Our food system has been experiencing recent shocks that are affecting both the availability and cost of many staple food products. The need to increase agricultural productivity to meet the requirements of a global population, predicted to reach c.10 billion by 2050, is well documented. Recent stresses, including Brexit, the COVID-19 pandemic and conflict in Europe, also highlight both the need and opportunity to increase domestic food production to mitigate against future supply chain challenges.

Within this context there is a growing demand for protein sources for both human and animal consumption. Consumers are also increasingly looking for alternatives to traditional meat and dairy products for a variety of lifestyle choices, driving significant global market opportunities in this space. As a result, the alternative protein sector is predicted to reach $27 billion by 2027, and the UK is well placed to access this global market through our world-leading science-base and industry capability across the agri-food supply chain. Opportunities also exist to develop new domestic protein sources to displace reliance on global commodities like soya- and fishmeal in the animal feed and aquaculture sectors, which also have the benefit of helping to reduce the environmental impact of food production.

The publication of the National Food Strategy highlighted the potential in the alternative protein industry, with recommendations describing actions to support the creation of a competitive domestic marketplace. To better understand our current position and capability within this exciting new space, a cross-sector workshop was held in February to identify opportunities and challenges to establishing a competitive UK industry over the short, medium and long term. The workshop was taken forward by UKRI’s Transforming Food Production (TFP) programme and the Growing Kent & Medway Strength in Places Strategic Priorities Fund.

A series of roadmaps have been developed as an output from the workshop which identify key priorities for the sector towards 2030. The TFP programme is already supporting a number of projects developing novel technologies and innovations to establish new industries across this sector, from insect and algal proteins, to advanced fermentations for single-cell proteins, and lab-cultured meat. This report provides an initial blueprint for how the sector can come together and work collaboratively for mutual benefit, helping to unlock the global market opportunities that are emerging across the alternative protein sector.

Tom Jenkins
Deputy challenge director – Transforming Food Production
Innovate UK
The UKRI Transforming Food Production (TFP) team and Growing Kent & Medway both recognise the emerging opportunity in the alternative protein sector, and have come together to explore the UK priorities for industry, academia, regulatory bodies and funders. This was achieved through the development of a focussed workshop to provide a series of roadmaps for key categories of alternative proteins. The workshop brought together relevant stakeholder experts to determine the UK capabilities and capacity in the alternative protein sector, and where future investments can be targeted to maximise impact.

The workshop objectives were to:

- Provide a catalyst to build effective consortia
- Identify project concepts for forthcoming competitions
- Provide a consolidated view of opportunities and barriers in the sector
- Prioritise Technological, Commercial, Regulatory and Consumer actions required across short- (1-2 yrs.), medium- (2-5 yrs.), long- (5-10 yrs.) and very long- (10 yrs.+ ) term timescales to realise a competitive UK alternative protein sector.

This activity builds upon a previous ‘Alternative Proteins Roadmapping Workshop’ held on 23rd March 2021, the aim of which was to develop a conversation between the TFP programme, participating funded companies and a selection of stakeholders to create a shared vision and preliminary roadmap for the UK alternative protein sector. A link to the report and roadmap can be found here: [https://www.ukri.org/wp-content/uploads/2021/08/UKRI-060821-AlternativeProteinsRoadmapSummaryReport.pdf](https://www.ukri.org/wp-content/uploads/2021/08/UKRI-060821-AlternativeProteinsRoadmapSummaryReport.pdf).

This latest online workshop, held on 22nd February 2022, brought together 30 attendees, all experts from this specialised sector – including senior managers and technical professionals from both UK SMEs, and large businesses in each of the priority sectors listed below. In addition, leading researchers from Higher Education Institutions (HEIs) and representatives from UKRI, Defra, industry bodies, regulators and policy makers associated with alternative protein food products were invited.

The priority sectors for workshop participants were:

- **Plant proteins** – pulses, extracts from other plants, agri-food side streams etc
- **Fermentation** – proteins from fermentation-based systems (based on algae, bacteria, fungi or gas-/energy-based systems), and cell culture technologies that are primarily developing lab meat products
- **Novel systems** – new aquaculture, insect proteins

The workshop produced a series of roadmaps, one for each priority sector, with expert insight into the current status of the sector, the size of the opportunity and the barriers, and detailed information on the following aspects: Technical; Commercial; Regulatory; Consumer insight.
The alternative protein sector is evolving rapidly, and this report is a snapshot in time. Some of the key recommendations were shared across the priority sectors, and included:

- Development of an implementation and action plan to coordinate interdisciplinarity, integrating research into the production, novel processing and the potential for onward product development;
- Provide sustainable sources of funding to explore disruptive research and innovation ideas;
- Strengthen capability in the UK to deliver purposeful technology solutions;
- Assessment of the UK landscape to facilitate early engagement and consortia building with suitable industry and academic partners;
- Develop mechanisms to successfully speed up pioneering innovations through the UK market, including access to finance for scale-up;
- Develop a core team for coordinating and building the UK ecosystem, providing a centralised resource accessible to all UK stakeholders; and
- Distribute pump-priming funds for onward discovery science and collaborative R&D.

The Alternative Proteins ‘UK Priorities’ Workshop delivered a deeper and more up to date understanding of the landscape and potential opportunities for the UK in the global alternative protein sector, providing insights and recommendations for maximising impact from future public and private investment.
Introduction

Global food systems currently have a high emissions profile, which is projected to grow as a proportion of total emissions due to other sectors decarbonising, a lack of resilience to weather extremes and elements of resource inefficiency with high externality costs [1]. Shifting to sustainable, alternative proteins can, in part, help with the transformation of our food system to become more climate smart. For the UK and Europe, this means improving protein self-sufficiency, deconstructing unsustainable supply chains, and increasing diversity both in sources of protein and end user products.

The definition considered here for alternative proteins are proteins which are produced from sources that have low environmental impact in order to augment livestock protein sources or offer an alternative to meat and dairy protein sources which directly or indirectly address 13 out of 17 UN Sustainable Development Goals (SDGs), and provide promising innovation opportunities.

In the UK, the land footprint and dietary Green House Gas (GHG) emissions per capita for animal protein production and consumption is approximately twice that of plant protein production and consumption [2][3]. The independent UK Committee on Climate Change reported the requirement of 20% reduction in the consumption of meat (particularly red and processed) and dairy products to achieve net-zero carbon emissions by 2050 [4], and to contribute to food security, healthy diet, biodiversity, and resilience.

Here lies an opportunity for UK-led disruptive innovation. One of the UK’s ambitions should be to foster connections within the UK research community in the alternative protein-based food area, and work in tandem with domestic and international industry partners to deliver global innovation impact.
Nutritious protein sources from plants, seaweeds, or via non-animal cell culture/fermentation (e.g. fungi and microalgae) or cultured meat, can provide an alternative to more traditional protein sources.

Alternative protein-based foods in Europe and UK are projected to grow to £6.8 billion by 2025 [5]. For the EU and UK, the current meat alternatives (£1.3 billion) and dairy alternatives (£2.7 billion) represent only 0.7% and 3% of total meat and dairy market share respectively [5], which indicates a huge opportunity for further market growth. Investment will be required at the production, processing and product level for the UK to capitalise on the cutting-edge research and innovation potential across the alternative protein sector.

Growing Kent & Medway

Developed through the UKRI Strength in Places Fund, Growing Kent & Medway is a world-class research, innovation and enterprise cluster supporting growth in technology-driven horticulture, fresh produce packaging, food and drink processing and its supply chains. Growing Kent & Medway is a diverse and dynamic collaboration that brings together innovative growers and processors, scientists, technologists, and entrepreneurs to deliver a shared goal of improving productivity and sustainability in the sector.

We are building on Kent and Medway’s established reputation and industry base to make this region one of the most dynamic, competitive and successful horticultural and agri-tech locations in the world. Our unique geography means we are home to most of the UK’s high-value horticultural production, packaging and processing, and a major gateway to global markets.

Growing Kent & Medway has created a Special Focus Group to support the opportunity for UK-led, disruptive innovation in alternative protein-based products. Plant-based food is the fastest growing trend in the UK food sector. According to Nielsen MarketTrack report the sales value in the UK grew by 73% during 2018-2020, with plant-based milk and cheese showing triple digit sales growth over this period. In the UK, sales are predicted to be £1.1 billion for meat alternatives in 2024 and £565 million for dairy alternatives in 2025.

Building on the expertise, research capabilities and resources across its research organisations (see annex 3), Growing Kent & Medway is coordinating an interdisciplinary approach; one that will develop and support a new innovation-led, alternative protein ecosystem for the UK.
Roadmaps

An online workshop was attended by 30 delegates (see annex 1) in February 2022 to identify the key challenges and opportunities facing the UK alternative protein sector.

Participants were invited to register for the workshop through Growing Kent & Medway. The attendees were then selected to ensure there was a broad range of expertise in plant-based, fermentation (lab-cultured meat and mycoprotein) and novel (new aquaculture or insect) proteins. There were representatives from UK-based academia, industry and policy makers.

The discussion groups considered the challenges and opportunities around the technical, commercial, regulatory and consumer factors impacting the alternative proteins sub-sectors.

In advance of the workshop, 26 respondents completed a questionnaire to identify the highest priority challenges and opportunities facing their sub-sector, and indicated the likely timeframes to realise or overcome those barriers. The survey responses guided the workshop discussion (see annex 2).

The knowledge and information collected from both the workshop and questionnaire have informed the following roadmaps by sub-sector.
Plant-based

OBJECTIVE
Understanding drivers and barriers to develop globally competitive plant and algal protein sector in the UK to help deliver the sustainable protein-based diet shift.

Current Status

Technical
The plant-based protein sector is dominated by imported materials, largely soya. New processing facilities are upcoming in the UK for plant-based food, including:

- A new facility in Lincolnshire by Naylor Farms for plant protein extraction
- Europe’s largest plant-based factory (Plant & Bean by Griffith Foods and Gushen) at Boston, Lincolnshire
- A £6 million UK potato protein extraction facility at the Branston site
- Substantial improvement in taste and texture of plant protein-based products

Commercial
There is an estimated £1 billion market for plant-based alternatives in the UK, with a huge potential to grow; predicted market growth (year-to-year growth in %) for meat alternatives (30%), dairy free milk (48%) and cheese alternative (38%). This will be mainly driven through the expansion of start-ups.

Regulatory
Workshop discussion centred around how to use post-Brexit UK regulation to drive innovation and further accelerate market. There is great potential to leverage algae harvest in the UK by exploiting the coastline.

