pressure off the land, build a more resilient food system and grow the green economy.

Increasingly, there are signs that the UK Government recognises this, as set out in the Benefits of Brexit white paper, the Carbon Budget Delivery Plan, UK Research & Innovation priorities, and the Agriculture Breakthrough. The Prime Minister's Council for Science and Technology, chaired by Sir Patrick Vallance[1], recently highlighted sustainable proteins as a key avenue of opportunity for engineering biology – one of the UK's "five critical technologies". Most clearly, the Government Food Strategy (2022) laid out an ambition for the UK to lead the world in sustainable proteins.

To deliver on this ambition, the UK must build a dynamic, resilient and well-resourced sustainable protein ecosystem, capable of developing delicious and affordable foods and manufacturing them at scale. We are in a global race with international competitors to do so. Forged by a clear plan of action developed between government, industry, academia and third-sector partners, sustainable proteins can help the UK make significant progress towards its national priorities for food, the environment, science and economic competitiveness in the era of green industrial growth.

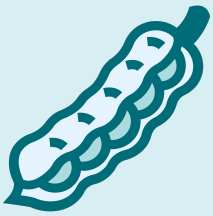
[1] Sir Patrick Vallance retired from his position as Chief Scientific Advisor to the UK Government in summer 2023.

About this report

In 2023, the UK's sustainable protein ecosystem is in its infancy. This report provides a snapshot of its development to date. In particular, we focus on two core pillars of the ecosystem: public research and development, and private-sector commercial activity. We focus strongly on the *spatial* dimension of the ecosystem, following the assumption that sustainable proteins are likely to be reasonably similar to other high-value net zero industries, which are emerging where the UK has significant underlying local and regional capabilities.

In the final chapter, we put forward a series of policy recommendations across five pillars – leadership, R&D, infrastructure, regulation and fair competition – designed to ensure that by 2030, the UK's sustainable protein ecosystem can truly be described as world-leading.

What are sustainable proteins?

Plant-based	Fermentation-made	Cultivated
		
Plant-based meat looks, cooks and tastes like conventional meat – but it's made entirely from plants like peas, sunflowers and wheat.	Fermentation can be used in many innovative ways to produce food, for example by fermenting fungi to make mycoprotein or using microorganisms like yeast to produce animal-free dairy proteins.	Cultivated meat involves taking a small sample of real animal cells and growing them in a fermenter to produce chicken, beef, seafood and more.
Learn more	**Learn more**	**Learn more**

02 UK public investment in sustainable protein research and development

The UK Government's recent Carbon Budget Delivery Plan recognises that sustainable proteins can produce emissions savings in the next 10 years, but that this potential is conditional on research and development. Globally, an estimated £3.5 billion in R&D spending is required annually to scale sustainable proteins. Given the foundational, pre-competitive nature of the vast range of R&D whitespaces, **the public sector is best-placed to invest in and coordinate this R&D activity.** This logic is not novel, nor is it unique to sustainable proteins. In fact, it is at the core of the UK's Net Zero Research and Innovation Framework:

"Publicly funded R&I will be needed where market failures or barriers are holding back private sector investment and to create and shape markets which may not otherwise form fast enough to meet net zero targets." – *Net Zero Research and Innovation Framework, 2023*

This chapter reviews:

- How public funding for sustainable protein R&D has progressed to date.
- What research is taking place at British universities.
- The links between sustainable protein companies and universities.
- How effectively the UK is addressing critical R&D whitespaces with its public funding.

What is sustainable protein research & development (R&D)?

Sustainable protein R&D refers to any activity that leads directly to the advancement of scientific and technical knowledge or capability in the fields of plant-based, fermentation-made and cultivated meat, seafood, eggs and dairy.

For the purposes of this report, our interest is in the UK Government's investments in sustainable protein R&D in the form of both financial support for public sector-led open-access research and businesses-led R&D (often carried out in collaboration with university-based researchers). We do not explore the impact of other forms of cross-sectoral financial support such as R&D tax credits.

UK Research and Innovation is the driving force behind public investment in sustainable proteins

The key public agency funding innovation in plant-based, fermentation and cultivated meat, seafood, eggs and dairy is UK Research and Innovation. Within UKRI, three councils are the driving force.

Biotechnology and Biological Sciences Research Council

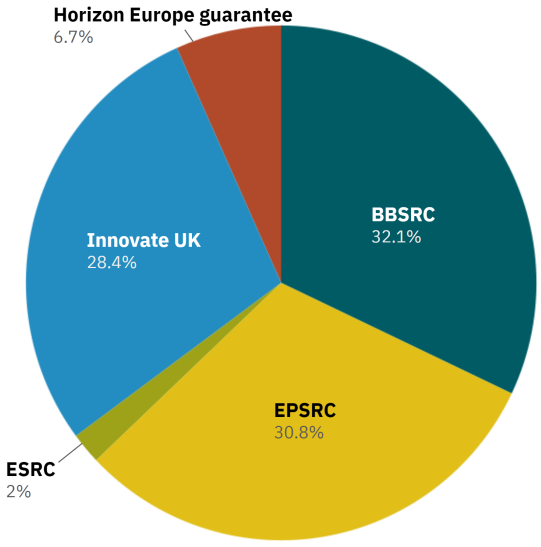
Engineering and Physical Sciences Research Council

Innovate UK

The Biotechnology and Biological Sciences Research Council (BBSRC) and the Engineering and Physical Sciences Research Council (EPSRC) finance university-based research, primarily in the form of research grants and studentships. Innovate UK provides non-dilutive grants to businesses, for example for feasibility studies and collaborative sustainable protein R&D, often undertaken in partnership with universities and/or other private sector actors.

More than 90% of all UKRI funding to the field comes from these three public agencies. Higher education institutions are also allocating research funding to sustainable protein R&D, though the complex funding mix for university-based research makes tracking its origins almost impossible – hence our focus on UKRI in this paper.

Figure 1: Composition of UKRI funding for sustainable protein R&D



Source: UKRI gateway, GFI analysis

Notably, we are aware of very few significant financial contributions from central government departments, including the Department for Business, Energy and Industrial Strategy, which had more than £1 billion to spend on discretionary R&D initiatives before its dissolution in early-2023. While this represents a significant opportunity for the future – especially given the Department for Science, Innovation and Technology's recent prioritisation of engineering biology – it should be noted that government departments do work in partnership with UKRI to develop strategic priorities and funding calls. One recent exception is a small number of projects funded under the Department for Food, Environment and Rural Affairs Farming Innovation Programme - a £270 million initiative delivered by UKRI - of which five sustainable protein projects have received around £3 million.

How have we calculated public investment in sustainable protein R&D?

In May 2023, GFI Europe estimated funding levels for R&D focused on developing plant-based, fermentation-made and cultivated meat, seafood, eggs and dairy by carrying out a keyword search of more than 100 relevant terms using the UKRI's Gateway to Research tool.

Importantly, **we have therefore only captured funding directly from UKRI**. For this reason, **the data presented in this report are likely to be an underestimate** and limitations in our keyword search may contribute to variance. Our estimates do not include funding for alternative protein animal feed sources, such as insect farming. They also do not capture R&D that could have spillover impacts on the development of sustainable proteins, for example in the fields of crop breeding and tissue engineering. For more detail on how the data were gathered, see Annex I.

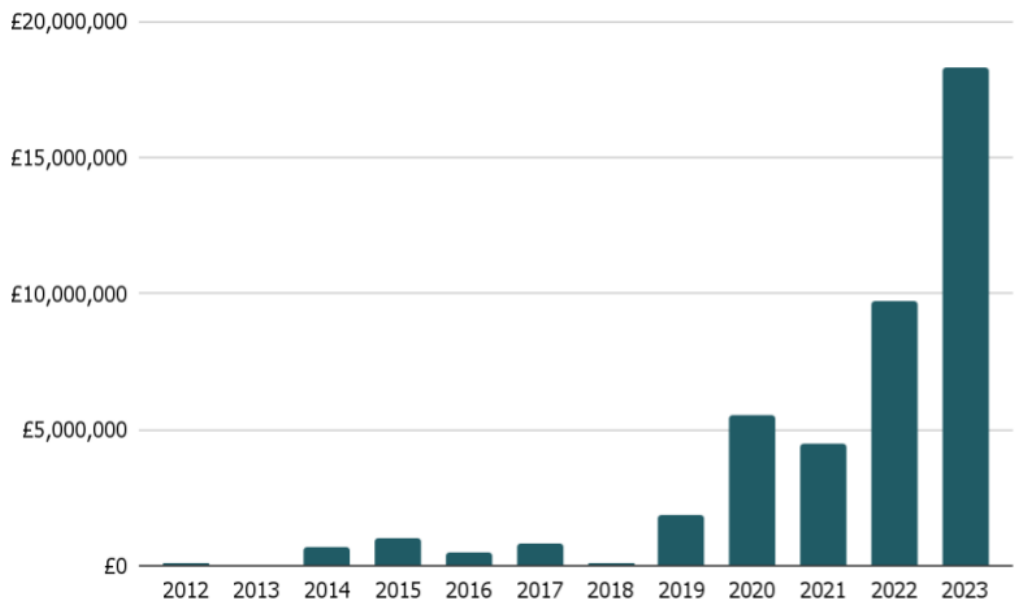
Public funding for sustainable protein R&D has accelerated considerably since 2022.

Since 2012, UKRI has funded at least **£43.1 million** in R&D focused on developing plant-based, fermentation-made and cultivated meat, seafood, eggs and dairy. **65% of this funding was allocated between January 2022 and May 2023 alone**, suggesting that the UK is beginning to seize the opportunity to develop sustainable proteins. Importantly, this estimate does not include two significant UKRI funding calls[2] where sustainable proteins were a key focus, since the outcomes were not known at the time of writing. In any case, the first five

[2] Better Food For All (£20 million) and Novel Low Emissions Food Production Systems (£16 million plus £3 million investor partnerships), which contained a strong focus on sustainable proteins.

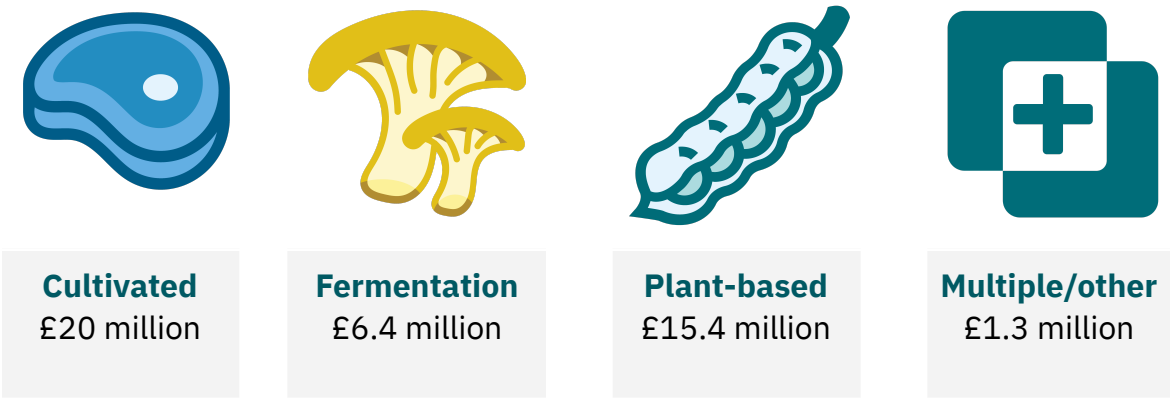
months alone mean that **2023 is already a record year for UK public investment in sustainable proteins**.

Figure 2: Total UKRI funding for sustainable protein R&D, January 2012 - May 2023



*Source: UKRI Gateway to Research, GFI Europe analysis. *2023 covers the period up to May 2023 only.*

Figure 3: Total funding for sustainable protein R&D in the UK, by production pillar, January 2012 - May 2023



Source: UKRI Gateway to Research, GFI Europe analysis. 2023 covers the period up to May 2023 only.

See page 13 for examples of publicly-financed R&D driving British innovation in plant-based, fermentation and cultivated meat.

Beyond these headline numbers, several important trends emerge:

- **The size and frequency of grants is increasing:** Alongside the game-changing investment in the UK's new cellular agriculture manufacturing research hub (£12 million), individual grants to researchers and companies are growing in size. Between 2016 and 2019, only six UKRI-funded sustainable protein projects had a budget of more than £100,000.[3] Between January 2020 and May 2023, there were 34 such projects.
- **Cultivated meat R&D has overtaken plant-based and fermentation:** While plant-based and biomass fermentation R&D received more funding in the 2010s, in the last few years cultivated meat has become a growing priority. Of the £20 million invested in cultivated meat R&D since 2012, £17.2 million of this has come since the start of 2022.
- **Sustainable proteins are becoming an explicit focus in funding calls:** In our conversations with the academic community, we have often heard that securing funding for plant-based, fermentation and cultivated meat research involves competing with far more established disciplines. Encouragingly, the tide appears to be turning. Most notably, the BBSRC and Innovate UK jointly pledged £20 million for sustainable protein R&D specifically as part of BBSRC's 2022-2025 strategic priorities.
- **The number of PhDs focused on sustainable proteins is increasing:** 28 studentships were awarded between 2020 and 2022, compared with just 11 between 2012 and 2019. This is a welcome development – GFI's recent workforce development survey[4] found that 94% of industry respondents viewed technical talent bottlenecks as "very severe" or "moderately severe" challenges to their long-term success. Universities are uniquely placed to train future academic and commercial scientists for the sector.
- **Precision fermentation research remains highly neglected:** The majority of fermentation-related R&D has been focused on biomass fermentation applications, in particular around *fusarium venenatum* – the fungal strain pioneered by Quorn. While there will be spillover effects from mycology and recombinant protein research, the vast

[3] Excludes funding for studentships.
[4] 130 responses, with representation from North America, South America, Europe, Asia, Australia, and Africa

span of precision fermentation whitespaces for meat, seafood, eggs and dairy does not appear to be receiving considerable public investment in the UK.