Consumer
Plant-based food is the fastest growing consumer trend.
Size of opportunity

Technical
The technical opportunities discussed included:

- Develop improved varieties and introduce new crops as protein sources
- Impart circularity within the plant protein value chain (e.g. upcycled proteins)
- Eco-innovative technology for plant protein extraction and scale up
- Develop sustainable process – shift to bio-processing
- Deliver better taste and texture for plant-based products

Commercial
In order to realise these opportunities, there is a need for the sector to adapt to growing consumer demand. Commercial opportunities include co-product market development to impart circularity at reduced cost and nutritional labelling.

Regulatory
There is a Post-Brexit opportunity to utilise novel technology like gene editing. Discussion also focussed on addressing agronomy at the primary production stage by identifying new crop protection approaches.

Consumer
There is a growing demand for novel protein products as the consumer is aware of the climate benefit of this form of protein over animal-based alternatives.
Barriers and/or trade offs

Technical
Numerous challenges were identified at a technical level which need to be addressed to realise a competitive UK plant-based alternative protein sector, including:

- Lack of diverse protein sources to develop innovative ingredients
- Lack of tools (varieties, crop protection, agronomy) to maximise sustainable domestic production
- Need for technology to make plant protein extraction more sustainable and efficient
- How to impart circularity within the plant protein value chain (e.g. minimising waste from upstream protein production)
- How to improve and adapt the functionality (emulsification, taste and texture) of plant-based products
- Lack of understanding for bioavailability of macro and micronutrients from alternative plant protein sources

Commercial
Commercial barriers which need to be overcome include the need to reduce the cost of the raw materials and products, scaling up processing facilities and investment in infrastructure.

Regulatory
Regulatory barriers that need to be addressed include the regulation around novel crop production, lack of robustness of product claims within the plant-based food sector, impact of novel food legislation (resulting in longer time to market) and high salt, sugar and chemically modified starch in meat and dairy alternatives.

Consumer
From a consumer perspective of plant-based alternative proteins there is a lower acceptance in terms of naturalness and clean label compared to traditional products. There is a negative connotation with ‘ultra-processing’ which needs to be addressed through educating the consumer and transparency. Another consumer barrier is the willingness to try new products. For repeat purchase affordability of alternative protein sources versus animal-based alternatives is also key.
# Challenges: Technical

<table>
<thead>
<tr>
<th></th>
<th>Short term (1-2 years)</th>
<th>Medium term (2-5 years)</th>
<th>Longer term (5-10 years)</th>
<th>Very long term (10 years +)</th>
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<tbody>
<tr>
<td><strong>Functionality</strong></td>
<td>- mimic animal derived proteins</td>
<td>- improve and adapt</td>
<td></td>
<td>- nutritional comparison to animal-based equivalence</td>
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<tr>
<td><strong>Diet</strong></td>
<td></td>
<td></td>
<td></td>
<td>- small pilot scale research facilities</td>
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<td>- scalability of novel/sustainable technologies</td>
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<tr>
<td><strong>Extraction</strong></td>
<td></td>
<td>- small pilot scale research facilities</td>
<td>- scalability of novel/sustainable technologies</td>
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<tr>
<td><strong>Flavour</strong></td>
<td>- mimic animal derived products/ remove flavour taints</td>
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<tr>
<td><strong>Genetics and Breeding</strong></td>
<td>- lack of transformation technologies</td>
<td></td>
<td></td>
<td>- lack of suitable varieties</td>
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<tr>
<td><strong>Processing</strong></td>
<td>- scalable facilities</td>
<td></td>
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<tr>
<td><strong>Production</strong></td>
<td>- establish “new” crops in rotations</td>
<td>- grower investment</td>
<td>- yield stability</td>
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<tr>
<td><strong>Supply Chains</strong></td>
<td>- resilience</td>
<td>- import/export</td>
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<tr>
<td>Functionality</td>
<td>Within the medium term the taste and functionality of plant-based protein products will increasingly mimic the animal derived proteins, although some believe that benchmarking against animal derived products may not be useful. In order to improve and adapt the functionality of the plant-based products there is a need for better and more diverse raw materials to develop innovative ingredients for the food industry.</td>
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<tr>
<td>Diet</td>
<td>There is a focus on crude protein content in the alternative protein market but the animal-based offer is providing more than just protein (e.g. micro- and macronutrients) and these additional nutrients are bioavailable and well studied. There is a need for more research to identify the nutritional equivalence of alternative protein sources vs. the animal derived proteins. Are the comparisons correct? i.e. 1KG of meat vs. 1KG of plant-based – need to look beyond protein alone.</td>
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<tr>
<td>Extraction</td>
<td>In the longer term there is a need for technology development to make protein extraction processes more sustainable, more efficient and less costly. The cost of protein raw material production is still high and there is a lack of efficient scaling – for example there is no pilot scale extraction facility in the UK for fava bean. Moreover, there is a sustainability challenge to address the waste/side-streams generated following the protein extraction process. This presents a co-product development opportunity which will lead to an increase in the sustainability of products via valorisation of the waste streams (see opportunities section). To address the sustainability challenge there is also an opportunity to integrate energy, water and waste utilisation into these manufacturing processes.</td>
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<tr>
<td>Flavour</td>
<td>In the short to medium term there is the challenge to improve the flavour quality of plant-based protein ingredients and products through the masking/elimination of off-flavours (e.g. beany and earthy flavours of certain crops like legumes) and to mimic animal derived products (for example fat profiles often overlooked but it is the fat profile of meat, cream and butter etc which is perceived by many to taste good).</td>
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<tr>
<td>Genetics and Breeding</td>
<td>There is a lack of diversity of species and varieties of legumes suited to the UK climate. Over the medium term there is a challenge to develop and deploy transformation technologies to improve variety availability. In the very long term the challenge will be to breed varieties suitable for UK conditions – currently most breeders are based overseas and not actively breeding in the UK/for the UK. There are no commercial UK plant breeders focussing on these crops.</td>
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<tr>
<td>Processing</td>
<td>There is currently little investment in processing facilities in the UK beyond extrusion. In the short to medium term this challenge needs to be addressed by scaling facilities and adding diversity in the processing capabilities (e.g. 3D printing, shear cell, electrospinning). There is a lack of funding to de-risk scale up of processing. There is a need for efficient processing to minimise side-streams/ loss in order to become more sustainable.</td>
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<tr>
<td>Production</td>
<td>There is a need to improve production for these “new” crops. In the medium term we need to develop more technical knowledge and agronomy about where and how to grow the crops in the UK climate with good rotations giving the potential to support pulse cropped area 4-5 times larger than present. Also in the medium-term the lack of available crop protection chemistry needs to be addressed for these relatively minor crops. Currently the ROI for beans is low to none most years but if yield stability can be improved they can give high returns – “beans are a wish crop meaning growers wish they put more in the ground on a good year and less in the ground in a bad year”. There is a need to improve yield stability in the long term in order to ensure grower investment to grow these crops. Large investment is required to diversify a farms crop portfolio (i.e. crop specific machinery and developing the knowledge base within a farmers business).</td>
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<tr>
<td>Supply Chains</td>
<td>There is a medium term challenge to ensure that the domestic plant-based protein sources (= lower food miles) achieve climate resilience, dietary diversity and agri/biodiversity. Supply closer to point of manufacture is ideal however local is not always possible (as it can sometimes be less efficient both in cost and environmentally). Multiple sourcing options across a wider range of locations (including local) would increase supply chain resilience. Currently most raw ingredients are coming from North and South America with limited availability from Europe – this situation is unlikely to change as the demand increases unless there is a marked increase in the production capacity within Europe.</td>
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### Challenges: Commercial

**Investment**
- **Sustainable supply chain**
  - Economically viable supply chain

**Flavour taints**
- Economically viable supply chain

**Clean label**
- Economically viable supply chain

**Business sector structure**
- Economically viable supply chain

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Short term (1-2 years)</th>
<th>Medium term (2-5 years)</th>
<th>Longer term (5-10 years)</th>
<th>Very long term (10 years +)</th>
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</thead>
<tbody>
<tr>
<td>Economically viable supply chain</td>
<td></td>
<td></td>
<td>• high cost of raw materials</td>
<td></td>
</tr>
<tr>
<td>Investment</td>
<td></td>
<td>• infrastructure investments – farmer</td>
<td>• ROI to Farmer</td>
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<tr>
<td></td>
<td></td>
<td>• infrastructure investments – processor</td>
<td>• R&amp;D</td>
<td></td>
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<tr>
<td>Flavour taints</td>
<td></td>
<td>• high costs of masking flavours</td>
<td>• reduce and/or eliminate beany/earthy flavours</td>
<td></td>
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<tr>
<td>Clean label</td>
<td></td>
<td></td>
<td>• products with added ingredients</td>
<td></td>
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<tr>
<td>Sustainable supply chain</td>
<td></td>
<td></td>
<td>• access to UK sustainable protein sources</td>
<td></td>
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<tr>
<td>Business sector structure</td>
<td></td>
<td></td>
<td>• fragmented – lots of SMEs</td>
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<tr>
<td><strong>Economically viable supply chain</strong></td>
<td>A key supply chain challenge to address in the longer term is the cost of raw material (per unit protein). For animal feed the challenge is finding an economically viable alternative to replace soymeal. If soya is to be replaced by domestic sources there is a need to address the capacity and locality of mills in relation to the point of consumption. For food as opposed to feed, the cost of raw material can be a significant barrier as manufacturers are reluctant to pass this on to consumer. The lack of futures trading, like for other major crops, means processors cannot hedge against future purchases. Certain sources of plant-based protein are prohibitively expensive e.g. hemp is 3-4x the cost of soya/pea. If compared to animal derived protein plant-based raw materials can be inline or cheaper.</td>
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<tr>
<td><strong>Investment</strong></td>
<td>The sector is currently experiencing market failure due to the volume driven supply chain which is a typical characteristic of our commodity market; growers won’t commit until market guaranteed; breeders won’t invest until grower demand exists. In the short/medium term there is a need to invest in infrastructure at the primary producer and processor level. Primary producer investment is needed to start to grow novel crops (i.e. crop specific machinery) and this requires a critical mass in order for processors to invest in processing capabilities. Processor investment could start with a pilot production plant in UK for pea or faba. Volume is an issue for processors – e.g. Lupins for feed – need a critical mass grown locally to warrant the millers investing and/or adapting their equipment for diversifying their product range. R&amp;D investment in bigger research programmes to develop long term alliances through out the supply chain from breeder to processor is required to address the challenges leading to market failure. In the longer term this will help deliver an ROI to the farmer ensuring a UK supply within the global supply mix.</td>
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<tr>
<td><strong>Flavour taints</strong></td>
<td>Not a priority for animal feed (where cost point and nutrition are more of a priority). In specific food products, optimal flavour profile remains an issue but is a competitive area of active inhouse R&amp;D. Currently off-flavour (of plant protein like legumes) are masked by masking agent (supplied by flavour companies) but these can add to costs and contribute to complex labelling and go against the consumer perception of naturalness. In the longer term the market perhaps needs time to evolve “a consumer journey” e.g. we keep masking flavours but the consumer should be given the chance to adapt to the actual flavour (of ingredients).</td>
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<tr>
<td><strong>Clean label</strong></td>
<td>The clean label challenge is a priority which will be addressed in the medium term.</td>
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<tr>
<td><strong>Sustainable supply chain</strong></td>
<td>There is a medium term challenge to address the sustainability of the sources of raw ingredients and a risk that we will move from an unfair/unsustainable animal-based diet to an unfair/unsustainable plant-based one. There is a need to grow more from less in both the UK and globally to ensure sustainable supply chains beyond the medium term.</td>
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<tr>
<td><strong>Business sector structure</strong></td>
<td>The plant-based alternative protein sector was described as an unusual business sector which was very fragmented with lots of SMEs – this also creates an opportunity as the sector matures.</td>
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</table>
Challenges: **Regulatory**

**Novel food legislation**
- Negative impacts on health
- Genetics and breeding
- Protein digestibility

- Hemp
- Agrochemicals
- Trade
- GM
- Allergenicity
- Uncertainty

**Opportunities**
- Innovation
- Market expansion
- Sustainability
Although novel food legislation is perceived to be less of a problem for plant-based alternative protein compared to other alternative protein sectors it is still a challenge in the medium term as emerging plant proteins and different fractionated derivatives from established and novel crops could trigger novel food status (and also raise standards of identity issues). Beyond the medium term there is confidence that the legislation around novel foods will catch up on granting food safety etc and that regulators will soon have more efficient processes in place to deal with crops which haven't had the long history of consumption which other staples have. If introducing novel ingredients be aware these might become allergens of the future.

Standards of Identity (SOI) is not a high priority issue for the plant-based alternative protein companies represented at the workshop as they can deal with this challenge through marketing. The challenge of SOI is that it is confusing the consumer – to address this in the medium term there just needs to be transparency in how the product is described to the consumer.

There is a need for the labelling of the products to be consumer driven (consumer relevance and interpretation). The product has to be adequately described so that labelling can help the consumer understand unfamiliar sources of raw ingredients and ensure the robustness of product claims. In the longer term, labelling could be used to report on sustainability metrics and to make nutritional claims more robust.

Regulatory barriers are preventing a tool kit for novel crop production in the UK to be developed and utilised to its full effect (e.g. use of breeding techniques, variety diversification, crop protection options, Integrated Pest Management (IPM) optimisation in the field). In the short term, as its own regulator for crop protection and IPM regulation, UK government and devolved administrations can support the sector by facilitating regulation for minor crops (e.g. research to develop agronomic solutions and crop protection product approval (e.g. through EAMUs – Extensions of Authorisation for Minor Uses)). In the longer term, breeding novel crops will help support the sector, however there are challenges which need addressing including the prohibitively large regulatory burden of getting new/minor crops registered particularly for smaller companies (see Defra under utilised crop review). Plant breeders therefore need significant seed sales guaranteed to justify investment in breeding programmes for these crops. There is a need to reduce cost of market entry for breeders in order to address this challenge. Promising changes in gene editing regulation may help address the availability of new varieties and crops better adapted to the UK climate in the medium term.
Challenges: Consumer

<table>
<thead>
<tr>
<th>Perceived as ultra-processed</th>
<th>Short term (1-2 years)</th>
<th>Medium term (2-5 years)</th>
<th>Longer term (5-10 years)</th>
<th>Very long term (10 years +)</th>
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<tr>
<td></td>
<td>• misinformation</td>
<td></td>
<td>• change consumer mindset</td>
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<tr>
<td>Consumer acceptance</td>
<td>• willingness of consumers to try new products</td>
<td>• ROI to Farmer • R&amp;D</td>
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<tr>
<td>Consumer behaviour</td>
<td>• improving engagement and education • drive demand for healthier and sustainable option</td>
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<tr>
<td>Sensory acceptability</td>
<td></td>
<td></td>
<td>• simulate organoleptic properties</td>
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<tr>
<td>Affordability and availability</td>
<td>• sourcing/supply chains • price of final product</td>
<td>• mismatch between sustainability and affordability</td>
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<tr>
<td>Perceived as ultra-processed</td>
<td>There is a perception that ultra-processed food is always unhealthy. “Sympathetic processing” is the processing of foods which can promote the release of more nutrients. There is a need in the medium term to bring narrative back to the evidence base and open the dialogue across the stakeholders (industry, farmers, government, knowledge partners (scientists and engineers) and consumers) to achieve this. Once the misinformation is neutralised by evidence, in the longer term there is a need to change the consumer mindset about the need of processing. After all, most processing is good – it helps to extend the shelf life of products so they can be mass marketed, safe, convenient and affordable. Many crops can’t be eaten in their raw form or are not palatable. New processes are being used for 1) protein production (using solvents, water and energy), 2) processing steps of modifying raw protein for better function such as extrusion and 3) formulating new products (NPDs) which need to be defined and communicated transparently to the consumer.</td>
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<tr>
<td>Consumer acceptance</td>
<td>In the medium term there is a need to address the willingness of consumers to try new products through marketing and accessing different segments of the market. The alternative protein product market is exciting where consumers have a lot of choice so once they have tried once they are likely to try more. There is a need to conduct research in to what the consumers see as important sensory attributes for alternative protein products to achieve wider acceptance of plant-based in the longer term. Currently, sensory research is benchmarked against animal protein sources – this may change as current diet habits shift and sensory perception evolves in consumers. In the longer term there is a need to provide awareness of deficiencies e.g. calcium and iron as diet habits shift away from animal-based sources of protein.</td>
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<tr>
<td>Consumer behaviour</td>
<td>In the medium term there is a need to improve engagement and education of the consumer – this could be achieved through story telling e.g. around reducing your carbon footprint and health benefits when compared to certain animal-based alternatives. In turn this will drive demand for a healthier and more sustainable option.</td>
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<tr>
<td>Sensory acceptability</td>
<td>In the longer term there is a need to simulate organoleptic properties (texture, flavour, colour, taste, smell, etc) of animal-based alternatives.</td>
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<tr>
<td>Affordability and availability</td>
<td>Health and climate are important consumer drivers for certain markets but locally produced, sustainable food can come at a higher cost. Affordability is the primary driver for food choice to many households and it is the households with poorer diets that would benefit most from incorporating healthier and more sustainable plant-based proteins into their diets. In the US a survey (conducted by McKinsey) which investigated the drivers for first time purchase of alternative protein products found that sustainability, nutrition and safety were top but repeat purchase was about cost. The mismatch between sustainability and affordability needs to be addressed in the longer term.</td>
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</tbody>
</table>
## Opportunities: Technical

### Genetics and breeding
- Short term (1-2 years)
  - Gene editing
  - Breed varieties with enhanced protein/nutrition
- Medium term (2-5 years)
  - Breed varieties with climate resilience/ adapted to new locations
  - Breed varieties with enhanced health properties
- Longer term (5-10 years)
  - Genome sequencing of crops
- Very long term (10 years+)

### Circular economy
- Short term (1-2 years)
  - Co-product market development
  - Engineering design
- Medium term (2-5 years)
  - Engineering design
  - Utilising waste and underutilised resources
- Longer term (5-10 years)
  - Co-product market development
- Very long term (10 years+)

### Differentiated characteristics
- Short term (1-2 years)
  - Nutrition
  - Functionality
- Medium term (2-5 years)
  - Nutrition
- Longer term (5-10 years)
  - Nutrition
- Very long term (10 years+)

### Diversify protein source
- Short term (1-2 years)
  - Different sources of proteins
- Medium term (2-5 years)
  - Different sources of proteins
- Longer term (5-10 years)
  - Different sources of proteins
- Very long term (10 years+)

### Efficient extraction and processing methods
- Short term (1-2 years)
  - Lower environmental impact
  - Higher extraction yields using sustainable process
- Medium term (2-5 years)
  - Lower environmental impact
  - Higher extraction yields using sustainable process
- Longer term (5-10 years)
  - Lower environmental impact
  - Higher extraction yields using sustainable process

### Agronomy
- Short term (1-2 years)
  - Alternative control
- Medium term (2-5 years)
  - Alternative control
- Longer term (5-10 years)
  - Alternative control
- Very long term (10 years+)