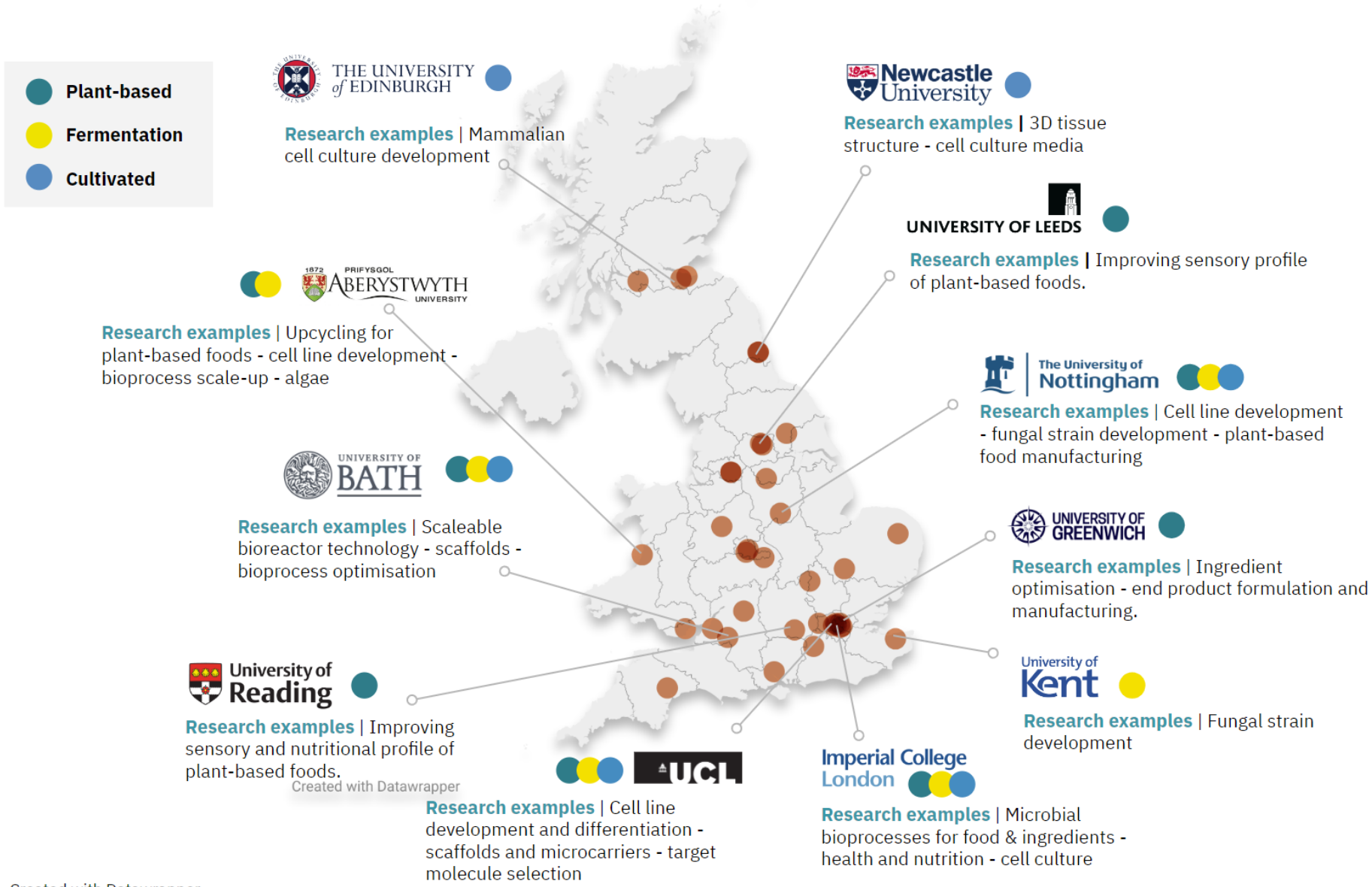
- **Compared with other nations, plant-based has received relatively little R&D:** Although the UK has spent at least £15 million on plant-based R&D, other governments are investing more heavily. Denmark committed £78 million in 2022 (The Fund for Plant-based Food Products) and by the end of 2022, Canada had invested £100 million into 55 projects spanning proof of concept, technology scaling, and commercial development.
- **Social-scientific research represents only a very small fraction of all funding:** 2% of all funding has come via the Economic and Social Research Council, of which a landmark study into the challenges and opportunities for farmers associated with cultivated meat represents the vast majority

Examples of UKRI-funded sustainable R&D projects in the United Kingdom					
Project title	**Academic partners**	**Industry, government & non-profit partners**	**Funded amount**	**Funder**	**Description**
Cellular Agriculture Manufacturing Research Hub	University of Bath University College London University of Birmingham University of Aberystwyth Royal Agricultural University	3D Bio-tissue MilliporeSigma Multus Media Ivy Farm Veolia Water Technologies Roslin Technologies Quest Meat Campden BRI Cellular Agriculture Ltd Clean Food Group Qkine Naturbeads Hoxton Farms	£12 million	EPSRC	A seven-year initiative, the UK's first Cellular Agriculture Manufacturing Research Hub was announced in 2023. It is the single largest investment made by the UK in sustainable proteins to date. The project is multidisciplinary and brings together a host of UK universities, researchers and companies. A core focus will be on creating open-access findings to help scale cultivated meat and precision fermentation production, for example by exploring whether traditional biotech separation processes are suitable for use in cellular agriculture.
Pasture to Plate (P2P): realising the enormous potential of UK grasslands	Harper Adams University	DEFRA Finnebrogue AAK AB Sainsbury's The Vegan Society Food Standards Agency Lallemand Bunge Innovations for Farming Beeswax Dyson Farming Saputo Linking Environment and Farming (LEAF) Agri-EPI Centre	£2 million	BBSRC	P2P explores whether grass can be converted into a novel sustainable protein source. Grass will be broken down into edible fractions (protein, fibre, lipids etc.), with the cellulose used to culture a yeast strain – *Metschnikowia pulcherrima* – which is already being explored at the University of Bath to create an alternative to palm oil. The process is intended to create a sustainable oil alternative and a mycoprotein.

Understanding hyphal branching in *fusarium venenatum* to design improved strains	National Institute of Agricultural Botany (NIAB)	Marlow Foods (Quorn)	£750,000	BBSRC	During the fermentation process pioneered by Quorn, the fungal strain *fusarium venenatum* can 'branch' in an undesirable way – making the mycoprotein less texturally appealing. The problem is caused by spontaneous variants arising during fermentation. The project aims to pinpoint the genes responsible for controlling hyphal growth and branching, so that mycoprotein producers can take steps to make the strain less prone to the problem.
Mind the (protein) gap: applying new knowledge to improve muscle and fat cell differentiation for cultivated meat	University of Edinburgh	Roslin Technologies IBioIC	£620,000	Innovate UK	This investment provides funding to Roslin Technologies to further develop its cell line offerings to cultivated meat researchers and companies in the UK and globally. The focus is specifically on bovine muscle and fat progenitor cells.
Sustainable ingredients for the plant-based food market	University of Leeds	Baker Perkins SPG Innovation	£160,000	Innovate UK	This project aims to reduce the use of soy-based isolates which are not produced domestically and have less favourable environmental credentials. It will demonstrate that a UK-sourced protein can be a cheaper, sustainable and healthier alternative to imported protein isolates, supporting the continued growth of the domestic and global plant-based market.

Source: *UKRI Gateway to Research (Gtr). We did not seek to verify within individual funding recipients and project partners about their individual involvement or the proportion of funding allocated to them (if any).*

Figure 4: Snapshot of sustainable protein R&D currently being undertaken at UK universities



Created with Datawrapper

Britain's top universities are driving innovation in sustainable proteins

The map above provides a snapshot of some of the sustainable protein R&D taking place within UK universities.[5] Although it is not a comprehensive overview, it shows that **there is a nascent but diverse range of sustainable protein R&D taking place at universities across the country.**

Some universities have become more specialised, such as the University of Leeds' focus on plant-based foods, while others have ongoing research across all three production pillars, including University College London and the University of Nottingham. Sustainable protein research activity is also regionally distributed and taking place at universities with different underlying backgrounds. For example, the University of Edinburgh has a historic reputation in animal genetics, while the University of Reading is a leader in agricultural research.

This ecosystem has emerged out of the UK's long-standing strengths in a host of scientific disciplines that are highly relevant in the sustainable protein space, including stem cell biology, tissue engineering, mycology, food science, genomics and crop breeding. Academics working on sustainable proteins tend to have developed their expertise in these fields, adapted them and continue to work in departments associated with them.

Explore profiles of the researchers pioneering sustainable proteins in the UK

Dr Parag Acharya, Senior Fellow in Food Innovation, University of Greenwich.

Professor Marianne Ellis, Professor of Bioprocessing & Tissue Engineering, University of Bath.

Dr Alan Javier Hernandez Alvarez, Lecturer in Nutrition and Global Health, University of Leeds.

Professor Che Connon, Professor of Tissue Engineering, University of Newcastle.

However, research groups and labs remain very small (1-4 researchers is common per group working on sustainable proteins), suggesting that **the UK is currently only tapping into a**

[5] A recent report from Cell Ag UK also provides rich insights into some of the UK's universities conducting precision fermentation and cultivated meat research.

fraction of the potential offered by the wider pool of knowledge and talent from relevant scientific disciplines. Public R&D funding is critical in changing this: academics cannot undertake a research project without the requisite finance. It follows that without sufficient resources, jumping from an established discipline to sustainable proteins is almost impossible. This is true for both early-career researchers and established academics. This problem shouldn't be underestimated and several UK-based researchers are today only working in the field because they have been provided grant funding from the Good Food Institute and other nonprofit organisations such as New Harvest.

Momentum is building behind efforts to catalyse and coordinate research activity within a number of UK universities, notably through the creation of the Alternative Protein Project (APP)[6]. The mission of these student-led initiatives is to develop curricula, stimulate open-access research and boost entrepreneurship, knowledge and inclusivity within universities with high potential to work on sustainable proteins. Two APP chapters already exist at Cambridge and Oxford, with new chapters launching in 2023 at Imperial, UCL and Warwick.

Since the research community remains in its infancy, **siloisation is an ongoing risk. This is especially true in the absence of any national institute or university-based centres of excellence (COE)**. Research in the fields of plant-based, fermentation and cultivated meat, seafood, eggs and dairy is highly multidisciplinary and there is no sustainable protein equivalent to the UK's Floating Offshore Wind COE, designed to convene academia, industry and other partners to address critical R&D bottlenecks, reduce risks and bring down technology costs. Links between universities are certainly growing and the founding of the cellular agriculture manufacturing research hub should improve the coordination of cultivated meat R&D, while there is also an algae researcher network. Nonetheless, a step-change is still required in the size and scope of funding to create the institutional capacity to better stitch together the UK's sustainable protein R&D ecosystem both within and between universities and the private sector.

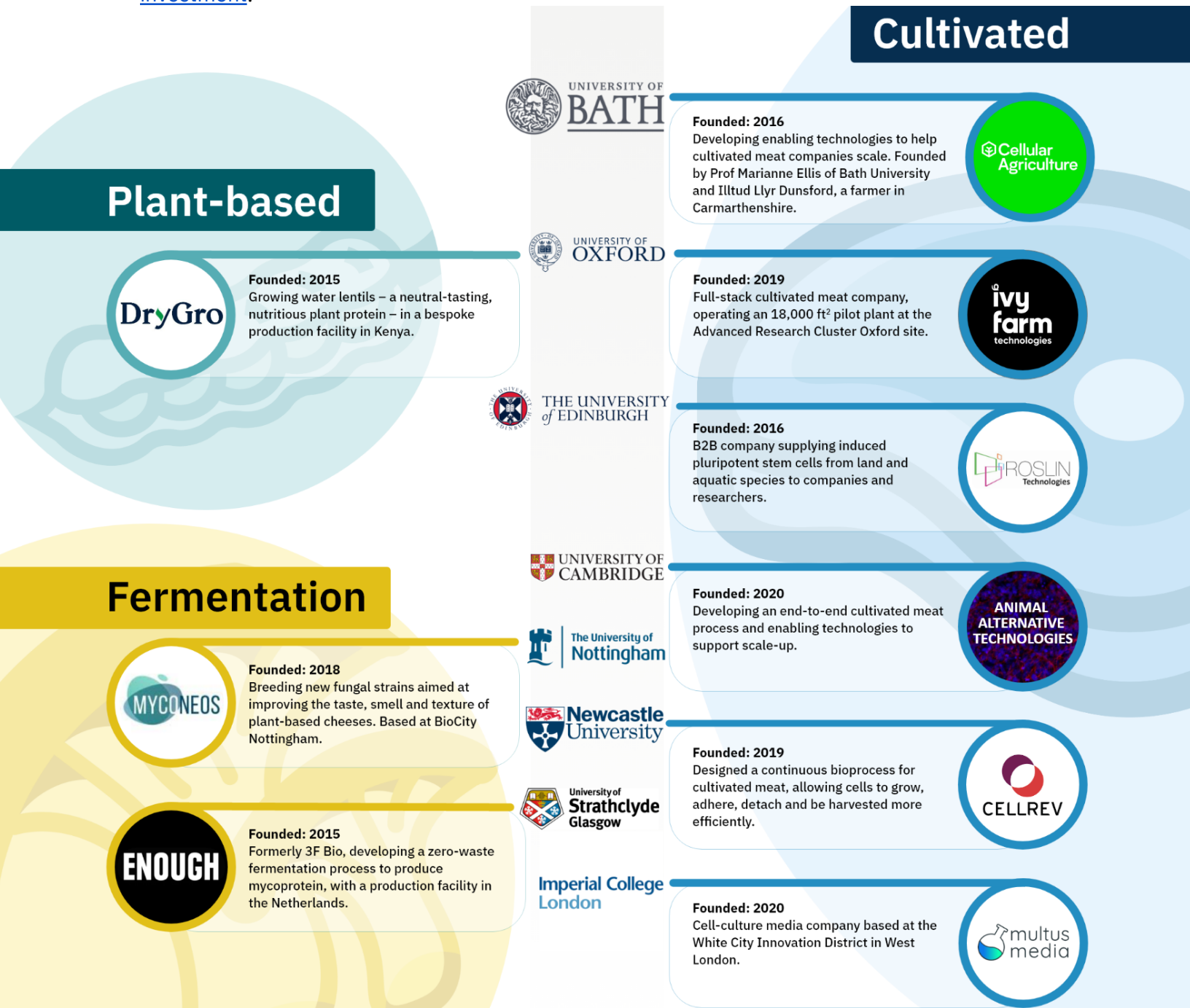
Strong partnerships are being forged between British universities and sustainable protein companies, enabling rapid commercialisation

A common charge against UK universities is a failure to commercialise research. While there are certainly improvements that could be made in the fields of plant-based, fermentation and cultivated meat, it is encouraging that **UK universities are seeding the sustainable protein companies of the future**.

[6] The Alt Protein Project is funded and coordinated by the Good Food Institute.

The nature of relationships between sustainable protein spinouts and universities varies. In some cases, they are very loose – for instance, the university may provide access to infrastructure and services, like labs and accelerator programmes. In others, universities have licensed intellectual property to the company and taken an equity stake. There are also some PhD students placed with sustainable protein spinouts.

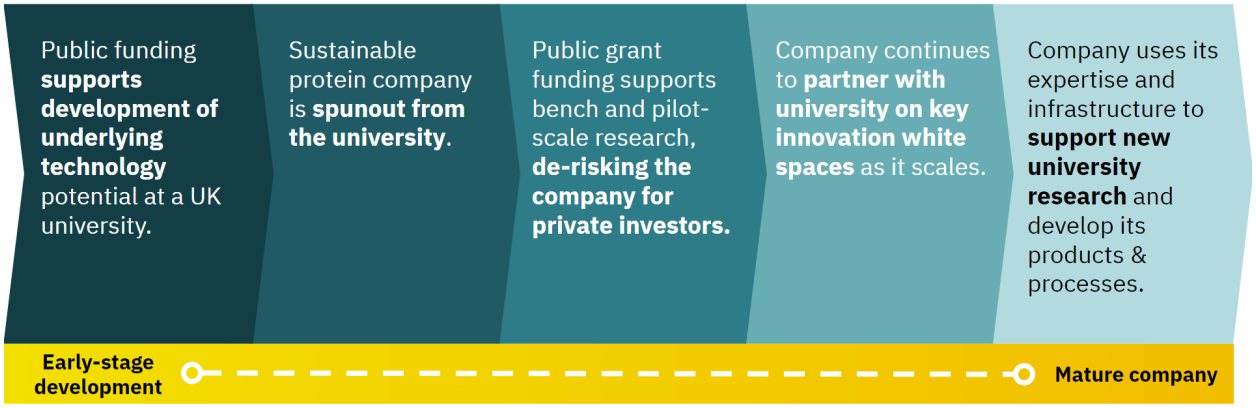
Perhaps unsurprisingly, given the complex nature of the technologies and the costly research infrastructure required to develop them, university spinouts have been most common in the cultivated meat sector. For many of these companies, subsequent public R&D investment from Innovate UK has accelerated their development. For instance, Imperial spinout Multus Media received more than £2 million from Innovate UK to help formulate and scale-up production of its Proliferum® M serum-free media. The company has since secured an £8 million Series A investment.