### Labelling
- Short term (1-2 years)
  - Nutrition
- Medium term (2-5 years)
  - Nutrition
- Longer term (5-10 years)
  - Nutrition
- Very long term (10 years+)
| **Genetics and breeding** | There are a number of opportunities to breed varieties with new/enhanced traits including increased protein content/quality, enhanced nutrition/health properties (e.g., biofortification), varieties with climate resilience/adapted to new locations. These are all opportunities which will be realised in the long term (5-10 years) because of breeding cycles however, there is an opportunity to expedite this for some traits through gene editing and genome sequencing of legume crops. Some of the issues, raised in the challenges section, which could be addressed through genetics and breeding were; “right crops, wrong places” (breeding and trialling of different crops in new territories) and; the inefficiency of pulling apart proteins/starches/fibres into separate streams and then combining during processing may be addressed through breeding varieties that are more amenable to processing. The development of more functionalised legumes with higher protein content will lead to the availability of better raw materials. |
| **Circular economy** | In the medium term there is an opportunity to develop co-products as observed in the more mature soya/wheat sector. If an increase in protein content is realised through genetics and breeding (see above) then this will provide an opportunity to reduce waste/side streams. Either way, circularity needs to be integrated into the supply chain in order to improve sustainability credentials versus other protein sources. There is also an opportunity to utilise waste streams from other processes (e.g. brewer’s spent grain) and other underutilised resources for plant-based protein extraction. Circularity was covered in further detail in the challenges section. |
| **Differentiated characteristics** | In the medium term the plant-based alternative protein sector has an opportunity to deliver competitive advantages by developing differentiated characteristics including improved nutrition and better functionality. On nutrition, there is an opportunity to develop targets with nutritionist to determine what the nutritional characteristics would be optimal. There is an opportunity to develop tailor-made protein ingredients with enhanced functions and/or targeted for specific applications. Cost-benefit wise, any new products must deliver at/above soya/wheat to compete in the market place (these are the benchmarks). On functionality a better fat profile will deliver better product quality (e.g. meat alternatives). |
| **Diversify protein source** | Alternate sources, e.g. hemp and buckwheat, are interesting for more marginal land e.g. much of Scotland. There are extensive opportunities in the long term to trial and assess plant-based proteins from different sources across a broad range of applications. |
| **Efficient extraction and processing methods** | In the long term there is an opportunity to develop novel methods of extraction which have a lower environmental impact, higher extraction yields and at reduced costs. More research will be required to address this challenge to understand how to generate better protein fraction (= improved quality via downstream process). On processing, a systematic understanding of the process-function relationship for wider varieties of plant/algal proteins (i.e. a link to fundamental research is required). Also, to sustainably deliver the desired protein functions, the effect of non-thermal processing on the inter-relationship between (micro)structure and function (e.g. solubility, emulsification or texture ) needs to be further studied. |
| **Agronomy** | In the medium term there is an opportunity to address agronomy at the primary production stage by identifying new crop protection approaches. Integrating legume crops into the rotation which will offer potential benefits in soil and net-zero. |
| **Labelling** | There is an opportunity for labelling products to inform the consumer of nutritional benefits beyond the protein content/level, which may include fibre and phytonutrients. Like animal sources of protein, nutrient profile of plant proteins will be highly variable depending on the source (species/variety choice) and the processing system. Therefore it is important to communicate this to the consumers. Protein is easily measurable and the consumer has a good understanding of what it means. Opportunity could focus on other micro- and macronutrients which are often harder to estimate in complex food matrices and difficult to communicate to the consumer. There is also a need to understand how much is lost during processing (e.g. vitamins). |
Opportunities: **Commercial**

### Commercial Opportunities

<table>
<thead>
<tr>
<th></th>
<th>Short term (1-2 years)</th>
<th>Medium term (2-5 years)</th>
<th>Longer term (5-10 years)</th>
<th>Very long term (10 years +)</th>
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</thead>
<tbody>
<tr>
<td><strong>Circular economy</strong></td>
<td></td>
<td>• co-product market development</td>
<td></td>
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<td></td>
<td></td>
<td>• use of agri-food waste</td>
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<tr>
<td><strong>Sustainability</strong></td>
<td></td>
<td>• sustainable alternatives to animal derived foods</td>
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<tr>
<td><strong>Consumer demand</strong></td>
<td></td>
<td>• increased consumer interest – 15% CAGR globally</td>
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<tr>
<td><strong>Net-zero</strong></td>
<td></td>
<td>• opportunity to fix N and reduce artificial N input</td>
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<tr>
<td><strong>Dietary shift</strong></td>
<td>• shift toward vegan/vegetarian diets</td>
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<tr>
<td><strong>Labelling</strong></td>
<td></td>
<td>• naturalness/ Eco labelling</td>
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<td></td>
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<td>• marketing</td>
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<td></td>
<td></td>
<td>• nutritional labelling</td>
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</tbody>
</table>

### Circular economy
- Co-product market development
- Use of agri-food waste

### Sustainability
- Sustainable alternatives to animal derived foods

### Consumer demand
- Increased consumer interest – 15% CAGR globally

### Net-zero
- Opportunity to fix N and reduce artificial N input
- Help achieve climate targets

### Dietary shift
- Shift toward vegan/vegetarian diets

### Labelling
- Naturalness/Eco labelling
- Marketing
- Nutritional labelling
<table>
<thead>
<tr>
<th>Circular economy</th>
<th>In the medium to long term there is a commercial opportunity to develop co-products and identify opportunities for waste streams developed within the manufacturing process but also to utilise waste streams from outside (i.e. extract protein from brewer’s spent grain). There is also an opportunity to partner with other alternative protein sub sectors e.g. use of the waste streams from plant-based protein manufacturing process could be utilised by the precision fermentation subsector. This sector is very amenable to circular economy models.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainability</td>
<td>Eco labelling initiatives is an opportunity in the medium term which will be required to communicate environmental benefits to consumer (see labelling below).</td>
</tr>
<tr>
<td>Consumer demand</td>
<td>There is a growing consumer demand for novel protein products as evidenced by most consultancy reports which gives high Compound Annual Growth Rate (CAGR) for plant-based protein sector and a Food Standards Agency (FSA) commissioned survey looking at consumer perceptions of alternative, or novel, sources of protein (<a href="https://www.food.gov.uk/research/behaviour-and-perception/survey-of-consumer-perceptions-of-alternative-or-novel-sources-of-protein">https://www.food.gov.uk/research/behaviour-and-perception/survey-of-consumer-perceptions-of-alternative-or-novel-sources-of-protein</a>).</td>
</tr>
<tr>
<td>Net-zero</td>
<td>Plant-based proteins make a strong net-zero case and this is measurable making policy easier to implement to support the sector. In the medium term, with increasing fertiliser costs, there is an opportunity to fix Nitrogen and reduce artificial Nitrogen input in primary production. In the very long term as alternative proteins displace animal-based alternatives there is an opportunity to help achieve climate targets.</td>
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<tr>
<td>Dietary shift</td>
<td>There is a clear commercial opportunity in the short term as there is an increasing shift in the UK population towards vegan and vegetarian diets which is being realised by the sector. With this momentum there is an opportunity to address some of the issues in our current food landscape. The public health, nutrition and food security aspects of alternative proteins are all positive messages. Should the government use the opportunity presented by the Eat Well Guide and National Food Strategy documents to revise the dietary guidelines (led by department of health) in light of the increase in the diversity of protein sources available to the consumer? A need was recognised by the group to focus commercial messaging on balanced diet i.e. needn’t be a 100% plant-based = small shift e.g. AHDB Eat Balanced campaign. Is there an opportunity for some social science research here (building on the FSA consumer perceptions survey cited above)?</td>
</tr>
<tr>
<td>Labelling</td>
<td>There is an opportunity in the medium term to communicate the environmental benefits to the consumer through eco labelling initiatives allowing the sector to communicate the product to the consumer transparently e.g. crops that are unfamiliar to them. Pea and faba offer positive story (low footprint, biodiversity, pollinators). As expanded upon in the technical opportunity section, there is a commercial opportunity to highlight the nutrients plants do bring e.g. dietary fibre. More work could be undertaken in this area to understand what dietary properties are available from the plant-based diets and where these could be used to address issues in our current food landscape. Perception that plant-based = healthier, greener but needs fortification.</td>
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</table>
Opportunities: **Regulatory**

**Genetics and breeding**
- Standardise food safety methodology

**Trade**
- Health claims
- Reduced allergenicity

**Regulatory standards**
### Genetics and breeding

- gene editing
- genetic modification

### Reduced allergenicity

- food ingredients with reduced or no allergenicity

### Regulatory evolution

- develop robust evidence for regulators
- post-Brexit opportunities
- standard of identity

---

There is an opportunity to educate the consumer about the use of breeding techniques such as gene editing (GE) and genetic modification (GM) to give them the information required to inform their position on these technologies. There is a role here for ‘knowledge partners’ (i.e. Universities and Research Organisations) to educate the consumer (might seem to the consumer that the food manufacturer is conflicted). This can be achieved through openness and transparency and active engagement with the consumer.

There is an opportunity here to offer alternatives to allergy causing animal-based products (e.g. lactose) but an associated challenge may see increased prevalence of different allergies as diets shift e.g. to pea allergens.

Post-Brexit, the UK is its own regulator for crop protection products and GM/GE regulation. This is an opportunity for this sector, however, it will require a coordinated precompetitive space to accelerate regulatory approval = Scientific community develop robust independent evidence that is communicated to the regulator and subsequently to the consumer – but this will need funding. On standards of identity (SOI), post-Brexit, UK regulators have the opportunity to change SOI regulation with just the one regulator rather than the multiple regulators which make up the EU position = easier for industry to navigate.
## Opportunities: Consumer

### Sustainability
- **New market development**
- **New product development**

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<tr>
<th></th>
<th>Short term (1-2 years)</th>
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<th>Very long term (10 years +)</th>
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<tr>
<td><strong>Sustainability</strong></td>
<td>• increased awareness</td>
<td>• climate benefits</td>
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<td>associated with plant-based diets</td>
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<td><strong>Lifestyle shift</strong></td>
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<td>• increased awareness</td>
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<td>of healthy lifestyle</td>
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<td></td>
<td>• improved nutrition</td>
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<td><strong>Dietary shift</strong></td>
<td>• wider product</td>
<td>• shift towards</td>
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<td>range is inclusive</td>
<td>plant-based/</td>
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<td></td>
<td>of consumer diets</td>
<td>flexitarian diets</td>
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<tr>
<td><strong>New product development</strong></td>
<td></td>
<td>• satisfy new</td>
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<td>• cost reduction of</td>
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<td>dietary trends</td>
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<td>raw material</td>
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<td>• targeting different</td>
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<td>sectors of the population</td>
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<td>• utilise plant</td>
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<td>functionality</td>
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<td>to enhance consumer</td>
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<td>experience</td>
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<tr>
<td><strong>Affordability</strong></td>
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### Net-zero

### New market development

### New product development

### Dietary shift

### Lifestyle shift

### Flavour

### Demand
### Sustainability
According to FSA survey (cited above) consumers are choosing plant-based proteins over animal-based protein primarily (44%) due to perception of food safety ahead of perception that it is healthier and more sustainable – this finding presents a potential opportunity to pursue through further research into the safety aspects of plant-based proteins. Agricultural sector are good at promoting the sustainability issue – needs to translate to end product (see labelling opportunities above).

### Lifestyle shift
Wealthy individuals can shift their lifestyles around sustainability and nutrition however affordability is preventing those people who we most want to see shift their dietary choices for a healthier and more sustainable society. In the medium term policy and government guidelines should incentivise industry to address this by making products that they want to eat affordable so the shift is an easy one e.g. plant-based protein supplemented chicken nuggets.