Links between the sustainable protein sector and universities go beyond companies operating at bench and pilot scales. For instance, the University of Leeds has recently worked with THIS – a plant-based brand whose products are widely available throughout the UK – on a project to develop and commercialise plant-based eggs. Quorn has long-standing relationships with several UK universities including Exeter, Nottingham and Northumbria, King's College London. Their work has focused on optimising Quorn's biomass fermentation process and evidencing the myriad nutritional benefits of mycoprotein. However, it is perhaps telling of the scarcity of public funding to date that Quorn has funded many of its early-career researchers at UK universities.

In any case, **the links between sustainable protein companies and British universities are a vital component of the ecosystem**. Of the UK-based sustainable protein companies we engaged with for this research, 12 out of 14 had partnered with a UK university at least once in the last 12 months. Increasing public R&D funding is likely to incubate new companies, aid scale-up and improve the taste and price of plant-based, fermentation and cultivated meat. The model below shows just one way that the symbiotic relationship between university and business can play out over time.

Figure 5: Example framework of how sustainable protein companies partner with public sector research institutions over the business lifespan



Beyond universities, the UK has high-quality institutions and infrastructure to support sustainable protein R&D – but this isn't well leveraged yet.

University-based research is an essential ingredient in a thriving sustainable protein ecosystem. Equally, it depends on other science and technology institutions outside the higher education sector. These include publicly-financed and managed research institutes, science

and technology parks, accelerators, and contract development and manufacturing organisations (CDMOs).

As the map below (Figure 6) captures, **the UK has a rich diversity of agritech and biotech R&D expertise and infrastructure applicable to the sustainable protein sector**. **Yet at present, this is not being especially well-utilised to develop plant-based, fermentation and cultivated meat.**

Several research institutes stand out as candidates to conduct and support sustainable protein R&D. These include Rothamsted Research (agriculture), the Quadrum Institute (food and health), the Roslin Institute (animal health), the Earlham Institute (living systems), and the John Innes Centre (plant science). The UK's four Agri-Tech Centres can also be considered in this category. The unique role played by these institutions – which are wholly or heavily funded by the BBSRC and Innovate UK – is in their capability to address long-term, strategic priorities defined by UKRI, rather than operate on a hand-to-mouth basis. To date, however, sustainable proteins have been at best a marginal focus for these institutes. Much of their expertise and capacity is being directed towards the life sciences and traditional agri-food sectors. The recent £164 million investment received by the three Norwich-based BBSRC institutes – Earlham, Quadrum and the JIC – offers a unique opportunity to create new workstreams aimed at addressing plant-based R&D whitespaces, like breeding for higher yield, taste and functionality, trialling underutilised crops and improving the profile of plant-based fats.

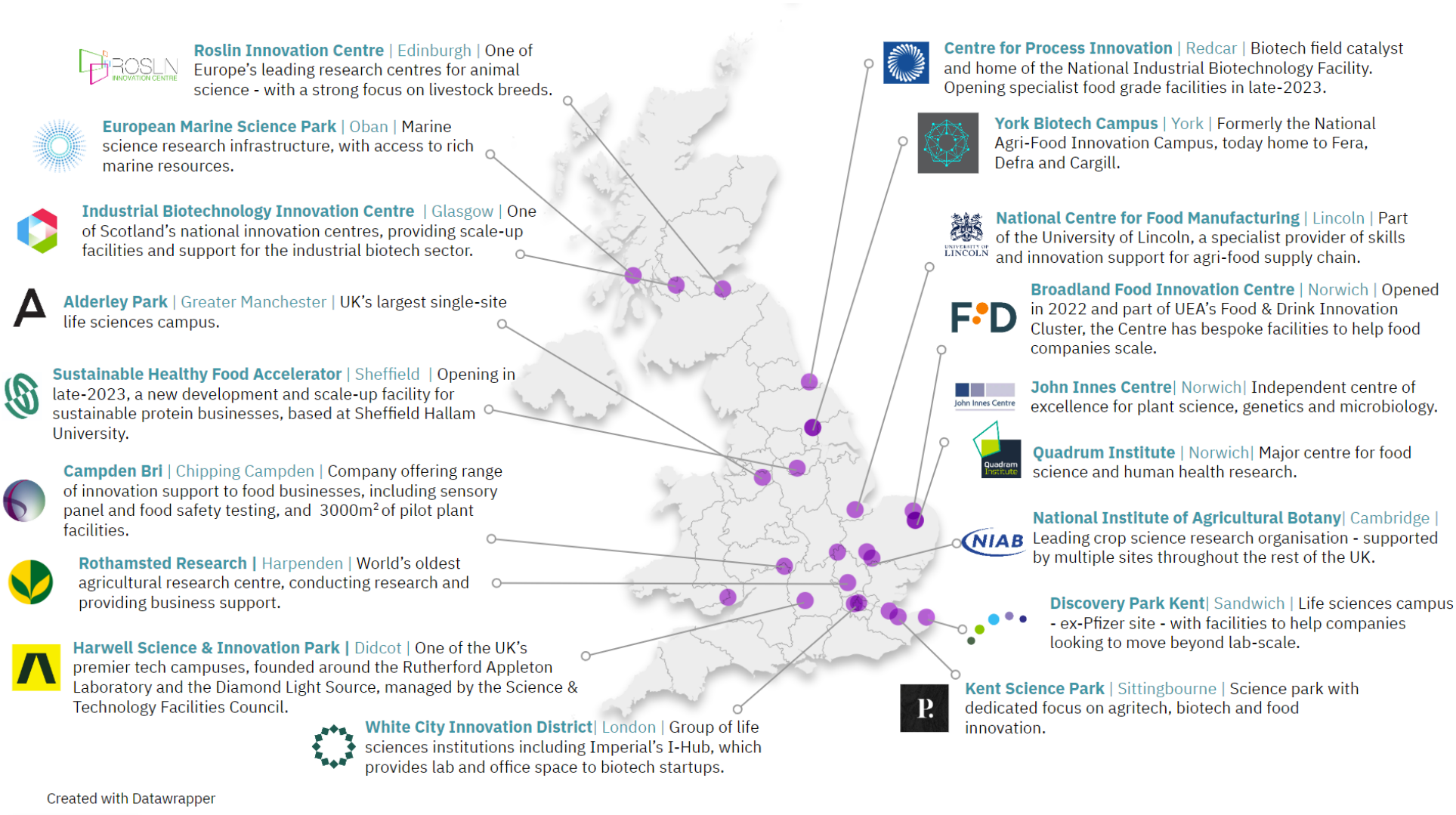
Science and technology parks are another critical ingredient in the ecosystem. There are more than 100 campuses throughout the UK, and many of these have a strong sectoral affiliation and function as research clusters, such as the York Biotech Campus – home to agritech companies, a Defra office and the agrifood science company, Fera. Other parks have high-quality scientific infrastructure and a global reputation, like Harwell and Alderley. Where large-scale campuses aren't an option, co-located institutions often form networks or clusters. The White City Innovation District in west London – home to a range of life sciences and engineering biology organisations and infrastructure – is one such example.

The labs, fermentation capacity, test kitchens, business and innovation support, knowledge exchange and much more offered by scitech campuses and networks are crucial for catalysing sustainable protein R&D. Yet as has been repeatedly pointed out, for example by the Centre for Policy Studies, the UK has consistently failed to build enough of this kind of infrastructure, leading to significant rental costs for start-ups. This is especially problematic in the fermentation and cultivated meat sector, where capital expenditure can be very high but companies depend on angel investments and venture capital funding, which is unsuited for such long-term asset investments.

With that in mind, **a critical bottleneck is the lack of pilot infrastructure necessary to transition sustainable protein companies from lab to market**. In the fermentation and cultivated meat sector, in particular, there are very few businesses or universities capable of offering specialised infrastructure and support. Exceptions include CPI, which has worked with Newcastle-based cultivated meat company 3D Biotissue to develop a cell culture media formulation, and IBioIC, which partners with two Scottish universities to offer bioprocess scale-up and optimisation. IBioIC has worked with both ENOUGH and Roslin Technologies.

Of the very limited pilot fermentation capacity available in the UK, only five sites listed on the Capacitor Database have food-grade capacity, meaning that fermentation and cultivated meat companies depend on over-engineered and costly pharmaceutical-grade equipment to scale. Similarly, companies entering the plant-based industry often struggle to secure line time at demonstration-scale and mid-scale commercial production facilities. Arguably this represents a significant opportunity for biotech and food manufacturing CDMOs to diversify their business models and offer specialised support to the sustainable protein sector. CPI, for instance, has received £2 million from the Tees Valley Combined Authority to grow its food-grade R&D capacity, targeted at novel foods, which will launch in late-2023.

Figure 6: Snapshot of institutions with capabilities to support sustainable protein R&D in the UK



Scores of R&D white spaces remain in the sustainable protein field – with continued increases in funding, the UK stands well-placed to address them.

In this final section, we unpack in more detail what specific research and development bottlenecks the UK has dedicated funding to as of May 2023. As with all the data presented in this chapter, this only includes UKRI funding we identified from a comprehensive search of the Gateway to Research portal.

Plant-based

Crop development is an evident strength of the UK plant-based research ecosystem (approximately £4 million in total investment). Faba beans, pea and rapeseed are examples of crops being developed to improve yield and downstream incorporation in plant-based meats. Algae research (including microalgae and seaweed) is a further strength and has been supported by a network grant (£735,475). In contrast, other crop research is concentrated around traditional agricultural research institutes (such as NIAB and the John Innes Centre) but isn't yet supported by a formal network.

Beyond crop development, plant-based food science in the UK has been focused on nutrition and health research (total of £3 million and £5.8 million, respectively), as well as product formulation (£1.7 million total). More research is needed into process innovations for plant-based proteins, such as methods of fibre formation and improved plant protein texturisation, including extrusion and electrospinning. This is essential for driving down costs and improving sensory properties like taste – the two biggest barriers to further consumer uptake of plant-based foods. There is untapped potential in plant-based seafood (currently only £69,000 has so far been invested in research), but the development of this research and industry segment would need cross-pillar research activity, for instance, linking omega-3 production to research to ensure its stability for addition to plant-based seafood.

Fermentation

In fermentation, the UK is particularly strong on strain development for biomass fermentation, driven by the research activity of Marlow Foods (Quorn), including in critically under-addressed spaces like suppressing hyper-branching of filamentous fungi (for example, a £749,000 BBSRC grant to NIAB to investigate this). More funding is needed for comprehensive approaches to

microbial screening and strain development for bacterial protein expression, with an eye on food safety (only five projects have so far been funded, totalling £1.6 million).

As the sustainable protein industry grows, increasing its sustainability by exploiting different feedstocks will be crucial. This includes circular bioeconomy approaches such as using sidestreams from crops and other processes (e.g. brewing), gas fermentation, and potentially even food waste. One flagship project (Pasture to Plate, a £2 million grant to Harper Adams University) exploring using grass as a feedstock demonstrates the direction that the UK should take.

Cultivated

Cultivated meat research in the UK will be brought together under the CARMA research hub, deepening existing research strengths in bioprocessing, tissue engineering, cell line development and growth factor production. More collaborative initiatives like the Extracellular licence-free cell bank, made possible by a grant from Innovate UK and created in collaboration with Multus Media, offer an outsize impact for the field.

In order for cultivated seafood to reach the same level of development as other cultivated meats, investment in fundamental understanding of fish cell proliferation is needed (only one project looking at cultivated seafood has been funded, with Innovate UK granting £245,000 to Roslin Technologies). This is a highly neglected area for UK R&D and it is perhaps telling that – to our knowledge – there are no start-ups in the UK focused on developing cultivated seafood products.

Hybrid

Fat production and incorporation for plant-based and cultivated meat, whether that is by uptake and biosynthesis of lipids by cultivated meat cells, encapsulating plant-based fats, or producing animal-like fats via fermentation, has thus far received very limited research funding (for instance, there is currently only one PhD explicitly looking at fat in each of plant-based and cultivated), and will be a growing roadblock to products that can mimic the texture and taste of conventional meat.

Given the UK's strengths across all three pillars of sustainable protein production, opportunities exist to fund research that is truly multi-disciplinary and focuses on hybrid products. For example, research focused on unlocking the potential of fermentation to support the plant-based sector – such as biological processing of ingredients for improved taste and

texture – could have an enormous impact. Opportunities should be explored to produce critical ingredients for the plant-based and cultivated meat sectors via fermentation.

In the final chapter of this report, we build on the above analysis and make a series of recommendations as to the highest priorities for UK sustainable protein R&D, which can further its competitive advantage.

Chapter 2 summary

- The UK has invested at least £43 million in sustainable protein R&D via UKRI since 2012. 65% of this has funding was allocated between Jan 2022 - May 2023.
- Cultivated meat has received the largest proportion of funding (£20 million), largely due to the creation of the new EPSRC cellular agriculture manufacturing research hub (£12 million).
- Plant-based meat R&D has been neglected, despite the UK's strengths in agri-food innovation. Precision fermentation has also been neglected.
- There is a nascent but diverse range of sustainable protein research taking place at universities across the country, including at some of the UK's most internationally-acclaimed institutions.
- UK universities have been instrumental in spinning out the sustainable protein companies of the future.
- Strong links exist between academia and industry, but these are often siloed and there is a lack of coordination of sustainable protein R&D, partly due to the absence of a major national institution like a centre of excellence.
- Public funding is critical for encouraging researchers active in neighbouring fields to apply their expertise to plant-based, fermentation and cultivated meat R&D.
- The UK has considerable latent potential across its agri-food tech and biotech expertise and infrastructure that it could better leverage to drive sustainable protein R&D.
- A critical bottleneck is the lack of pilot infrastructure, particularly for fermentation and cultivated meat, designed to help grow sustainable protein companies from the lab to market.

03 How is the UK's sustainable protein industry emerging?

Unlocking the transformative potential of plant-based, fermentation and cultivated meat, seafood, eggs and dairy requires the creation of a new and dynamic industry. This commercial ecosystem is beginning to emerge, from startups pioneering the next generation of sustainable protein products to established agrifood and biotechnology enterprises who are diversifying their business models. This chapter provides a birdseye view of how the sustainable protein industry is emerging in the UK. It reviews:

- The structure of the industry and its regional distribution.
- Public and private investment in the sector.
- Whether future manufacturing can be secured here in the UK.