### Dietary shift
The consumer opportunity is clear and already evident around society’s dietary shift however there is a need for industry, research organisations (ROs) and Government to address some of the short term challenges around consumer education. The consumer needs to be informed about health and sustainability of their food preferably by universities, ROs and the third sector, crucially with buy in from all the stakeholders. There is an opportunity to have a hybrid approach to products with reduced meat substituted with plant-based protein which will promote consumer acceptance (nutrition, appearance etc). The latter needs strong messaging (from the food industry/retailer).

### New product development
There are many consumer opportunities which can be realised by this sector in the medium term through new product development including satisfying new dietary trends, targeting different sectors of the population and utilising plant functionality to enhance consumer experience. The group discussed that these new products needn’t just mimic animal-based products – if consumers are given the opportunity to get used to it, new flavours and textures can be a positive (e.g. plant-based milk drinks).

### Affordability
There is an opportunity to address affordability through research into increasing production of the raw ingredients right through the supply chain from breeder> primary producer> processor> consumer. This should be realised over the next 5-10 years.
**OBJECTIVE**

**Mycoproteins:** Grow mycoprotein market to provide a sustainable and affordable protein alternative to replace meat and dairy products.

**Lab-cultured meat:** Provide consumers with an ethical and sustainable lab-cultured meat option at a cost equivalent to meat.

**Mycoproteins and lab-cultured meat:** Further improve sustainability of fermentation products.
Current Status

Technical

Mycoproteins
The UK is the world leader in mycoprotein fermentation, meaning production is well established at a national level. Nonetheless, the demand for mycoprotein products exceeds current supply capacities.

Lab-cultured meat
There are multiple small companies investigating the potential of lab meat cultivation. Cultures cannot currently be produced easily at scale. As such, this alternative protein industry is at an early stage of its development.

Commercial

Mycoproteins
The alternative protein space is highly competitive with the plant-based and mycoprotein sectors competing for market share.

Lab-cultured meat
Not yet commercially available in the UK.

Regulatory

Mycoproteins and lab-cultured meat
The regulatory framework for fermentation products is complex and difficult to navigate. For example, extensive food testing is required to bring lab-cultured meat to the market and extensive testing is also required to register novel mycoproteins as a food source. Brexit is an opportunity for UK regulatory bodies to streamline these processes.

Consumer

Mycoproteins
Even a well-informed audience can be under the impression that mycoproteins are highly processed and that they contain many other ingredients, but this is not true. Education of the consumer is required to ensure they are aware that these products are not heavily processed, and that consuming them is associated with health benefits.

Lab-cultured meat
Due to the nascent nature of the cultured meat sector, it is not currently known whether consumers will accept lab-cultured meat as a surrogate for farmed meat.
Size of opportunity

**Technical**

**Mycoproteins**

During the identification and development of *Fusarium venenatum*, extensive numbers of alternative fungal species were screened for their potential use in mycoprotein production. There is an opportunity to build upon this data in order to determine additional alternative species for mycoprotein production. The implementation of gene editing will allow the improvement of fungal strains/species to increase their potential for commercialisation.

**Lab-cultured meat**

Producing custom-built fermenters and development of food-specific growth regulators will help to optimise the production of cellular fermentation products. Developing an open-access model for the production of facility blueprints will enable technical advances.

**Commercial**

**Mycoproteins**

Harnessing fermentation products as a major food has the potential to provide a more sustainable protein source when compared to animal-based products. The conscientious consumer is increasingly aware of the environmental impact of food production. Thus, tapping into this market could be achieved through communicating the environmental sustainability of these products.

**Lab-cultured meat**

Extensive optimisation of lab-cultured meat generation has the potential to provide a sustainable alternative to animal farming. Such optimisation may provide an affordable meat product with a low carbon footprint.

**Regulatory**

**Mycoproteins and lab-cultured meat**

The participants felt a carbon footprint tax would help level the playing field within the wider protein food market. Such a strategy would ensure that the production of environmentally sustainable food sources is incentivised. Better training to navigate the regulatory process could help companies understand the steps that need to be taken in order to achieve the freedom to operate. In particular it may be useful if UKRI/KTN could develop a training package to support the navigation of this complex area (specifically to help small companies/start-ups).

Brexit provides a potential opportunity to make the regulatory process more agile, providing a quicker route to market for new and novel products. This could help UK companies to expediate the development of nutritious and sustainable alternative proteins.

**Consumer**

**Mycoproteins and lab-cultured meat**

Often curiosity will drive a consumer to try a new product, but the real challenge is to get people to make a second or third purchase. The cost of the product remains the primary factor that influences the likelihood of a repeat purchase.
Barriers and/or trade-offs

**Technical**

**Mycoproteins**
Scaling up production to meet demand is proving the largest technical challenge for mycoprotein production.

**Lab-cultured meat**
Recreating a comparable taste and eating experience to that of meat is important for repeat purchase. Lab-cultured meat companies are in need of precompetitive research on optimising the bio-processes of cultivated meat development. Currently, there is no body of literature detailing optimised production protocols, thus companies must each optimise processes independently. This lack of collaboration has impeded progression within the area.

**Commercial**

**Mycoproteins and lab-cultured meat**
Financial incentives for environmentally positive solutions will level the playing field where alternative protein companies are competing with the established meat industry.

**Regulatory**

**Mycoproteins and lab-cultured meat**
There are extensive regulatory procedures that must be followed in order to get a novel food product onto the market. The industry would like the process to be streamlined and felt regulators should look to expedite the regulation process, particularly where strain improvement and selection has led to products that are safer for human consumption.

**Consumer**

**Mycoproteins**
There are many opportunities outside of meat equivalents within the alternative protein sector. Indeed, the fermentation sector are not exploiting dairy and egg alternatives to the extent that the plant-based sector have.

**Lab-cultured meat**
Achieving consumer acceptance for lab-cultured meat is one of the major barriers that must be overcome in order for these products to become established in the market. It is anticipated that consumer acceptance can be achieved through the use of celebrity endorsement and media campaigns. The cultivated meat sector is working towards the development of a new product which is a hybrid of alternative protein sources. In particular, they are interested in the potential to integrate plant-based and fermentation products. This offers a potential route to market via tapping into an existing market base.
### Challenges: Technical

<table>
<thead>
<tr>
<th>Scale up</th>
<th>Short term (1-2 years)</th>
<th>Medium term (2-5 years)</th>
<th>Longer term (5-10 years)</th>
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</thead>
<tbody>
<tr>
<td>Lab-cultured meat</td>
<td>• scalable bioreactors</td>
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<td></td>
<td>• bioprocesses</td>
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<tr>
<td>Alternative cell culture media</td>
<td>• expensive</td>
<td>• not sustainable</td>
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<tr>
<td>Cost parity</td>
<td></td>
<td>• delivering price parity to traditional meat</td>
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<tr>
<td>Scale up and investment</td>
<td>• expansion of fermentation capacity</td>
<td>• economical extraction of protein</td>
<td>• integrated biorefineries for algae, fungi etc.</td>
<td>• overcoming the ‘valley of death’</td>
</tr>
<tr>
<td>Mycoprotein</td>
<td>• productivity</td>
<td>• building of robust production processes</td>
<td></td>
<td></td>
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<tr>
<td>Production optimisation</td>
<td>• How to control cell structure/metabolism during fermentation</td>
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</table>
### Scale up

In the medium term there will be a need for the sector to scale up from market access to industrial scale. This will require several fold increase in the cell quantities produced which can be achieved by developing robust bioprocesses in scalable bioreactors. Bioreactors are typically optimised for pharmaceutical production – the optimal bioreactor for meat culture may look different. As this is a very nascent area of research there are many opportunities to custom design purpose built bioreactors with greater efficiency. This could be achieved through scaling down activities in order to determine optimum conditions. The tissue being generated is very complex, with a large number of cells \((10^{12})\) needed to achieve 1 kg of product, these cells are mostly stem cells – in order to achieve the required density of stem cells there is a need to optimise bioprocesses.

### Lab-cultured meat

Cell culture media is currently optimised for human or mouse and not for livestock. There is a need within the medium term, as this sector scales, to develop alternative cell culture media which is optimised to livestock cells and also addresses the cost and sustainability of current options. For example, there is a need to replace animal components (i.e. serum-free) whilst still being cost effective. Also need to find alternatives for other expensive components (e.g. growth factors).

### Cost parity

Achieving cost parity with traditional meat is critical for the economic feasibility of cultivated meat products and there is a need within the medium term, as this sector scales, to address this challenge e.g. through scaling up and reducing costs of inputs as described above. Reducing the cost of production was considered in the workshop as one of the sector’s highest priorities to address and ranked over taste or production challenge.

### Mycoprotein

In the medium-term there is a need to increase fermentation capacity (and efficiency; see case study) and also develop efficient and economical extraction procedures for proteins from algae, fungi and bacterial fermentations. Case study: A market leading mycoprotein producer, present at the workshop, has demonstrated commercial viability and so is now focussed on scaling up productivity through the expansion of fermentation capacity however the number of fermenters that are required to meet demand is significant with each fermenter ordered requiring a long time to appreciate an ROI – this company would want to investigate optimising/innovation in the processes of fermentation of mycoprotein.

### Production optimisation

Production optimisation needs to be addressed within the medium term including improving productivity, building of robust production processes and investigating specific challenges such as how does cell structure/metabolism determine processing to meat-like texture and how to control this during fermentation.
Challenges: **Commercial**

### Scale up

- **Lab-cultured meat**
  - **Scale up**
  - Cost parity with alternatives
  - • efficiency/economies of scale
  - • lack of capacity for demo-scale and mid-scale co-manufacturing
  - • lack of model production facility blueprints
  - • lack of data sharing to inform process improvement

- **Competition**
  - • new alternative protein sources
  - • lack of B2B options

- **Mycoprotein**
  - **Scale up**
  - • capital investment for commercial-scale facilities
  - • needs economies of scale to hit mainstream

### Cost parity

- **Novel food approval**
- **Consumer acceptance**
- **Regulatory approval**
- **Market-size**

---

*Table showing challenges and solutions for different time frames.*
### Overview

<table>
<thead>
<tr>
<th>Plant-based Proteins</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lab-cultured meat</strong></td>
<td>Cost parity with alternatives</td>
</tr>
<tr>
<td><strong>Scale up</strong></td>
<td>Competition</td>
</tr>
<tr>
<td><strong>Mycoprotein</strong></td>
<td>Scale up</td>
</tr>
</tbody>
</table>
### Challenges: **Regulatory**

<table>
<thead>
<tr>
<th></th>
<th>Short term (1-2 years)</th>
<th>Medium term (2-5 years)</th>
<th>Longer term (5-10 years)</th>
<th>Very long term (10 years +)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novel food regulation</td>
<td>• navigating approval process is time consuming</td>
<td>• cost of registration and getting new foods approved for SMEs</td>
<td></td>
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</tr>
</tbody>
</table>
| Demonstrate robust and reproducible process | • cell derivation methods  
• manufacturing process |                                                                                         |                                                                                          |                             |
| Lack of clarity on policy and regulatory environment | • regulatory approval process for cultivated meat products  
• GM legislation for new strains |                                                                                         |                                                                                          |                             |
| Lab-cultured meat and mycoprotein in novel food environment |                                                                                         |                                                                                          | • standardised relative to other countries  
• need for clear and transparent path to market |                             |
| Demonstrate food safety | • food-safe reagents used in manufacturing process  
• safety |                                                                                         |                                                                                          |                             |
<p>| Freedom to operate in the R&amp;D space | • separate regulation for testing products in R&amp;D context |                                                                                         |                                                                                          |                             |</p>
<table>
<thead>
<tr>
<th>Lab-cultured meat and mycoprotein</th>
<th>Novel food regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>It is currently expensive and difficult to navigate food regulations creating a barrier of entry to start-ups and SMEs who want to diversify their product range within or from outside this space. The regulation process would benefit from being streamlined. Participants called for better training to navigate the regulatory processes and suggested that UKRI/KTN could develop a training package to support the navigation of this complex area (specifically to help SME/start-ups). Specifically this would help companies understand the steps that need to be taken in order to achieve the freedom to operate. Workshop participants also discussed the possibility of petitioning for improved legislation surrounding the regulation of novel food products as an industry.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lab-cultured meat and mycoprotein</th>
<th>Demonstrate robust and reproducible process</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>For the lab-cultured meat sector there is a need to demonstrate robust and reproducible methods for cell derivation and manufacturing processes for the regulator.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lab-cultured meat and mycoprotein</th>
<th>Lack of clarity on policy and regulatory environment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>There is a lack of clarity on the policy and regulatory environment for novel foods and genetic modification (GM). In the EU both GM and novel foods take a long time to reach approval. Furthermore there are packaging and labelling stipulations that must be adhered to. There is a need to review the food regulation strategy. Experience of established partners indicated costs of £1 billion were outlaid to reach the UK market, this was due to the extensive testing required to ensure the product is safe for human consumption. Indeed, they have since encountered similarly high regulations when attempting to enter into foreign markets. There is a strong desire to collaborate across partners to achieve fairer and simpler regulations. These issues should be addressed in the medium term by developing a regulatory approval process for cultivated meat products so that there is a clear and transparent path to market. There is also a call from the industry participants to standardise regulation (for GM and novel food) relative to other countries which have approved lab-cultured meat products.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lab-cultured meat and mycoprotein</th>
<th>Demonstrate food safety</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Improvements can be made through expediting the regulation process particularly where strain improvement and selection, e.g. of mycoproteins, has led to products that are safer for human consumption.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lab-cultured meat and mycoprotein</th>
<th>Freedom to operate in the R&amp;D space</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The USP for the UK’s fermentation industry is the fact that they are world leading in fungal fermentation through demonstrating the vertical integration of growing crops for glucose through to the production of the final product.</td>
</tr>
</tbody>
</table>
## Challenges: *Consumer*

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Short term (1-2 years)</th>
<th>Medium term (2-5 years)</th>
<th>Longer term (5-10 years)</th>
<th>Very long term (10 years +)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Consumer acceptance</strong></td>
<td>- low acceptance of meat alternatives</td>
<td>- suspicions of authenticity and likeness to existing products</td>
<td>- perceptions of cultivated meat as ‘unnatural’</td>
<td>- continued preference for real meat products</td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td>- labelling</td>
<td>- will consumers understand precision fermentation?</td>
<td>- perception that alt. prot. is antithesis of e.g. regen ag and organics</td>
<td></td>
</tr>
<tr>
<td><strong>Lab-cultured meat and mycoprotein</strong></td>
<td></td>
<td>- seek alternatives to animal testing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Appearance
- Nutritional equivalence

### Education
- Flavour
- Transparency

### Affordability
- Consumer preference

### Challenges:
- **Short term (1-2 years)**
  - Low acceptance of meat alternatives
  - Suspicions of authenticity and likeness to existing products
  - Perceptions of cultivated meat as ‘unnatural’
  - Continued preference for real meat products

- **Medium term (2-5 years)**
  - Labelling
  - Will consumers understand precision fermentation?
  - Perception that alt. prot. is antithesis of e.g. regen ag and organics

- **Longer term (5-10 years)**
  - Seek alternatives to animal testing

- **Very long term (10 years +)**
<table>
<thead>
<tr>
<th>Challenge</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer acceptance</td>
<td>Consumer acceptance, particularly of cultivated meat, is a big consumer challenge for this sector. The cultivated meat market are keen to tap into the mid ground market in order to reach those concerned about climate change. There is a need in the medium term for the sector to engage across different platforms including (social media/TV/influencers/endorsers/celebrities) to highlight the benefits of alternative proteins. Often curiosity will drive a consumer to try a new product, but the real challenge is to get people to make a second or third purchase. Taste and recreating an eating experience which is as good as meat is important for repeat purchase, however cost is the primary concern. Factors such as health benefits and low CO\textsubscript{2} outputs can help but they are not the primary factors influencing consumer purchasing.</td>
</tr>
<tr>
<td>Education</td>
<td>Labelling of the product is an opportunity to educate the consumer. Labelling is essential to help the consumer make an informed choice and can act as a way to identify that a particular standard is being met (e.g. organic foods). Although there is a risk that all the different schemes and standards confuse the consumer. Education of the consumer is required to inform the consumer about the minimal levels of processing and health benefits related with e.g. mycoprotein-based products. This break out group agreed that everyone must take ownership over education which aligns with the plant-based group whom felt that all stakeholders (producers, government, knowledge partners (scientists and engineers) and consumers) had a responsibility in educating the consumer. One market leading mycoprotein producer is working with medical professionals to determine and advocate the health benefits of their products, relying on doctors to translate the information that mycoprotein is good for you. Beyond this there are initiatives looking at labelling in order to put claims on the packaging, here there is often a role for non-profit organisations and consumer groups. Marlow foods/Quorn are pioneering messaging on their products with placement of environmental benefits on packaging.</td>
</tr>
<tr>
<td>Animal testing for food safety</td>
<td>Partners within this sector cannot easily use animal testing to confirm the safety of the food products, as there is a reduced appetite for animal testing within the target market. Alternative means of food testing by regulators is therefore required.</td>
</tr>
</tbody>
</table>
Opportunities: **Technical**

### Bioprocess technology
- Short term (1-2 years): computational modelling or novel bioreactor designs
- Medium term (2-5 years): improving efficiency of suspension growth
- Longer term (5-10 years): semi-continuous bioprocess for whole cut cultivated meat
- Very long term (10 years +): computational models of perfusion flow through scaffolds

### Cell line development
- New strains
- Scale-up collaboration
- Gas fermentation
- Cell culture media formations
- New functionality
- Precision fermentation

### Lab-cultured meat
- Cell culture media formulations
  - Short term (1-2 years): identify cheap sources of amino acids
  - Medium term (2-5 years): identify cheap sources of growth factors
  - Longer term (5-10 years): systematic investigation of growth factor needs and effects
  - Very long term (10 years +): computational models of perfusion flow through scaffolds

### Cell line development
- Establishment of cell line repositories
- Standardised isolation protocols

### Alternative feedstocks
- Short term (1-2 years): carbohydrates with increased sustainability and reduced cost
- Medium term (2-5 years): remove dependency on corn, beet etc as source of carbon
- Longer term (5-10 years): circularity
### Overview

**Plant-based fermentation**

**Challenges**

- **Bioprocess technology**
  - In the medium term there is an opportunity to apply computational modelling expertise to model the behaviour of mammalian cells at scale which will help inform novel bioreactor designs. Workshop participants also identified technical opportunities the sector could realise in the next 5 to 10 years (long term) as follows; 1) develop semi-continuous bioprocess for whole cut cultivated meat using simultaneous perfusion and stretch; 2) improve efficiency and assessment of adaptation to suspension growth and; 3) develop computational models of perfusion flow through scaffolds.

- **Cell culture media formulations**
  - Opportunities for developing new cell culture media formulations will be realised in the medium-term through; Identifying cheap sources of amino acids such as from plant hydrolysates, there may also be an opportunity to use agri waste as a substrate to this end, although this would need caution around mycotoxin accumulation; Identifying alternative cheaper sources of growth factors for proliferation (Medical grade growth factors are not required as the food industry does not need high purity growth factors); by mapping the secretome of animal myoblasts, adipocytes, and other cells used in cultivated meat then cell culture media can be designed to efficiently meet the cells needs (e.g. a systematic investigation of growth factor needs and effects). In order to achieve cheaper cellular process we need to think outside of the box – engineering processes alone will not let us reach cost parity – this needs to be achieved through combining biological opportunities to reduce costs, such as cheaper media components that can replace expensive growth factors currently being used.

- **Cell line development**
  - There are currently no commercially available livestock species cell lines, so generally they need to be sourced and isolated directly from animals by using abattoirs or slaughterhouses. There is an opportunity to address this issue through the opening up of access to immortalised cell lines this could be realised in the medium term through the establishment of cell line repositories (including for neglected seafood species) and standardized isolation protocols for the sector.

- **Alternative feedstocks**
  - There is a need in the medium term to develop cheaper and more sustainable feedstocks. There are opportunities to explore alternative carbohydrates with increased sustainability and reduced cost. In the longer term there are opportunities to valorise the waste products of processing = minimising waste and increasing profitability and utilising agri waste as a source of carbon (reducing current dependency on corn, beet etc), however this would need caution around mycotoxin accumulation.

- **Mycoprotein**
  - There is a current focus on meat analogues in the acellular fermentation sub sector however there is a huge technical opportunity in the medium term to develop fermentation-based protein ingredients which will challenge the dairy, egg and plant-based protein markets. Other functionality will follow in the longer term particularly as companies utilising precision fermentation become more established and diversify the market.

- **Precision fermentation**
  - There is a need to accelerate UK capabilities in precision fermentation to realise opportunities within the medium-term e.g. to develop animal-identical dairy, egg and meat proteins. Further opportunities will follow as this sector develops.