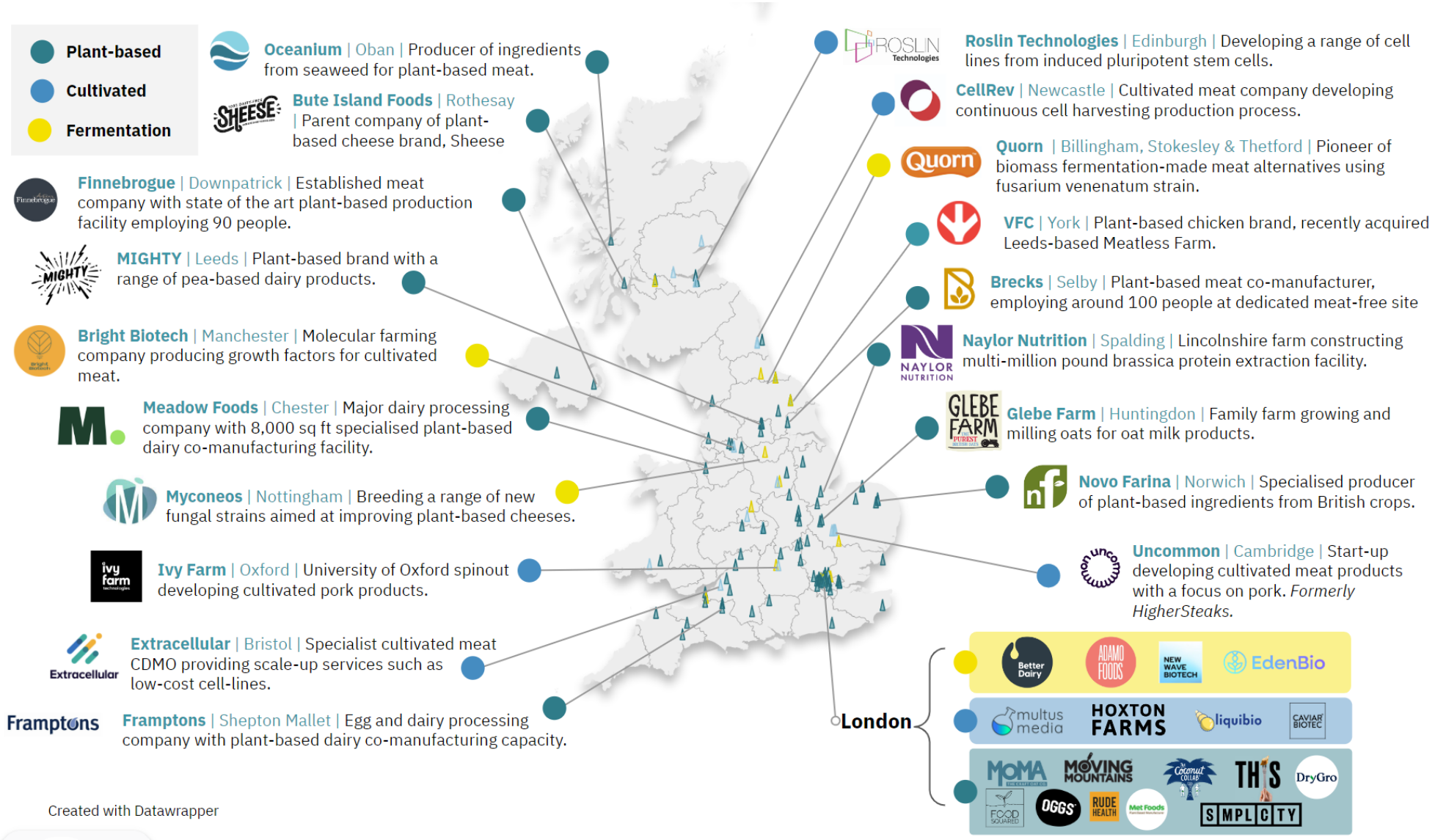
About the company information presented in this chapter

Throughout this chapter, we draw on a mapping exercise undertaken by GFI Europe in May 2023, which compiled various sources to establish a database of UK sustainable protein companies. Annex II describes our methodology in full. As well as assigning companies to either the plant-based, fermentation or cultivated production pillar, we also attributed companies under the following typology:

- **Core company:** Full-stack businesses or end-consumer brands whose sole focus or a major priority is to develop and produce sustainable protein products.
- **Specialised enabler:** Highly-specialised firms whose sole or major focus is to enable core sustainable protein companies to bring products to market.
- **Auxiliary actors:** Ingredient/input, equipment and infrastructure providers known to be operating in the wider sustainable protein supply chain, but whose commercial focus is considerably broader than plant-based, fermentation and cultivated *(**not mapped**)*.

When we talk about a 'sustainable protein company', we are referring to both core companies and specialised enablers. It is very likely that we have been unable to identify some sustainable protein companies through our research and therefore **we do not believe our map is comprehensive, but rather a snapshot of the industry**. **We encourage those not identified to add their details to the Good Food Institute's company database**.

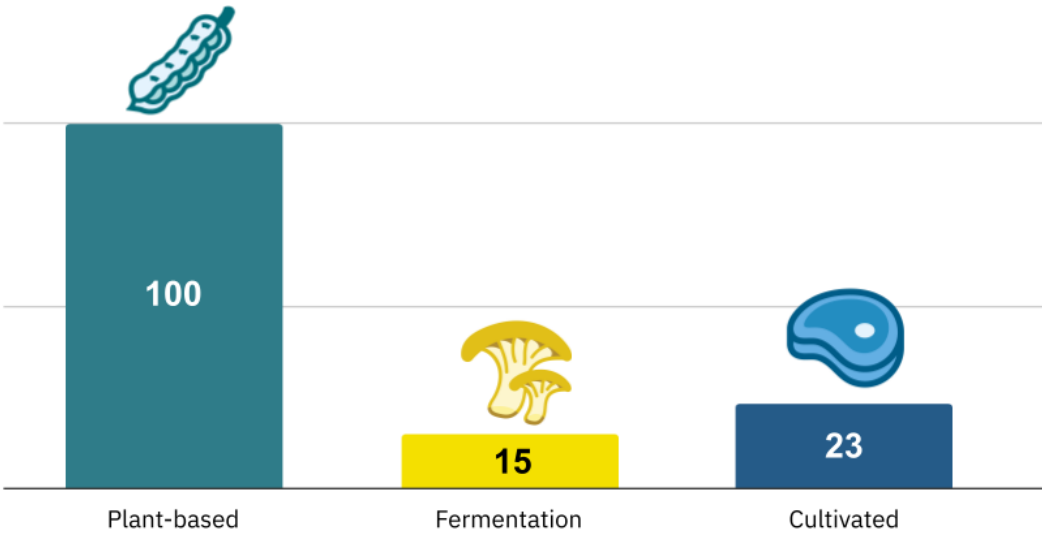
Figure 7: Examples of UK plant-based, fermentation and cultivated meat, dairy, egg and seafood companies



The UK's sustainable protein commercial ecosystem is structurally diverse and regionally distributed

The map above provides a snapshot of some of the UK sustainable protein businesses we identified. Even this birdseye view demonstrates that from farms to factories, startups to established multinational companies, **the UK's nascent sustainable protein industry is diverse, dynamic and distributed throughout the country.**

Figure 8: Estimated number of sustainable protein companies in the UK



Sources: GFI company database; Protein Directory; BRCGS Directory; UKRI Gateway to Research; desk research.

Note: estimates do not include auxiliary actors for whom sustainable proteins are only a small aspect of their wider business. For more details, see Annex II.

Unsurprisingly, the plant-based sector represents the largest proportion of the companies we identified, given that it has a more established basis and a lower barrier to entry. We are confident that there are *at least* 100 core companies and specialised enablers operating in the plant-based meat, seafood, egg and dairy sector, and we expect the number to be far higher in reality. This commercial base has driven a strong consumer market: our analysis of NeilsenIQ data indicates that **UK consumers spent £964 million on plant-based meat and dairy products in 2022**, with the value of sales and volume growing by 9% and 6% respectively from 2020. Plant-based milk and meat had a 7% and 3% share of their respective markets in 2022.

Many plant-based brands are headquartered in London and major cities, but **much of the economic impact and future development of the plant-based sector is in the food manufacturing capacity growing throughout the regions** – with examples in Cheshire, Downpatrick, North Yorkshire and County Down. A key observation is that a small number of

farms and meat and dairy processing companies are diversifying their business models to embrace opportunities in the plant-based sector. In some cases, this includes investing millions of pounds in state-of-the-art manufacturing capacity, such as Meadow Foods and Finnebrogue. Grower-producer models such as Glebe Farm, Good Hemp and Naylor Farm provide examples of how plant-based ingredients and foods can offer diversification options for growers and farmers.

Our estimates do not include many businesses active in the wider supply chain – since their remit is far larger than the plant-based sector alone – but whose presence in the UK is crucial to the ecosystem. Retailers are an important example, with the growth of supermarket private label products seen as a key market development in recent years. By bringing their economies of scale to bear, they are building confidence in demand for British-grown crops, creating opportunities for co-manufacturers and conducting research and development to reduce costs and improve the quality of product offerings.

Another two key categories are ingredient suppliers and equipment manufacturers. Many of these are multinationals with a footprint throughout the UK, such as Kerry, Firmenich, IFF, GEA and Kalsec. To zoom in on one example, Givaudan – a global flavour and fragrance enterprise – has nine locations in the UK, including DDW Colour House in Manchester, which produces natural colourings for plant-based meat and dairy. Very often, however, it is difficult to unpick what commercial activity is taking place *where* within these businesses, so we have not sought to map them.

In the fermentation sector, the boundary between Teesside and North Yorkshire is home to Quorn, pioneer of a biomass fermentation process used to produce mycoprotein at an industrial scale. Their Billingham site is the largest sustainable protein production facility in the world. With its significant climate mitigation potential – Quorn's mycoprotein has an emissions footprint 70% lower than chicken – it is encouraging that other companies in the UK are developing mycoprotein foods, including Adamo Foods and ENOUGH.

Precision fermentation, by contrast, is relatively underdeveloped in the UK compared to countries such as Israel and the United States. London-based Better Dairy is creating animal-free cheeses by using precision fermentation to produce casein, but our research did not identify any other precision fermentation startups focusing on sustainable proteins. There are, however, a small number of companies building the underlying technologies to advance precision fermentation. For instance, Eden Bio, is using machine learning to better engineer microbial strains used for precision fermentation. One plausible reason why precision fermentation has not been as widely developed as cultivated meat in the UK is because – as discussed above – public R&D investment into this space has been relatively low in comparison.

The UK is home to at least 23 core companies and specialised enablers developing cultivated meat products. As a benchmark, there are at least 43 companies in the United States – suggesting the UK is playing an outsized role in the space globally. A range of full-stack companies – e.g. Uncommon (formerly Higher Steaks), Ivy Farm – and B2B enterprises – e.g. Hoxton Farms, Multus Media, CellRev – are distributed throughout the UK. Commercialising cell lines is an area where the UK is pressing ahead, with Quest Meat, Extracellular, Pluricells and Roslin Technologies all working to commercialise cells for companies and researchers to source from. The majority of cultivated meat companies tend to be co-located with critical R&D infrastructure, such as university labs and science parks. As the sector scales to industrial volumes of output, it is plausible that a similar trend to the wider food industry will emerge, with scaled production taking place in areas where land is more available and affordable.

In the last two years, **two organisations have been founded to represent the diversity of the sustainable protein industry in the UK**: the Plant-based Food Alliance (PBFA) and the Alternative Protein Association (APA). These organisations together represent around 40 plant-based, fermentation and cultivated meat, seafood, egg and dairy businesses and investors in policy and media engagements, and are supported by a number of other NGOs. The founding of the APA and PBFA is an important milestone. It is common for emerging sectors to require specialist representation for the needs and viewpoints of their industry; the creation of Hydrogen UK in 2020 is an instructive comparison.

Public and private investments in sustainable protein businesses

A successful sustainable protein ecosystem depends on both public and private sector investments in plant-based, fermentation and cultivated meat businesses increasing considerably over the coming years.

Our analysis of UKRI spending shows that **since 2012, UKRI has directly invested £11 million in UK businesses to develop sustainable proteins**.[7] Of this funding, more than half (£6.2 million) has gone to cultivated meat companies, £1.4 million to fermentation businesses (with Marlow Foods/Quorn receiving close to half) and £4.5 million to algae.[8] It is striking that **plant-based meat, seafood, egg and dairy companies have received very little funding, both in total and in terms of the average size of grant**.

Examples of companies who have received Innovate UK funding include:

[7] At least an additional £2.4 million was received by private research institutions, such as NIAB and the John Innes Centre.

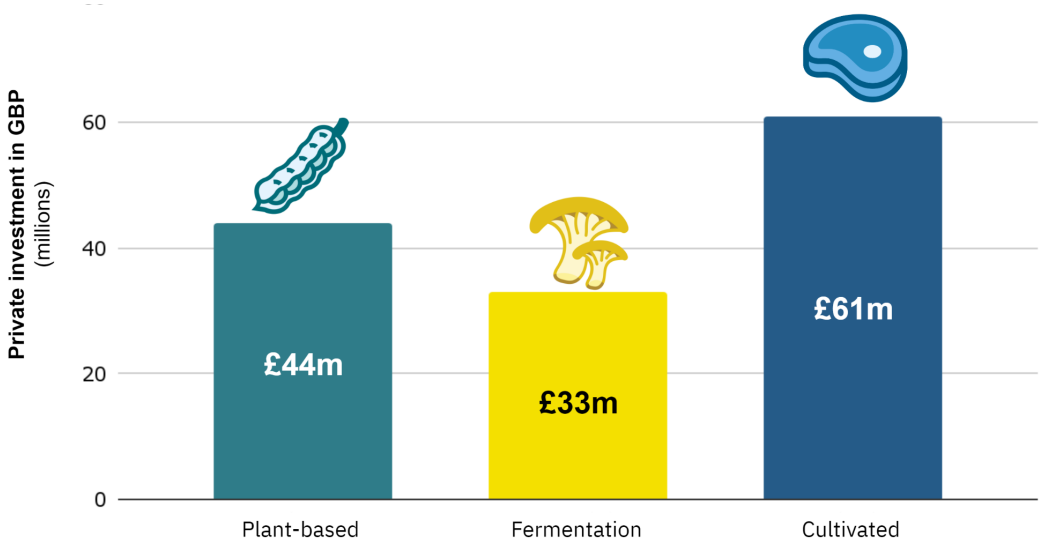
[8] The vast majority of the algae funding was directed to the AGRI-SATT project - producing marine algae in desert environments as a source of plant-protein and carbon sequestration.

- **Adamo Foods** – a London-based fermentation company developing whole-cut meat from mycoprotein.
- **Baker Perkins** – Peterborough-based specialists in food manufacturing equipment for plant-based foods.
- **CellRev** – a University of Newcastle spinout developing a circular bioprocess for cultivated meat.
- **Extracellular** – a Bristol-based B2B company offering specialised cell lines and scale-up support for the cultivated meat sector.
- **Oceanium** – a Scottish startup producing nutritious functional ingredients from seaweed for a range of applications, including in plant-based foods.

The trend towards cultivated meat is replicated in private investments. Our analysis of Pitchbook data shows that **in 2022, private sector investment in UK cultivated meat companies rose to £61 million – up 400% compared with 2021 and totalling more than the rest of Europe combined.** British plant-based companies raised £43 million – more than the sector raised in the five years to 2019 – and the fermentation sector attracted £33 million.

Sustainable protein start-ups in the UK are between seed funding and Series B. Several companies have announced successful funding rounds in 2023, including THIS (£15 million, Series B), Uncommon (£24 million, Series A) and Multus Media (£8 million, Series A). The UK is also home to a number of sustainable protein-focused investors, including Agronomics, CPT Capital, Milltrust Ventures, Synthesis Capital and Veg Capital, who have invested in a diverse portfolio of companies in the UK and internationally.