### Novel Proteins

<table>
<thead>
<tr>
<th>Component</th>
<th>Short term (1-2 years)</th>
<th>Medium term (2-5 years)</th>
<th>Longer term (5-10 years)</th>
<th>Very long term (10 years +)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mycoprotein</td>
<td>• protein ingredient to challenge dairy and egg protein market</td>
<td>• other functionality...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precision fermentation</td>
<td>• for animal-identical dairy, egg and meat proteins</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Opportunities: **Commercial**

### Lab-cultured meat - Process innovations

<table>
<thead>
<tr>
<th>Short term (1-2 years)</th>
<th>Medium term (2-5 years)</th>
<th>Longer term (5-10 years)</th>
<th>Very long term (10 years +)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• developing open-access model production facility blueprints</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• expand capacity for demo-scale and mid-scale co-manufacturing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• data lake for aggregating process data and informing process improvements</td>
<td></td>
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</tr>
</tbody>
</table>

### High quality and sustainable protein

<table>
<thead>
<tr>
<th>Medium term (2-5 years)</th>
<th>Longer term (5-10 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• to feed growing global population</td>
<td></td>
</tr>
</tbody>
</table>

### New product development - Mycoprotein - Product innovation

<table>
<thead>
<tr>
<th>Medium term (2-5 years)</th>
<th>Longer term (5-10 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• beverage development</td>
<td></td>
</tr>
<tr>
<td>• creation of new supply chains</td>
<td></td>
</tr>
<tr>
<td>• protein ingredients</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Long term (5-10 years)</th>
<th>Very long term (10 years +)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• consumer driven desire for alternative products</td>
<td></td>
</tr>
<tr>
<td>• using unique characteristics to diversify products</td>
<td></td>
</tr>
<tr>
<td>Process innovations</td>
<td>Lab-cultured meat</td>
</tr>
<tr>
<td>---------------------</td>
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</tr>
<tr>
<td></td>
<td>There is an opportunity to innovate the processes in the cultivated meat sector by adopting an open-access model within the next 5 to 10 years (long-term) and could include; developing a national capacity for demo-scale and mid-scale co-manufacturing, produce model production facility blueprints and data sharing to inform process improvement (see further information at <a href="https://gfi.org/advancing-solutions-for-alternative-proteins/">https://gfi.org/advancing-solutions-for-alternative-proteins/</a>).</td>
</tr>
</tbody>
</table>

| High quality and sustainable protein | Cultivated meat will play an important role in providing high quality and sustainable protein to feed the growing global population. This provides global opportunities for this sector beyond the developed markets. |

<table>
<thead>
<tr>
<th>New product development</th>
<th>Mycoprotein</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>The lab-cultured meat and acellular fermentation sub sectors are working towards the development of new supply chains that enable development of new products which including beverage development and hybrids of alternative protein sources. In particular the sector were interested in the potential to integrate plant-based and fermentation-based products, some collaboration is already underway but attendees are also looking for new collaborations. This offers a potential route to market via tapping into an existing market base.</td>
</tr>
</tbody>
</table>

| Product innovation | |
|-------------------| There is a huge commercial opportunity for this sector to deliver the consumer driven desire for new products which in turn drives innovation. Mycoprotein for example has some unique properties (e.g. fibrosity) which in the short term will deliver a "best in class chicken replacement". |
Opportunities: Regulatory

Clear path to market
Easing GM food regulations

Post Brexit opportunities
Easing gene editing regulations
Easing novel food regulations

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Post Brexit opportunities</td>
<td>• freedom from EU regulation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Easing novel food regulations</td>
<td>• make registration easy</td>
<td>• use lessons learnt in other countries</td>
<td>• provide clear guidance</td>
<td></td>
</tr>
<tr>
<td>Easing gene editing regulations</td>
<td></td>
<td>• accelerate approval process of gene editing techniques</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab-cultured meat and mycoprotein</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Funding landscape</td>
<td>• invest in R&amp;D</td>
<td></td>
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</tbody>
</table>

Post Brexit, we are seeing some movement on novel food introduction. There is an opportunity to collaborate across stakeholders to achieve fairer and simpler regulations.

With respect to the novel food regulations there is an opportunity for policy makers and regulators to make registration easy, use lessons learnt in other countries (e.g. Singapore for cultivated meat) and provide clear guidance in order to show a clear path to market for current and would-be companies and investors operating in this space. There is also an opportunity to provide better training to navigate the regulatory process of novel food regulations.

There is a great opportunity to use gene editing to improve strains used in acellular fermentation and the sector welcomes an accelerated approval process to allow these techniques to be utilised, however, its use may lead to greater restrictions associated with selling produce in some export markets, particularly within the EU.

The Netherlands can be seen to have extensive funding available for research and development of alternative food sources, this is an excellent example to follow in order to boost the UKs standing within the sector. Also see: https://www.foodvalley.nl/our-focus/protein-shift/.
Opportunities: **Consumer**

**Health benefits**
- Differentiation from highly processed alternatives
- Labelling

**Net-zero**
- Improved organoleptic properties
- Increased B2B

**Sustainability**

<table>
<thead>
<tr>
<th>Dietary shift</th>
<th>Short term (1-2 years)</th>
<th>Medium term (2-5 years)</th>
<th>Longer term (5-10 years)</th>
<th>Very long term (10 years +)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Net-zero</strong></td>
<td></td>
<td></td>
<td>• policy</td>
<td>• major factor in engaging consumers</td>
</tr>
<tr>
<td><strong>Consumer engagement</strong></td>
<td>• transparency about the production process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Health benefits</strong></td>
<td></td>
<td></td>
<td>• increased awareness of healthy lifestyle</td>
<td></td>
</tr>
</tbody>
</table>

Net-zero goals have provided a strong consumer opportunity for fermentation-based alternative proteins however the sector requires policy incentives to produce sustainable products. This would ensure that materials for food production are not sourced from the other side of the world. Particularly as this is a nascent industry and it needs to be able to compete with the heavily established agricultural industry, who are incentivised towards sustainable production. There were calls for open access for life cycle assessment (LCA) of products to allow them to incorporate sustainable practices at the beginning of establishing new companies/products.

On policy, there was a discussion about a carbon tax for food products that is costed proportionally to associated CO₂ production costs. Such a tax would factor in externalised costs thus levelling the playing field for food producers, through extending this tax to imports and meat production.

Central to consumer engagement with fermentation-based products is ensuring that consumers and farmers are communicated to in a transparent way through highlighting clearly the benefits to the climate, public health, and food security.

With the increased awareness of a healthy lifestyle following the COVID-19 pandemic consumers will be seeking healthy alternatives to certain traditional animal-based products.
Novel systems

OBJECTIVE
Develop insect and new aquaculture protein industries as economically viable alternate sources of protein for human food and animal feed. For insects, the real value is in the potential to utilise waste streams on and off farm and convert them into useful products, including protein, towards a circular bioeconomy. Whilst new aquaculture has the potential to exploit the extensive coastline of the UK.
Current Status

**Technical**

**Insects**
The insect protein industry is dominated by a few species, particularly the Black Soldier Fly larvae (BSFL; *Hermetia illucens*), the mealworm (*Tenebrio molitor*) and the house cricket (*Acheta domesticus*). There is a need to reduce cost of production by scaling up and automating production processes, improving genetics, as well as using cheaper feedstocks currently unavailable due to regulatory constraints. Also, by-products need to be valorised to increase price competitiveness.

**New aquaculture**
For new aquaculture, again only around 17 seaweed species are currently used, 10 cultivated, mostly for non-protein uses. Red algae have shown promise in reducing methane production if included in ruminant diet. There is a need for increased R&D to enhance productivity, as well as to reduce the use of plastics (polypropylene) in the production processes.

**Commercial**

**Insect and new aquaculture**
The insect and new aquaculture protein industries currently comprise of a few start-ups and small-scale companies that cannot compete with cheaper sources of proteins, such as soya bean. Production volumes are low, and the novelty factor of these proteins hinders both consumer acceptance and the removal of regulatory barriers, which in turn hampers large-scale investment into their production.

**Regulatory**

**Insects**
The regulatory situation is fairly complex and challenging for both producers and consumers. Only certain species have been cleared for human food and animal feed in EU. Post-Brexit, the regulatory situation in the UK is in a bit of a limbo, as no approval exists for processed insect protein in pig and poultry feed, and also the regulatory status for use of frass for organic fertiliser is unclear. Another major regulatory hurdle is the current ban on manure and other organic wastes as feedstock, this is preventing the insect protein industry from achieving its full potential in enabling the circular bioeconomy.

**New aquaculture**
The regulations are currently aligned well with the industry, but regulations need to be adapted rapidly as and when new species are commercialised for protein.

**Consumer**
There is a lack of consumer awareness and stigma on the use of insect proteins as human food, and as food ingredients. Also, insect proteins cannot currently compete with other proteins on taste perception or cost.
Size of opportunity

Technical

Insects
There is a huge opportunity to use insects to utilise on-farm and organic wastes to produce protein for animal feed and, in the longer term, human food. Automation should cut down on labour and production costs, thereby making insect protein more cost competitive for certain applications (e.g. as replacement for imported soya bean meal).

New aquaculture
Secondary products such as anti-microbials and other chemicals can enable the sector to achieve cost-competitiveness with cheaper sources of proteins.

Commercial
There is an opportunity to reduce dependence on imported soya bean meal in the near term, with the additional benefits of enhanced environmental sustainability, reduced carbon footprint and a reduction in greenhouse gas emissions through better utilisation of manure and other organic wastes.

Regulatory

Insects
Amending the regulatory framework will allow the development of the market potential for insect proteins in feed applications, as well as allow valorisation of secondary products such as frass (as fertiliser in organic agriculture). Manure and other organic wastes could be utilised as feedstock, thereby enabling the circular bioeconomy, with environmental and sustainability benefits.

Consumer

Insect and new aquaculture
Insect and novel aquaculture proteins can help address the high carbon footprint of animal protein, while labelling changes can enhance consumer awareness and reduce the stigma of using insects in food.
Barriers and/or trade offs

**Technical**

**Insects**
Major technical barriers include lack of breeding expertise for insect species, as well as lack of automation. Investment into automation is inhibited by the size of the market under current regulations. Also, increasing automation will increase the initial capital requirements and serve as a barrier to entry for firms into this market. Instead of large factories, it may be advantageous to have smaller, decentralised production systems based on farms to enable efficient utilisation of on-farm and organic wastes.

**New aquaculture**
Climate change/global warming offer both opportunities and challenges in terms of species management and production.