Figure 9: Private investments raised by UK sustainable protein companies, 2022



Source: Pitchbook, GFI analysis

Uncertainty remains over whether sustainable protein companies will scale in the UK or overseas

With the sustainable protein sector still in its infancy, **it remains an open question whether the UK will be a home to this innovative food manufacturing sector in the future**. The plant-based industry may be more established, but there are relatively few specialist large-scale processing and manufacturing facilities. Quorn is the only company globally producing mycoprotein at industrial scale. And no UK-based cultivated meat company is yet ready to construct a commercial-scale facility, partly since, as of the date of publication, no pre-market authorisations had been submitted to the Food Standards Agency by a UK company.[9]

A significant opportunity therefore lies ahead to build sustainable protein processing and manufacturing capacity in the UK. UKRI research has identified a lack of domestic plant protein processing capabilities, including for well-suited domestic crops like pea and fava beans. GFI modelling suggests that for plant-based meat to capture a conservative 6% of the global meat market by 2030, an estimated 810 extrusion facilities will need to be in operation worldwide (each producing 30,000 metric tonnes annually). Similarly, according to an analysis by McKinsey, for cultivated meat to reach even 1% of the global protein market by 2030 will require 220 to 440 million litres of capacity, eclipsing the estimated 10 to 20 million litres of pharmaceutical-grade cell-culture capacity currently built - which would not be suitable for the commercial production of cultivated meat in any case.

How many green jobs could be created in sustainable proteins?

Analysis published in August 2023 by Green Alliance, an environmental think-tank, has estimated the potential future economic benefits of sustainable proteins. Drawing on modeling from Boston Consulting Group forecasting the growth of sustainable proteins by 2035, Green Alliance estimated that, under a high-innovation and supportive-regulatory environment scenario, **25,000 jobs** could be created by 2035. These green employment opportunities - including 4,000 in agriculture - would be generated throughout the UK. The analysis also identified several potential industry clusters, similar to those we discuss in Chapter 4 of this report. Overall, £6.4 billion would be added to the UK economy under this scenario.

[9] Aleph Farms, an Israeli cultivated meat company, submitted an application under the novel foods framework for a cultivated beef product in summer 2023 - the first pre-market authorisation submission of its kind in the UK.

The risk is that **the UK could fail to scale companies domestically, with businesses seeking go-to-market and manufacturing opportunities overseas**. This would limit the country's potential to capture the wider benefits – particularly for the economy and food security – of a strong future manufacturing base. A confluence of factors, including access to finance and a skilled talent pool, regulatory dynamics and gaining planning approvals for production facilities, will all influence the likelihood of this scenario emerging.

There is some evidence that companies are already looking to scale beyond Britain. Certainly **for some of the UK's precision fermentation and cultivated meat companies**, **Singapore and the United States are considered preferential markets, citing much greater regulatory clarity and speed of the path to market**. Mycoprotein company ENOUGH – whose circular biomass fermentation technology was developed at the University of Strathclyde and who received incubator support from the Industrial Biotechnology Innovation Centre in Glasgow – will produce at a commercial-scale facility in The Netherlands, in part thanks to European Union funding. The company recently closed a £34 million funding round.

Another cautionary tale is the UK's life sciences industry. The sector conducts more R&D activity than any other in the UK, and the UK Government ranks third in the world for R&D spending on life sciences (as a proportion of GDP). Yet research from the University of Cambridge shows that whilst in 2010, the UK had a $9.7 billion trade surplus in pharmaceutical products, this fell to a $1 billion deficit by 2020. In part, this has been attributed to companies offshoring their manufacturing and UK firms failing to secure manufacturing investment in the 2010s, which instead went to Ireland, Singapore, Germany and the US.

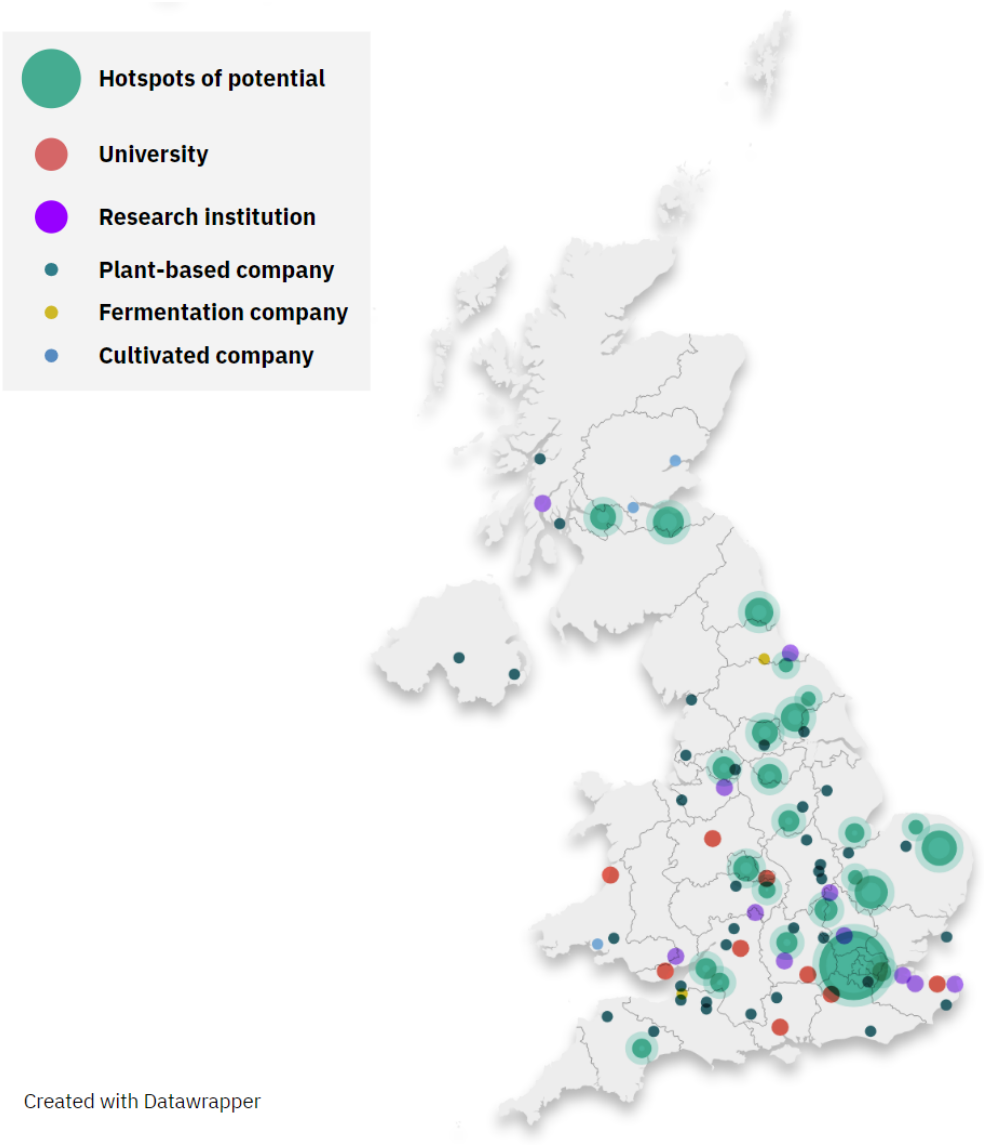
Chapter 3 summary

- The UK's nascent sustainable protein industry is diverse, dynamic and distributed throughout the country. We identified 23 cultivated meat companies, 15 fermentation and 100 plant-based businesses - it is very likely that this is an underestimate.
- Many plant-based brands are headquartered in London and other major cities, but much of the economic potential of the plant-based sector is in the food manufacturing capacity growing throughout the regions and the involvement of retailers and international food businesses in the wider supply chain.
- The UK is playing an outsized role in the global race to develop cultivated meat. There is a diverse set of full-stack and B2B companies based here, who raised £61 million in private investment in 2022 - more than the rest of Europe combined. UKRI has invested the most heavily (£11 million) in cultivated meat companies, with much less going to plant-based and fermentation businesses
- The UK has a strong history in developing mycoprotein but precision fermentation is comparatively underdeveloped, particularly when compared to Israel and the United States.
- It remains an open question whether the UK will move beyond being a hub for sustainable protein R&D to becoming a strong manufacturing base. Research from suggests the size of the prize could be extremely significant, with up to 25,000 jobs created and £6.4 billion added to the economy by 2035.

04 Where are sustainable protein hotspots emerging in the UK?

Pulling the camera back, when we view the public R&D institutions and commercial sustainable protein ecosystem together, **there are clear signs of potential hotspots located throughout the UK**. With a supportive policy framework and strong political leadership, there is no reason we could not emulate successes in other green industries by creating future R&D and industrial clusters in plant-based, fermentation and cultivated meat.

Figure 10: sustainable protein hotspots in the United Kingdom



Even at this early stage of the ecosystem's development, there are several hotspots of activity, including:

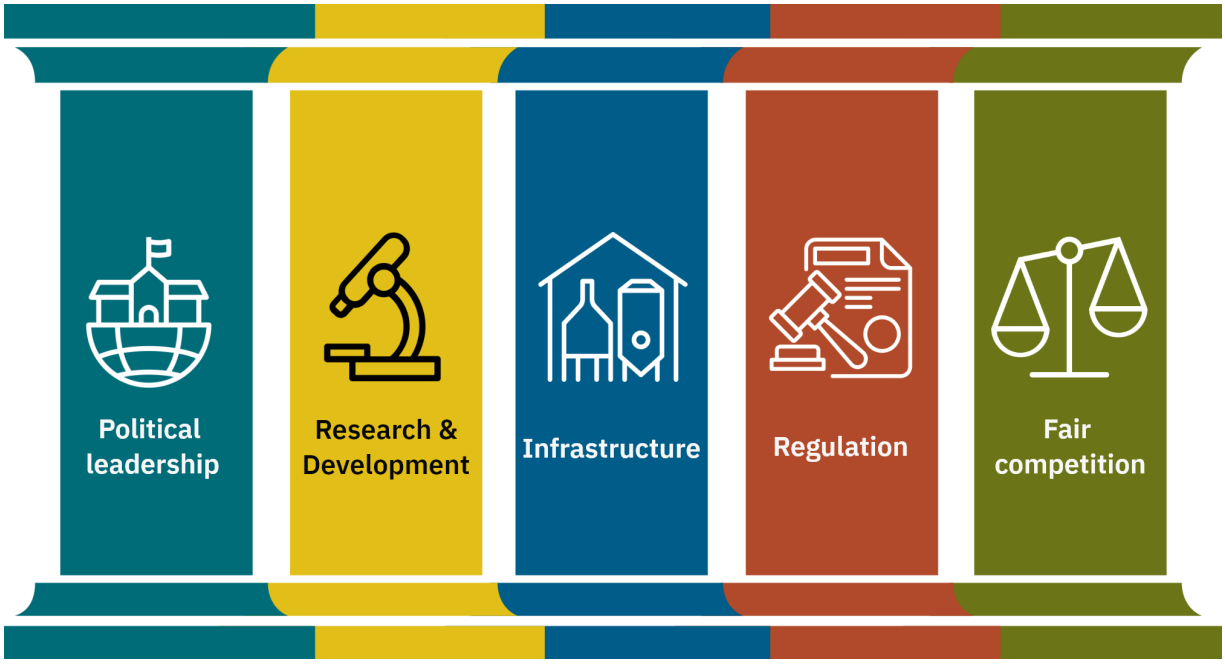
The Golden Triangle: Few areas in the world rival the Cambridge-Oxford-London area for biotechnology innovation and it is little surprise that many of the UK's cultivated meat companies have emerged inside the Golden Triangle (including Ivy Farm, Uncommon, Alternative Animal Technologies, Multus Media, Hoxton Farms). UCL and Imperial are beginning to apply their latent engineering biology strengths to sustainable proteins, while the University of Cambridge has recently been highlighted as a wellspring of potential yet to be tapped. Considerable R&D capacity is also offered by supporting R&D institutions in the Golden Triangle, such as Harwell, the White City Innovation District, Rothamsted, NIAB and Babraham.

North East & Yorkshire: With a strong net zero hub already present in the region, sustainable proteins are yet another example of how the north of England can drive the climate transition. The University of Leeds' expertise in plant-based innovation – and food science more broadly – alongside the presence of several plant-based companies (MIGHTY, VFC, Tofoo) and co-manufacturers (Brecks, Hughes Group) in the region makes Yorkshire a plant-based cluster opportunity. On Teesside, CPI offers industry-leading skills and infrastructure to support cultivated meat and fermentation-made food developers, with biomass fermentation pioneers Quorn's Billingham and Stokesley sites located nearby. The universities of Newcastle and Northumbria – both actively conducting sustainable protein R&D – bolster the region's academic research credentials; two cultivated meat companies have already been spun out of Newcastle.

Cambridge-Norwich corridor: With a vision to create a "new California" and drive innovation in agri-tech, the corridor could be the heart of a future sustainable protein cluster in the UK. Two key pillars of a plant-based cluster already exist. The R&D capacity and expertise across health, food and crop science offered by The Quadrum Institute, John Innes Centre, Earlham Institute, Sainsbury's Laboratory and the Broadlands Food Innovation Centre in Norwich is an unrealised opportunity. Meanwhile, the East of England's arable farmland is among the most productive in the UK, displaying high degrees of diversity in crop rotations, potentially suggesting farmers in the region would be well-suited to growing key inputs like peas, fava beans, oats and oilseed crops. Conceivably, the region could be the future home of a rival to Protein Industries Canada – a public-private innovation cluster on the Canadian prairies receiving more than £200 million of federal investment up to 2028, which is expected to create more than 10,000 jobs.

05 Conclusions and recommendations

In this final chapter, we propose **9 recommendations** designed to catalyse the growth of the UK's sustainable protein ecosystem over the remainder of the decade, grouped under five pillars.



The UK must decisively affirm its ambitions for sustainable proteins - beginning with the engineering biology action plan - or risk ceding competitive advantage.

Our research for this report shows the UK is starting to seize the moment – while latent potential also lies untapped beneath the surface. Much of this has been driven by UKRI, whose commitments are some of the most advanced of any public R&D funding body in the world.

Yet while further investment in public R&D is a critical component for catalysing the ecosystem (see below), joined-up thinking across departments and policy areas is urgently needed. Actions taken by policymakers over the remainder of the decade will be crucial as technologies mature. A plausible scenario is that ambivalence or inaction from central government means that the fruits of UKRI's investments in sustainable proteins are partially foregone. Mixed messages have not been uncommon, with some ministers being publicly critical and pandering to false dichotomies between sustainable proteins and livestock farming, despite the

Government Food Strategy recognising there is a place for both in a sustainable, resilient food system.

Decisive political leadership is the strongest remedy here. Following the lead of nations such as Singapore, Canada, Israel, Denmark and the Netherlands, ministers should state publicly their support for sustainable proteins and their capacity to bolster food security and address environmental challenges. **The forthcoming engineering biology action plan represents an opportune moment to decisively affirm a cross-government ambition to develop and scale sustainable protein production in the UK.** This will provide clarity to scientists, investors, businesses and other stakeholders that the UK intends to compete with other world-leading countries in the race to unlock the benefits of protein diversification.

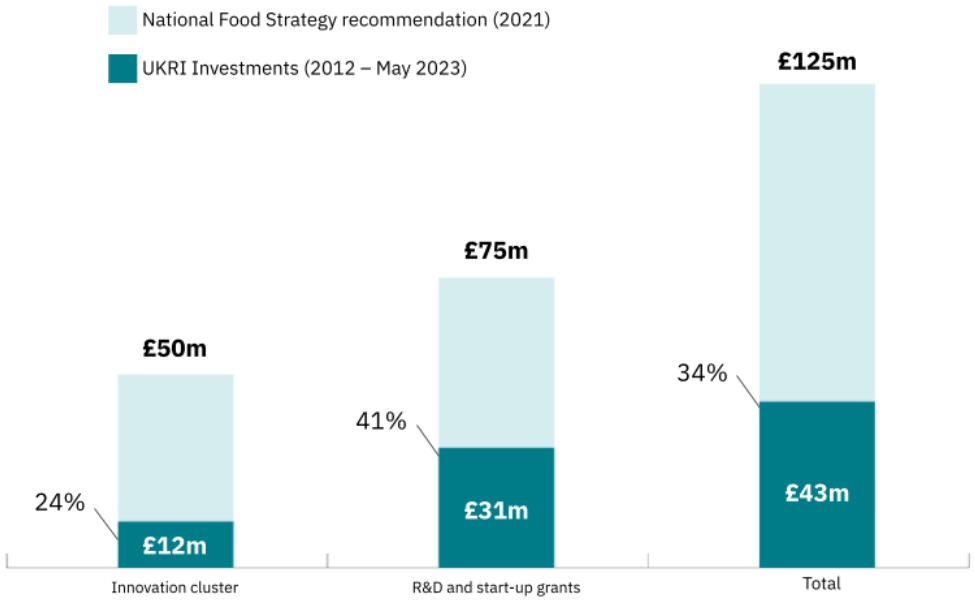
Building on this momentum, **the government should develop a national plan for sustainable proteins**. This should set out research priorities, the coordination of public research funding, an infrastructure strategy, fair competitive conditions and the role of agriculture in the transformation.

The UK Government should invest between £245-390 million in sustainable protein research and development between 2025-2030

Our analysis indicates that the UK has invested at least £43 million in R&D for plant-based, fermentation-made and cultivated meat, seafood, eggs and dairy to date. 2023 is already a record year for UK public spending on sustainable protein R&D, and the BBSRC and Innovate UK's joint commitment to invest at least £20 million by 2025 demonstrates real ambition.

Going forward, how far does the UK need to push this ambition to be globally competitive and unlock its latent strengths across the scientific community and industry? As a benchmark, Figure 11 shows the UK is still some distance from hitting the recommendations of Henry Dimbleby's National Food Strategy (NFS) in 2021. Only just over one-third of the recommended £75 million in support for startups and research has been committed, while the proposed £50 million innovation cluster has so far been addressed only by the ESPRC's £12 million cellular agriculture manufacturing research hub. The EPSRC hub is a decentralised, collaborative R&D network, and so ultimately the UK still lacks a physical innovation cluster, as proposed in the NFS.

Figure 11: National Food Strategy recommendations for R&D investment in sustainable proteins compared to actual spend by UKRI, January 2012 - May 2023.



The £125 million recommended in the Dimbleby Report is a helpful benchmark – but it is likely to be a relatively conservative estimate of what the sector needs. A report funded by the Foreign and Commonwealth Development Office and ClimateWorks in 2021 estimated that, globally, governments must invest £3.4 billion in public R&D spending every year up to 2050 to sufficiently reduce the technology costs to unlock the climate, health and economic benefits of sustainable proteins.[10]

Assuming that only OECD countries contributed to this spending, and each invested proportionally to its percentage of OECD GDP, the UK Government would need to invest on average £170 million annually over the next three decades. Clearly, this would represent a significant increase in current spending levels, equivalent to 8.7% of the combined budgets of the EPSRC, BBSRC and Innovate UK. In the current fiscal environment, it is challenging to see how the UK would hit that level of spending during the remainder of the decade.

However, given that other countries are stepping up their investments and since it is likely that in 2023 the UK will surpass the £25 million average annual investment earmarked in the National Food Strategy, we believe the UK should be more bullish. Green Alliance, in its recent report on scaling sustainable proteins in the UK, recommended a £250 million investment,

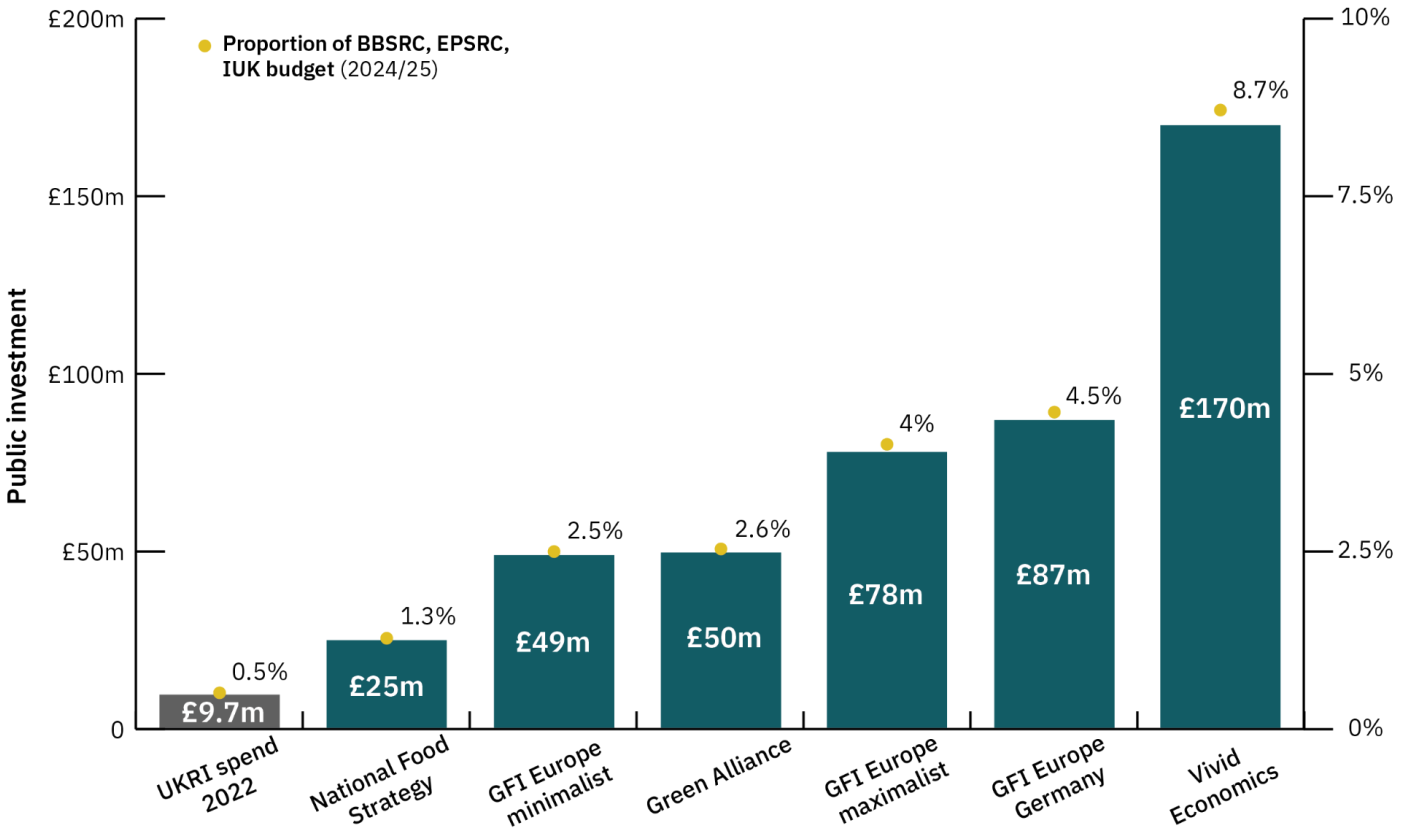
[10] ClimateWorks Foundation and Vivid Economics have partnered on a series of Global Innovation Needs Assessments (GINAs) across a range of low-carbon innovations. The methodology is adapted from a similar Energy Innovation Needs Assessment conducted by Vivid Economics in partnership with the Department for Business, Energy and Industrial Strategy.

with a focus on incubating industrial clusters. By way of an international comparison, GFI Europe has also recently proposed that the German government commit £87 million annually to sustainable protein R&D.

At an absolute minimum, we recommend that between 2025 and 2030, UKRI, DSIT and Defra should together target an average annual spend of £49 million (£245 million total) on public R&D to support plant-based, fermentation-made and cultivated meat, seafood, eggs and dairy. **To truly compete internationally, this should increase to a £78 million average annual spend (£390 million) between 2025 and 2030.** Below, we set out two scenarios for how this funding could be distributed.

To our recommendations in context, the lower and upper scenarios would be equivalent to 2.5% and 4% respectively of BBSRC, EPSRC and Innovate UK's combined budgets in 2024/25. Our lower scenario would represent a similar spend to the Farming Innovation Programme (£270 million) which has been delivered by Innovate UK since 2021.

Figure 12: Recommended average annual sustainable protein R&D investments

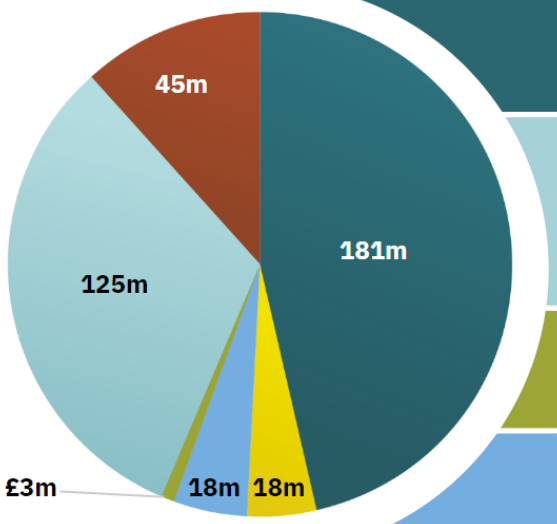


N.b. NFS = National Food Strategy. GFI-E = Good Food Institute Europe. Vivid Economics/Climateworks Foundation. NFS and Green Alliance figures have been adjusted for an annual average over 5 years

Priorities for sustainable protein R&D spending, 2025-2030

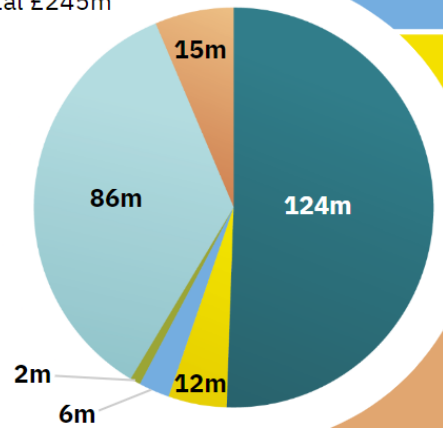
Upper scenario (£)

Total £390m



Lower scenario (£)

Total £245m



Academic grants (£124-181 million)

- In **Annex 3** we list 43 R&D priorities to address current and future bottlenecks in the development of sustainable proteins. Even areas already receiving funding will require a significant uplift for sustainable proteins to reach taste and price parity.
- The lower scenario would fund each R&D priority area at around £2.5 - £3 million. The upper scenario would fund each areas at around £4 million.

- This funding should be distributed through competitive sustainable protein-specific funding calls, alongside responsive mode grants, fellowships and finance for research equipment and infrastructure.

Business grants (£86-125 million)

- An annual competitive call focusing on a critical sustainable protein R&D white space, valued at at least £10 million.
- Dedicated call for plant-based meat, dairy, egg & seafood developers focused on taste, price & nutrition.

- Support for navigating the regulatory path to market for producers of novel food products.
- Responsive grants to scale-up from bench to pilot level.

Researcher networks (£2-3 million)

- At a minimum, establish a plant-based foods researcher network, akin to Algae UK.

- In a more ambitious scenario, an additional researcher network would be created focused on fermentation.

Centre of excellence (£6-18 million)

- A university-based institution with core funding of at least £6 million over five years, similar to the UKRI-funded Supergen Bioenergy Hub or Hydrogen Hubs.
- The centre should be interdisciplinary, focusing on critical, neglected R&D bottlenecks which could lead to commercialisable-solutions.

- A university with existing sustainable protein expertise, latent strengths in related fields and a history of commercialising research should be priortised.
- In the upper scenario, a hub-and-spoke model could be adopted, with smaller centres created in association, or a second major interdisciplinary centre established.

Studentships (£12-18 million)

- Funding for up to 150 PhD students from the BBSRC, EPSRC and ESRC.
- Funding should be roughly distributed between plant-based, fermentation and cultivated meat research.

- Wherever possible, studentships should be collaborative between industry and universities.

Pilot facility (£15 million) *Lower scenario*

- Dedicated facility for fermentation and cultivated meat developers to demonstrate feasibility and scalability of their bioprocess with a range of food-grade capacity, (small-scale reusable 1-5 litre bioreactors to ~75,000 litres).
- The facility could be a 'spoke' of any new agritech catapult; an investment into an existing university or private company site; and/or networked into existing investments such as the cellular agriculture manufacturing research hub.

Catapult (£45 million) *Upper scenario*

- An addition to the UK's catapult network focused on sustainable proteins, capable of rivalling the ambition of Protein Industries Canada.
- The catapult would contain a pilot facility, but include significant additional lab space, technical expertise and scale-up support.
- The catapult should be based in an area of existing capability and focus on the UK's specific strengths in sustainable proteins.

The UK Government should review sustainable protein infrastructure capacity and plan for the future to guarantee domestic industry growth

Our research for this report and engagement with academics and businesses operating in the sustainable protein ecosystem has highlighted that, even at this early stage, from bench to commercial-scale there are infrastructure bottlenecks in the UK. Examples include a lack of bespoke texturisation equipment, food-grade bioreactors, crop fractionation capacity, and pilot or scale-up facilities for fermentation and cultivated meat.

As part of our proposals for R&D investment, we recommend the UK invest £15 million in an open-access pilot facility for precision fermentation and cultivated meat, to help companies test and demonstrate innovations at scale without purchasing expensive equipment. This could be networked into existing investments - such as Growing Kent and Medway or the Cellular Agriculture Manufacturing Research Hub - or be part of investing in any new agritech catapult. As the Tees Valley Combined Authority investment in CPI's food-grade facility demonstrates, regional funding could certainly play a role in (part-)financing pilot infrastructure; this was the case for BioBase Europe in Ghent.

As discussed in Chapter 3, the UK will need to vastly increase its industrial-scale sustainable protein infrastructure, to secure future manufacturing here. Jointly, **the Department for Environment, Food and Rural Affairs and the Department for Science, Innovation and Technology should conduct or commission a review of sustainable protein infrastructure**. This should consider both current and future needs, set out a roadmap for what capacity must be built or retrofitted[11] and by when, and outline how the government could inject public investments strategically to derisk private investments. This is crucial to transition the sustainable protein sector from venture to patient capital - since the former is not well-suited to expensive infrastructure investments. A failure to address questions of future infrastructure capacity increases the likelihood that manufacturing will be offshored, reducing the potential benefits to UK food security and economic growth.

The Food Standards Agency should focus on implementing 'quick win' changes to the novel foods framework – and receive a boost to its budget in 2025

It is no secret that businesses developing cultivated meat and fermentation-made products, as well as some innovative plant-based ingredients and foods, view the current regulatory system as a critical barrier on the path to market. As discussed above, international markets are often

[11] As recommended in two GFI reports published in 2023, one pathway to increasing infrastructure capacity in the plant-based and fermentation sectors is to retrofit idle or decommissioned assets, such as breweries, ethanol plants and extrusion facilities

viewed by UK companies as preferential to launching products at home first. The government recognises there are imperfections and is taking action: an independent review recently provided a menu of options for the Food Standards Agency to consider.

Some reforms could require substantive structural and legislative changes. This is likely to take years to implement even if retained EU law powers are exercised, given the necessary consumer and industry consultation, engagement with other regulators internationally (if a partnership model was sought), and discussions with ministers who will ultimately approve reforms. The FSA has repeatedly emphasised that it is under-resourced and is being forced into prioritisation.

To address these challenges, **we recommend that the FSA focuses on low-hanging fruit reforms that would improve trust and confidence in the novel foods pre-market authorisation process**. Many helpful changes could be made without legislation. Reforms commonly cited as top priorities include:

- A single point of contact within the FSA for companies submitting novel food dossiers to reduce knowledge and information sharing costs.
- Published guidance specific to sustainable protein companies – which is regularly updated to reflect the latest scientific knowledge and working practices, and developed in consultation with the sector.[12]
- A formalised process for pre-submission consultations with the FSA on issues of substance, including on toxicological and wider food safety testing requirements.
- Detailed guidelines on how safe pre-market tastings could be conducted under controlled conditions.

Second, **the FSA should learn from best practices of more innovation-focused regulators, both in the UK and overseas**. In the UK, the Financial Conduct Authority has developed a 'regulatory sandbox', which enables firms to test innovative concepts with real consumers. The FSA could translate this approach into food safety research, enabling companies to test innovative products and production methods in a controlled environment with ongoing regulatory support. Similarly, the UK Medicines and Healthcare products Regulatory Agency (MHRA) has recently announced that regulatory recognition routes for medicines will enable patients to have access to medicines approved by trusted regulatory partners in other countries, bringing cutting-edge medicines to UK patients faster by leveraging the expertise of international collaborators. The FSA could adopt a similar model for novel food regulation, taking into account approval decisions in other jurisdictions with similarly robust food safety standards to build a global knowledge base on innovative food safety.

[12] This approach has been taken by the Singapore Food Agency, which also has self-assessment checklists specifically for cultivated meat and precision/biomass fermentation companies.

Finally, having an effective regulatory framework for sustainable proteins will be severely limited without an increase in regulatory capacity. The FSA is operating on a frozen budget for the current spending review period (£113 million annually 2022-2025) at a time when inflation (CPI) has hovered between 8-11% - likely leaving the regulator tens of millions of pounds worse off by 2025. The FSA's remit has expanded considerably post-Brexit and it now has a clear responsibility to help foster a more sustainable food system. At a minimum, **at the 2023 Autumn Statement, the Chancellor should give a one-off £30 million cash injection to the FSA. The next Comprehensive Spending Review should ensure that the FSA's budget continues to grow in real-terms over the rest of the decade.** A better-resourced, more agile regulator is likely to boost company and investor confidence, helping to ensure the UK reaps the long-term economic benefits of sustainable proteins.

In the short-term, the FSA could explore whether sustainable protein companies should be eligible to pay to expedite their pre-market authorisation dossier, while also providing a sidestream income for the FSA hypothecated to its novel foods regulatory process. The MHRA also charges for a range of services, whereas novel food applications do not carry a fee.

The UK Government should create a fair and level playing field for sustainable proteins

Laws retained by the UK after leaving the EU mean that plant-based foods cannot use common dairy nomenclature like "milk", "cheese" or "cream" in the labelling and marketing of these products – despite widespread colloquial usage of terms like "plant-based milk". Asda and Morrisons, for instance, both have "milk alternatives" sections of their online shopping websites. Similarly, it is commonplace in other food and drink categories to use qualifiers to inform consumers that a product is different from the established norm – "alcohol-free lager" or "gluten-free bread", for instance.

Sales of plant-based milk are growing year-on-year in the UK, suggesting a consumer base which is clearly familiar with the origin of the foods they are buying. There is no robust evidence to suggest consumers are confused by the use of dairy terminology on plant-based products. Conversely, academic research indicates that the current regulatory framework for labelling plant-based dairy products is stifling innovation. Yet the Government has recently refused to intervene in the creation of new guidance by trading standards officers to restrict plant-based brands from using commonly-recognised play-on-words to explain how their products should be used in the context of existing restrictions.

It is bemusing to see the UK claim that it wants to be "at the front" of developing sustainable proteins, while simultaneously creating needless barriers to growth for the plant-based sector. **An evidence-based, commonsense solution would remove existing restrictions on the use**

of dairy terminology – provided adequate qualifiers are used. Powers in the Retained EU Law Act could enable ministers to take action on this front, which would position the UK as more progressive than the EU in supporting innovation in the plant-based industry.

With an eye on the future, **Defra and the FSA should implement a fit-for-purpose framework that allows precision fermentation and cultivated meat companies to communicate clearly the nature of their products to consumers** and compete fairly with animal-based foods. Government should also engage with the evidence base and fill gaps where necessary to build consensus around clear labelling of cultivated meat and precision fermentation-made foods. It is imperative for food safety reasons alone that labelling rules are permitted that correctly inform consumers that cultivated and precision fermentation-made products contain meat, seafood, egg and/or dairy, including reference to the respective species (e.g. "beef" or "tuna") to which products serve as alternatives. Restricting companies to unhelpful and inaccurate terms like "fake" or "in-vitro" will also damage the UK's chances of creating a thriving cultivated meat and precision fermentation sector.

Summary of recommendations

Pillar 1: Political leadership

1. Use the forthcoming engineering biology action plan to decisively affirm a cross-government ambition to develop and scale sustainable protein production in the UK.
2. Develop a national plan for sustainable proteins.

Pillar 2: Research and development

3. Between 2025 and 2030, UKRI, DSIT and Defra should together target an average annual spend of £49 million (£245 million total) on public R&D to support plant-based, fermentation-made and cultivated meat, seafood, eggs and dairy. To truly compete internationally, this should increase to a £78 million average annual spend (£390 million) between 2025 and 2030.

Pre-competitive, university-based funding (£144-220 million)		**Commercially-focused funding** (£104-170 million)	
Academic grants	£124-181 million	Catapult	£0-45 million (higher scenario only)
Studentships	£12-18 million	Business grants	£86-125 million
Centre of excellence	£6-18 million	Pilot facilities	£15 million (lower scenario only)
Researcher networks	£2-3 million		

Pillar 3: Infrastructure

4. Defra and DSIT should conduct or commission a review of sustainable protein infrastructure and use this as a basis for detailing plans of how the government can derisk the necessary private investment to scale sustainable proteins in the UK.

Pillar 4: Regulation

5. The FSA should focus on 'quick win' reforms that would improve trust and confidence in the novel foods pre-market authorisation process.
6. The FSA should learn from best practices of more innovation-focused regulators, both in the UK and overseas.
7. The Chancellor should give a one-off £30 million injection to the FSA at the 2023 Autumn Statement and the next Comprehensive Spending review should ensure that its budget continues to grow in real-terms over the rest of the decade.

Pillar 5: Fair competition

8. Remove existing restrictions on the use of dairy terminology – provided adequate qualifiers are used.
9. Defra and the FSA should implement a fit-for-purpose framework that allows sustainable proteins to communicate clearly the nature of their products to consumers

Annex I – estimating public R&D funding in the UK

The goal of this project was to map all of the publicly-funded research projects which have taken place in the UK, where the focus of the research was to develop sustainable proteins (plant-based, fermentation-made and cultivated meat, eggs, dairy and seafood for human consumption).

The information gathered from this is helpful to evaluate total funding quantities already disbursed at the national level, key trends in research focus, and to benchmark the UK's funding relative to other European countries.

Scope and approach:

GFI used the following approach to locate and compile the database:

1. We ran an extensive list of keywords relating to sustainable proteins directly through the UKRI Gateway to Research database to generate a shortlist of projects which contained these keywords (i.e. in the title or description of the project). These projects were then reviewed manually to confirm their relevance for sustainable proteins research, and included in the final database.
    - In general, research was included if:
        - It has already or might benefit sustainable proteins R&D in a clear, plausible way, and
        - Sustainable proteins was at least one, but may not have been the entire, intended application for the research.

2. Total sums allocated for studentships were often missing in the database. On the advice of several academics we spoke to, we included the rough estimate of 100,000 for each UKRI-funded studentship (as these are generally funded to the tune of £100,000).

3. We cross-referenced our findings to estimates we made in February 2022 to ensure that we accurately captured funding listed on the Gateway prior to February 2022.

Limitations of our approach (and therefore the data)

Whilst we aimed to be as exhaustive as possible, certain limitations in our approach mean that there are plausible reasons why some relevant projects might not be included. For example, these could be projects which:

- Were not present in the UKRI database. This could be because:
    - They received other sources of funding (e.g. decisions at institutional level to allocate a proportion of an existing funding pot) and these additional projects were not identified through our broader network.
    - The projects were too recent to have been updated on the UKRI database.
    - Horizon Europe funding is only included since the UK left the European Union in January 2021, though we expect some funding was channelled to the UK via Horizon while the UK remained part of the programme.
- Were present in the UKRI database, but were not pulled out using the keywords we chose to use. This could be because:
    - The projects themselves did actually include one of our keywords, but the database search function had a poor sensitivity to particular keywords
    - Relevant projects did not contain the keywords themselves. We strived as hard as possible to be exhaustive with these keywords, but it is impossible to capture everything. Reasons why relevant projects may not have matched our keywords include:
        - There are many research projects which have been funded which have ultimate relevance for sustainable proteins R&D, but their relevance only became apparent later (i.e sustainable proteins was not actually the intended application of the project, as is true with much crop breeding and bioprocessing research).
        - Projects which did have intended relevance for sustainable proteins use different language to describe the research (this is likely because sustainable proteins R&D encompasses many different research fields and approaches)
        - More fundamental research may have a range of possible applications (including the production of sustainable proteins), and may not highlight any of these applications in the project description.
        - Researchers are actively disincentivised to apply under the banner of addressing sustainable protein research, as opposed to more fundable foci such as medical research or functional foods and nutraceuticals. For this reason, projects addressing sustainable proteins research may have

framed the research as focusing on these other applications, and never mentioned sustainable proteins in the project description.

- Researchers receive funding for sustainable protein research from non-UKRI sources which were not flagged for specific projects or research foci. For example, certain institutions receive lump sums of money (e.g. for 'levelling up' specific institutions or regions, or general 'Centre of Excellence' grants), which are at their discretion to disburse. Some of these may go to sustainable protein projects, but they will not be flagged as such on the national level database.

For the above reasons:

- **The eventual list of projects is very likely to be an underestimate, due to the difficulty in obtaining this kind of information.**
- **However, the true number of research projects and funding quantities are likely within one order of magnitude and the general trends, relationships, and ratios of funding are likely to be representative of the reality.**

Keywords

Overall	Plant-based	Cultivated	Fermentation	Fish and seafood	Dairy	Egg
Alternative protein	Plant-based meat	Cultivated meat	Precision fermentation	Fake seafood	Plant-based milk	Plant-based egg
Sustainable protein	Vegetable-based protein	Cultured meat	Fermentation-derived protein	Seafood substitutes	Non-dairy milk	Plant based egg
Fake meat	Plant-based protein	Cell cultured	Biomass fermentation protein	Cultivated seafood	Oat milk	Egg substitute
Meat substitutes	Plant-based seafood	Lab-grown meat	Precision fermentation protein	Cultured seafood	Soy milk	Egg replacement
Clean meat	Plant-based fish	Lab grown meat	Traditional fermentation protein	Lab-grown seafood	Rice milk	Egg alternative
Slaughter-free meat	Plant protein	Cell-based meat	Mycoprotein	Cell-based seafood	Plant-based cheese	
Animal-free meat	Plant based	Cell based meat	Fungi-based meat	Plant-based seafood	Vegan milk -breast	
Meat analogue	Plant-based	Cellular agriculture	Fungi-based protein	Fake fish	Plant-based dairy	
Vegan meat	Algae protein	Synthetic meat		Fish substitutes	Vegan dairy	
	Algal protein	Artificial meat			Cashew cheese (no "")	
		Clean meat			Dairy alternative	
		Cell-grown meat				

Meat alternative Animal-free Animal substitute	Macroalgae protein Kelp protein Microalgae protein Seaweed protein	Cellular meat Stem cell meat (no “”) Cultivated seafood Cultured seafood Lab-grown seafood Cell-based seafood Lab-grown fish Cell-based fish Cell-cultured fish Cell-cultured seafood Cellular aquaculture Cell-grown seafood Cell-grown fish Cellular seafood	Single cell protein Single-cell protein Microbial protein Fusarium protein Quorn Fusarium venenatum Fungus protein Mycelial protein Mycelium protein Mycelium meat	Lab-grown fish Cell-based fish Plant-based fish Cell-cultured fish Cell-cultured seafood Cellular aquaculture Animal-free seafood Cell-grown seafood Cell-grown fish Cellular seafood		

Annex II – mapping UK sustainable protein companies

This analysis seeks to account and then spatially project the commercial enterprises that comprise the United Kingdom's sustainable protein sector. **We do not believe that the results of this analysis will be fully comprehensive** – it is very likely that we have been unable to identify every company active in the sustainable protein sector. However, we do consider the analysis to provide a sufficient picture to demonstrate the diversity of the industry.

Our primary aim is to map those companies for whom the development and production of plant-based, fermentation and cultivated meat products is the primary focus or a major component of their business model. In this sense, we are trying to identify 'sustainable protein companies (both B2C and B2B). However, we have also included an auxiliary actor category (see below) to demonstrate that there are a range of enterprises in the wider supply chain whose focus is much broader than sustainable proteins, but will nevertheless play a critical role in scaling up the sector.

To conduct our analysis, we first extrapolated a list of UK-based companies from the following databases:

- GFI's company database – maintained collaboratively by the sustainable protein community and with support from GFI
- GFI's co-manufacturing database
- Capacitor
- Protein Directory
- Gateway to Research (UKRI)

The data drawn from these databases were sense-checked for relevance and supplemented with desk research to create a list of UK companies. The businesses compiled in this list were then grouped into three categories: core companies, specialised enablers and auxiliary actors.

Category	Description	Examples
Core companies	Firms who are developing/producing end-consumer products.	• Plant-based meat and dairy brands • Fermentation and cultivated meat companies developing end products (full stack companies).
Specialised enablers	Highly-specialised firms whose sole or major focus is to enable core sustainable protein	• Contract manufacturers of plant-based meat and dairy products • Developers of enabling technologies and resources

	companies to bring products to market.	specifically for sustainable proteins, like cell lines and cell-culture media specifically for cultivated meat and seafood.
Auxiliary actors[13]	Ingredient/input, equipment and infrastructure providers known to be operating in the wider sustainable protein supply chain, but whose commercial focus is considerably broader than plant-based, fermentation and cultivated.	• Large-scale food ingredient companies • Large-scale manufacturers of food industry equipment • Companies selling pharma-grade cell-culture media for use in cultivated meat and seafood R&D. • Infrastructure providers for piloting fermentation/cultivated meat.

We have only included companies who are currently active in the alternative protein sector, rather than those who *could* become active. For instance, we do not include contract fermentation capacity used for primarily pharmaceuticals production, even if the company could theoretically support fermentation and cultivated meat development/manufacturing.

We also excluded:

- Companies developing or selling insect protein or other alternative animal feeds; pet food; sports nutrition drinks; non-dairy based confectionary (e.g. sweets/candies);
- Established food brands and companies whose main product range is comprised of conventional animal-based foods but offers a plant-based option(s).
- Financial investors in alternative proteins.
- Restaurants that produce plant-based products for sale in-store or online.
- Businesses whose primary function is importing ingredients, inputs or end products produced outside of the UK.

[13] We have chosen to only include ingredient/input, equipment and infrastructure providers in the auxiliary actors category since these represent three of the most crucial components of scaled sustainable protein production. We have *not* included the full range of businesses who core companies and specialised enablers might procure from, such as office suppliers, software, professional services, packing and so on. We have also excluded distributors, retailers, wholesalers, hospitality and food service.

Annex III – Sustainable protein R&D priorities with high suitability for UK scientific strengths

The proposals below represent a subset of high-impact opportunities that have emerged from a GFI analysis of the white spaces and innovation priority areas in the sector. Projects within the portfolio will have synergistic impacts, supporting the whole portfolio will therefore have a greater effect than the sum of each individual project and provide a greater return on investment. **The following priority areas have been identified as particularly well-suited to the UK's scientific and technical strengths:**

Plant-based priority areas

- **Protein sequence, structure, and functionality database**
  There is a need for deeper fundamental research on the relationships between protein sequence, structure, functionality, and ultimately performance in plant-based food products.

- **Plants as a recombinant protein expression platform for functional food ingredients**
  Microorganisms are typically used as recombinant protein hosts but more exploration is needed into the use of plants as expression platforms. This may yield a number of benefits: the use of plants as production hosts may require minimal processing into value-added ingredients, such as baking flour with integrated egg and dairy functional proteins. Plants offer ready scalability with less need for expensive equipment or downstream purification to isolate proteins of interest from inedible or undesirable hosts.

- **Biological processing methods for isolating protein ingredients**
  Processing crops into flours, isolates, and concentrates often relies on chemical and mechanical methods. Biological processing techniques may impart the desired composition and molecular structure for optimal functionality with increased precision, lower cost, and greater suitability for small-scale processing, but this needs further exploration.

- **Animal-free, non-recombinant albumin and transferrin for cultivated meat**
  Identifying and validating native plant sources of proteins with suitable functionality to mimic the roles of serum albumin and transferrin in cell culture would reduce the need for extra research and development in recombinant production and allow for greater scalability via direct extraction from crops.

Fermentation priority areas:

The UK has consistently strong microbial science and synthetic biology research capabilities across the country, particularly in leading institutes such as Nottingham, Oxford, Cambridge, Imperial College and Edinburgh. This means the UK would be exceptionally well-placed to make meaningful progress in the following areas:

- **Suppressing hyper-branching of filamentous fungi**
  Prolonging continuous cultivation of filamentous fungi by suppressing hyper-branching could improve texture and boost production efficiency.

- **Comprehensive microbial screening to identify new protein production candidate strains**
  A systematic, open-access, comprehensive analysis of novel microbial strains could drastically expand the available strains that can compete on flavour, efficiency, cost, and nutrition.

- **Microbial strain-development contract research organisations for fermentation applications**
  It may be more efficacious for startups to optimise strain productivity by engaging contract research organisations with both deep microbial strain development expertise and also intimate familiarity with the unique considerations of the fermentation sector.

- **Biosynthetic pathway discovery for fermentation-produced molecules**
  Microbial biosynthetic pathways have not yet systematically been mined computationally to identify candidate pathways for manufacturing high-value ingredients via fermentation.

- **Expanding options for food-safe genetic selection markers**
  The sustainable protein field would benefit greatly from an analysis of which food-safe selection markers exist and can be used orthogonally, as well as efforts to develop new selection markers.

- **Producing animal-like fats through microbial fermentation**
  Microbial fermentation may be able to help us produce lipids that are identical or similar to animal fats—especially saturated fats, which are exceedingly rare in the plant kingdom.

- **Fat production & encapsulation within oleaginous yeast**
  Oleaginous yeast with durable cell walls may be able to serve as natural methods of fat encapsulation to protect fats through manufacturing, storage, and preparation.

- **Novel methods for long-chain omega-3 fatty acid production**
  As the plant-based and cultivated seafood industries scale up, a low-cost and abundant source of long-chain omega-3 polyunsaturated fatty acids will become necessary. Additional innovation is needed to build a robust and scalable supply chain, particularly around precision fermentation and cell-free systems.

Cultivated priority areas

WHITE SPACES OF PARTICULAR RELEVANCE TO ANIMAL SCIENCE, STEM CELL & CELL BIOLOGY RESEARCH:

- **Establishment of cell line repositories and standardised isolation protocols**
  Development of humanely-sourced and thoroughly documented and characterised cell lines from a variety of common food species—together with a mechanism for licensing and distributing these lines to researchers and companies—will remove a key barrier to entry into the field of cultivated meat. In addition, development of open-access, standardised protocols for performing cell isolation from a variety of source tissues and establishing robust cell lines will streamline the processes for those who do end up needing to perform their own isolation and cell line establishment.

- **Species-specific genomic studies enabling assay development for regulatory standards and cell line optimisation**
  A suite of assays and genomic knowledge exists for humans and commonly used laboratory species such as mice or fruit flies. However, the same species-specific infrastructure does not exist equally across the species used in cultivated meat, with an especially large gap in seafood species. Commercialised, standardised assays for species identification such as Short Tandem Repeat (STR) or Cytochrome C Oxidase I (COI) assays are needed. Additionally, richer genetic datasets, including thorough genome annotations that facilitate

- **Understand animal and cellular efficiency, yield, and input**
  Because cultivated meat replicates the fundamental biology of the source animal, animal-level data may be informative for predicting cellular behaviour in culture.

- **Metabolic modelling for cultivated meat**
  Academic researchers or consortia consisting of several cultivated meat companies should undertake research aimed at understanding metabolic pathways and fluxes within cultivated meat-relevant cell types. The outputs of this research could be used to improve the efficiency of media optimisation efforts and to enhance the organoleptic and nutritional properties of cultivated meat products.

- **Mapping the secretome of animal myoblasts, adipocytes, and other cells used in cultivated meat**
  Stem cells secrete a variety of signalling factors that can influence the behaviour of surrounding cells, known as paracrine signals. In high-density bioprocesses, these secreted factors can accumulate to concentrations that can dramatically influence productivity and behaviour of neighbouring cells. By mapping the secretome of animal myoblasts, adipocytes, and other stem cells used for cultivated meat, a better understanding of which factors influence proliferation, differentiation, and other cellular traits can be obtained.

identification of safe harbour loci, can broadly accelerate cell line optimisation studies.

- **Developing assays for meat-specific cell traits**
  Research to align on the appropriate assays would introduce standardisation that can accelerate R&D efforts.

- **Guidelines for cultivated meat starter cell selection**
  Improving our understanding of the relative advantages and disadvantages of different cell types for cultivated meat would enable researchers to make these decisions more effectively with less duplicative effort.

- **Systematic investigation of growth factor needs and effects**
  Open-access research into growth factors required for proliferation, maintenance, and differentiation of cell types relevant to cultivated meat will support both academic and industry research efforts. This research could include screening of species-specific growth factors under a variety of conditions and in a variety of cell types to characterise cross-species compatibility. Research should also seek to define optimal concentrations of individual growth factors and cocktails for achieving various cell states or behaviours, as well as understanding interactions between growth factors.

- **Growth factors from conditioned cell culture media**
  Rather than relying on recombinant growth factors, cultivated meat companies could use conditioned media from animal cells producing high levels of these molecules. Mapping efforts will inform how to best leverage this knowledge to improve cultivated meat production.

- **Open-access formulations & optimisation methods for cell culture media and growth factor cocktails**
  The availability of more open-access formulations will provide a foundation to enable both academic researchers and startup companies to develop their own customised formulations with far less effort and cost.

- **Fat uptake & biosynthesis in cultivated meat cells**
  Determining which lipids muscle and fat cells are capable of producing and absorbing directly from cell culture media.

- **Incorporating omega-3s into cultivated seafood**
  Cultivated seafood will need to be supplemented with long-chain omega-3 polyunsaturated fatty acids to be nutritionally equivalent or superior to conventional seafood. However, how these compounds can best be incorporated has not been determined, and there are several potentially-viable strategies. Further research is needed to determine which strategies are most cost-effective and scalable and whether there are appreciable differences between methods in the quality of the final product.

- **Understanding uptake and interconversion of omega-3 fatty acids by cultivated fish cells**
  Although fish are among the best dietary sources of long-chain omega-3 fatty acids (FAs), these compounds are mostly

- **Species-specific research toolkits for cultivated meat-relevant species**
  Coordinated efforts to develop standardised, comprehensive research toolkits of meat-relevant species would exponentially accelerate cultivated meat research.

- **Plant-based scaffolds to improve cultivated meat nutrition**
  Scaffolds provide the necessary structure to create 3D designs, enabling variety in the shape of cultivated meat products. Current scaffolds are limited by expensive, sometimes inedible materials, which would require additional processing prior to consumption. Additional investigation is required to assess edible scaffolds' nutritional value and to test the food safety of processes such as plant decellularization.

bioaccumulated from a fish's diet rather than synthesised de novo. Consistent with this, studies have found evidence of reduced omega-3 content in fish as a result of replacing fish-based feed with plant-based feed. Therefore, for cultivated fish to compete with conventionally-produced products, it will be necessary to identify cost-effective strategies for increasing the content of nutritionally-important omega-3 FAs in cultivated fish.

- **Incorporating growth factors into scaffolds to reduce costs and introduce spatial heterogeneity**
  Growth factors (GFs) can be incorporated into scaffolds as a strategy for both reducing costs and improving product quality of cultivated meat. Open-access research is needed to test the feasibility of this strategy and determine the most appropriate methods.

WHITE SPACES OF PARTICULAR RELEVANCE TO TISSUE ENGINEERING AND REGENERATIVE MEDICINE:

- **Computational models of perfusion flow through scaffolds**
  For tissue-structured cultivated meat production, the transition from the proliferation phase to differentiation phase may involve seeding cells onto a prefabricated scaffold within a perfusion bioreactor. Medium is then perfused through the cell-laden scaffold, providing nutrients and oxygen as cells differentiate and mature. Computational models are needed to describe fluid flow through scaffolds to better understand mass transfer and shear forces. These models will inform

- **Scaffolding development for culinary and biomechanical requirements of cultivated seafood**
  A number of published studies have focused on scaffolds for cultivated meat (see Related Efforts) yet, to our knowledge, no studies have specifically attempted to formulate scaffolds for fish or tested growth of fish cells on scaffolds developed for terrestrial meat. Because fish uniquely differ from terrestrial meat in structure, research aimed specifically at developing and testing scaffolds for fish products would advance the

considerations for scaffold materials, geometries, dimensions, fabrication methods, and bioprocess design as well as considerations for the composition and viscosity of the medium.

- **Improving affordability, nutrition, and organoleptic properties of cultivated meat through co-cultures with support cells**
  Cultivated meat research focuses primarily on muscle fibres and fat cells. However, the other cell types in muscle serve important functions that are potentially underappreciated in their relevance to cultivated meat. In the context of a whole animal, muscle tissue does not exist in isolation. Research into co-culture methods with various support cells could solve a variety of challenges on the road to developing affordable, high-quality cultivated meat.

- **Biomaterials for scaffolding**
  A handful of companies and researchers are developing scaffold materials for use in various steps of the cultivated meat production process, but to date, the topic of scaffolding has been largely overshadowed by the challenge of producing cell mass at scale. This topic needs much more R&D as the industry matures in order to enable the development of products that have meat-like structure and texture, which will be more appealing to consumers than unstructured meat products.

- **Promoting stemness and proliferation in fish cell cultures**
  industry. Both scaffolding materials and methods for achieving the correct three-dimensional structure should be investigated.

- **Semi-continuous bioprocess for whole-cut cultivated meat using simultaneous perfusion and stretch**
  Stretching of engineered muscle constructs has been previously demonstrated to induce alignment and maturation of muscle fibres, which is desirable for whole-cut cultivated meat. Stretch stimuli could also be incorporated into a semi-continuous bioprocess in which a piece of tissue is expanded over time and portions of the tissue periodically harvested. The large amount of meat produced could offset the high initial cost of fabricating a construct capable of continuous growth.

- **3D microenvironments for cell expansion**
  Proliferation and high-density cell growth are fundamentally important to scaling cultivated meat production. Recent demonstrations of stem cell expansion in 3D microenvironments such as encapsulated spheres or tubules can generate cell densities far higher than industry-leading stirred tank bioreactors with minimal loss of cell viability or stemness. As a scalable platform, the use of 3D microenvironments for stem cell expansion and differentiation – particularly with the relevant cell types used in cultivated meat – warrants further investigation.

- **Improving efficiency and assessment of adaptation to suspension growth**

Efficient and cost-effective cultivated fish production will require precise optimisation to encourage fast proliferation and highly efficient use of inputs while preventing premature differentiation. Strategies include optimising the starting cell line, improving the composition of the proliferation medium, and exploring the possibility of transdifferentiating easy-to-grow cell lines like fibroblasts into myogenic and adipogenic lineages.

Improving methods for adapting cells to suspension culture can facilitate cell line development and bioprocess design for cultivated meat.

Plant-based, fermentation and cultivated production processing priority areas

- **Production process innovations for fibre formation and improved plant protein texturisation**
  High moisture extrusion is currently the most widely used technique for plant-based protein texturisation, but innovative alternatives to extrusion are desperately needed. Fibres from techniques like electrospinning, jet spinning, or blow spinning may be able to impart texture throughout a product even if they do not comprise the bulk of the end product, which may render these approaches economically viable for enhancing texture within a bulk product even at a relatively small scale.

- **Preventing oxidation of omega-3 fatty acids before and after addition to plant-based and cultivated seafood products**
  Deeper fundamental knowledge of the causes and prevention of oxidation of omega-3 fatty acids before, during, and after addition to plant-based and cultivated seafood products is needed to improve their nutritional and organoleptic

- **Plant-based ingredient analytical and characterisation service**
  Plant-based food manufacturers often struggle with batch-to-batch ingredient inconsistency and variability between suppliers. Better analytical tools for predicting plant-based ingredient performance could improve manufacturing efficiency and create more transparent ingredient markets.

- **Fat and moisture encapsulation techniques for sustainable protein applications**
  Plant-based, fermentation-made and cultivated products will all require solutions for encapsulating fat and moisture to ensure that these components are protected from damage or loss throughout manufacturing, storage, and preparation.

properties. There is a need for antioxidation methods to be tailored to the formulations and processing of plant-based and cultivated seafood products, or perhaps new methods must be developed altogether.

- **Hybrid products to optimise nutrition, taste, cost, and sustainability**
  Hybrid products are a promising means to improve the cost and sustainability of animal-derived meat while improving the taste of plant proteins. Promoting the health benefits of hybrids may facilitate consumer acceptance, but more research is needed to identify the optimal blend ratios to increase nutrition without compromising flavour.

- **Scaffolds and structural approaches to optimise fat distribution and content in cultivated meat**
  The inclusion of fat and marbling in cultivated meat is likely to increase its flavour, texture, and consumer appeal. Structural approaches using edible microcarriers, hydrogels, and 3D bioprinting present promising options to support fat cell growth and reduce buoyancy in culture for integrating fat into cuts of meat.

- **Expanded product development in plant-based meat snacks**
  Plant-based meat snacks could tap into underlying trends in snacks replacing meals and increased consumer interest in high-protein, low-sugar foods. Product innovation is needed to match the taste, price, and availability of animal options.

About the Good Food Institute Europe

The Good Food Institute Europe is an international NGO helping to build a more sustainable, secure and just food system by transforming meat production.

We work with scientists, businesses and policymakers to advance plant-based and cultivated meat – making them delicious, affordable and accessible across Europe.

By making meat from plants and cultivating it from cells, we can reduce the environmental impact of our food system and feed more people with fewer resources. GFI Europe is powered by philanthropy.

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