**Commercial**

**Insects**
Insect protein is currently unable to compete on price with imported soya bean meal. This may change if there is disruption in the global trade or production, increasing fertiliser and agrochemical prices, or trade barriers due to environmental reasons on soya bean meal imported from the Americas. Barriers to scaling up include lack of automation, and lack of government incentives to increase production.

**Regulatory**

**Insects**
Currently, the insect proteins are regulated under Animal By-Products (ABP) guidelines, which hinder both use of cheap waste streams (e.g. manure, animal processing derived wastes) and the utilisation of insect proteins in feed and food, due to the risk of pathogen transmission and heavy metal accumulation. Further research and rapid testing methodologies need to be developed to mitigate these risks and reshape regulations to fulfil the potential of this sector.

**Consumer**
The stigma around eating insects will need to be tackled through consumer education, and the use of insect proteins as processed ingredients rather than through direct consumption of insects themselves.
### Challenges: Technical

#### Short term (1-2 years)
- **Scale up**: lack of expertise in breeding
- **Insect on price**: reduce cost of production, automation, scale up, utilise by-products economically
- **Production**: lack of automation, lack of available, tested machinery
- **Diversify species**: cultivation of some species
- **Cost of production**: need to be more competitive
- **Sustainability of materials**: alternatives to use of polypropylene in cultivation

#### Medium term (2-5 years)
- **Processing, rearing and production equipment**: variability of input, consistency of product
- **Breeding expertise**: standardised processing methods, high capex
- **Feedstock meeting demand**: access to cheaper feedstocks (e.g. manure)

#### Longer term (5-10 years)
- **Knowledge**: lack of expertise in breeding
- **Competitive on price**: reduce cost of production, automation, scale up, utilise by-products economically
- **Production**: lack of automation, lack of available, tested machinery
- **Diversify species**: cultivation of some species
- **Cost of production**: need to be more competitive
- **Sustainability of materials**: alternatives to use of polypropylene in cultivation

#### Very long term (10 years +)
- **Scale up**: lack of expertise in breeding
- **Insect on price**: reduce cost of production, automation, scale up, utilise by-products economically
- **Production**: lack of automation, lack of available, tested machinery
- **Diversify species**: cultivation of some species
- **Cost of production**: need to be more competitive
- **Sustainability of materials**: alternatives to use of polypropylene in cultivation
Currently only one producer in the UK is able to produce more than 100kg feed-grade insects per day, yet the industry will need to produce much larger volumes in order to meaningfully displace current meal used in animal feed. This needs to be addressed in the short to long term through the scale up of production processes and facilities which in turn will require the lack of insect breeding expertise to be addressed in the medium-term. R&D can help here by providing better knowledge/solutions of challenges in large scale systems e.g. tolerance of biotic/abiotic stresses in insects; optimum time and method of drying products (to extend shelf life); as well as appropriate equipment.

The high capital expenditure required for facilities is a major barrier to entry particularly when considering that the product, insect meal, is essentially a commodity which is competing against other mass produced commodities (soya bean/fishmeal) imported to the UK by large multinationals. In the medium to long term there is a need to reduce cost of production, automate, scale up and also utilise by-products economically. In the longer term the industry requires access to cheaper feedstocks using a de-centralised (e.g. on farm production systems) network could be beneficial both economically (reduced transport costs) and good for dealing with waste = lots of smaller factories instead of single large facility. This model will also work for manure/ farm waste-based feedstocks if this stream were to become legal. R&D invested into developing cheaper, less capital intensive production systems required here.

The insect farming sector raised a lack of automation and availability of tested machinery as a barrier that needs to be addressed in the medium term to overcome the production challenge they currently face. The machinery manufacturers were not represented at the workshop. Making connections between the machinery manufacturers and the relatively new industry of insect farming could encourage collaborative R&D in this space to address this gap.

Currently the new aquaculture industry are permitted to grow 17 wild species, 10 of which are currently grown at scale. In the short term there is a need to expand and diversify the cultivated species available to the industry. In the medium term scientific trials should be conducted to evaluate the performance of the different cultivated species with regards to yield and resilience to climate change.

The cost of production can be very high – novel production systems required to maximise seaweed production (to keep cost of production competitive) but balance with environmental impact.

To address a sustainability challenge of the industry, biodegradable and marine safe alternatives to polypropylene, used as seaweed supports, are required in the short term.
Challenges: **Commercial**

**Scale up**

- **Competition on price**: with existing protein sources i.e. soya

- **Scale up**: reducing per unit cost
  - limited by technical challenges
  - commercialise

- **New aquaculture and insect**
  - novelty/lack of track record
  - low consumer acceptance

- **Consumer awareness**
  - novel food ingredients

- **Dietary shift**

---

**Short term** (1-2 years)

**Medium term** (2-5 years)

**Longer term** (5-10 years)

**Very long term** (10 years +)

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**Competing on price**

The technical and regulatory aspects (described elsewhere) are more relevant to address this challenge however from a commercial perspective for new aquaculture the shipping costs are a big commercial barrier in competing on price. However this does also present an opportunity for domestic production (of seaweed and insect-based protein) to displace the soya and fish meal imports which are more exposed to shipping cost rises.

**Scale up**

In the short term the per unit cost will be reduced through the larger scale production and the technical and regulatory aspects to achieve this are described elsewhere. In order to scale up sustainably the sector needs to develop demand through commercialisation (of both primary product and by products).

**Consumer awareness**

Consumer education and awareness is required for products produced through these novel system to address suspicion and low consumer confidence about these food groups. The products, produced from these novel systems, like many other alternative protein sub sectors, have not had the long history of consumption which other staples enjoy. There is scope here for safety studies/biosafety studies to address this.

**Dietary shift**

Once the products from these novel systems become established in our diets (including through direct consumption) then biosafety studies would be required, e.g. Human microbiome studies, to assess any impact (positive/negative/neutral) to inform consumers.
### Challenges: Regulatory

#### Novel food regulation opaque

#### Approval of additional feedstocks

**UK regulation of protein for poultry and swine feed**

Protein feed regulation unclear

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<th>Short term (1-2 years)</th>
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<th>Very long term (10 years +)</th>
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<tbody>
<tr>
<td>• insect protein to poultry and pigs currently not permitted in the UK</td>
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<td>• insect processing regulated as a ABP activity</td>
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<tr>
<td>• all organic waste types</td>
<td>• animal by-products (ABPs)</td>
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<tr>
<td>• registering frass as a fertiliser</td>
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**New aquaculture and insect**

The use of processed insect protein in poultry and pig feed is currently not permitted in the UK. This is a big regulatory barrier to the industries growth and should be addressed through regulation in the short to medium term. The insect farming sector ask that the UK adopt sensible regulations which are harmonised with EU legislation. The sector recognise that insects fed on certain feedstocks would require ABP regulation (e.g. manure-fed insects destined for non-food/feed use) however, feed and food-grade insects grown on current feedstocks (legal) fundamentally don’t require that level of treatment and should be regulated in a framework closer to other animal protein sources with much longer histories of consumption such as dairies/butcheries. There is a need for science informed regulation, to replace the current regulatory situation which is using regulations made for other sectors which is restricting growth in this sector. ABPs = Animal by products = animal carcasses, parts of animals, or other materials (inc. manure).

**Approval of additional feedstocks**

There is a need for the regulators to approve a wider range of substrates for feedstock to address technical and commercial challenges such as access to cheaper feedstocks and realise commercial opportunities such as addressing circularity. In the short term there is a need to approve more organic waste feedstocks e.g. lignocellulose waste. In the medium term there is a need to assess the regulation of the use of animal by-products (ABPs) to help grow the sector. The regulatory framework was described by one workshop participant as “vertebrate-centric”. Science should inform regulations here with a need to robustly test for risk of manures as feedstocks for insects destined for feed and food, due to the risk of pathogen transmission and heavy metal accumulation – need for biosafety assessment here.

**Regulatory clarity for frass use**

There is a lack of regulator clarity on the main by-product of insect farming, frass (insect excrement). Frass is currently a waste product in the process and there is a cost associated with its disposal. In the short term frass could be registered as a fertiliser which will valorise this waste stream and make the process more economically viable and sustainable. Scope exists to utilise as organic fertiliser but the regulatory framework is holding the sector back from valorising this significant waste stream.
Challenges: Consumer

Affordability

Consumer acceptance

Consumer awareness

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<th></th>
<th>Short term (1-2 years)</th>
<th>Medium term (2-5 years)</th>
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<tr>
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<tr>
<td>Consumer acceptance/ awareness</td>
<td>lack of consumer awareness</td>
<td>consumer perception that accompany novel ingredients</td>
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<tr>
<td>Affordability</td>
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<td></td>
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<td>impact on cost of final product (soya fed vs. insect/seaweed fed)</td>
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There are perception challenges that accompany ‘novel’ ingredients such as seaweed and insect products (particularly if for direct consumption). To address this challenge consumer education and awareness is required together with transparency of processes and safety data. Probably more acceptance of insect protein as feed than food – this can be built upon. Vegans/vegetarians may not be happy with insect derived foods.

Cost will always be a factor being considered by farmers and consumers alike when comparing to other, cheaper sources of feed – uptake will depend on price point being right. One workshop participant highlighted that the price per kg of insect meal remains very high with the cost of cricket flour greater than a prime rib of beef by weight – this needs to be addressed through technical and regulatory aspects discussed above.
**Opportunities: Technical**

### Net-zero meat

**Diversify feedstocks**

- **Insect**
  - Diversify feedstocks: Using all organic waste types as substrate

- **Technology**
  - Fully automated production

- **Microbial control**
  - Compounds with antimicrobial properties

- **Sustainability of materials**
  - Alternatives to polypropylene

### Diversify feedstocks

There is a great technical opportunity to diversify feedstocks, if regulation permits, allowing the conversion of virtually any organic waste into insect biomass. This could revolutionise the circularity within a range of industries, beyond food & feed, while removing emission-emitting wastes from landfill. No other alternative protein strategy can turn large volumes of heterogeneous waste into valuable protein so quickly and efficiently as insects. Another technical opportunity highlighted at the workshop was using lignocellulose waste (plant dry matter) as a feedstock – further R&D will be required to make this a reality.

### Technology

The automation of insect farms is a technical opportunity that some companies in this space are already realising. In the medium term more companies will be able to automate the process by developments in this area including implementing already tested technology, designing bespoke solutions and equipment, company specialisation to address hardware market and the increasing availability of off the shelf hardware. If this opportunity is to be realised there is a need for greater buy in and involvement of machinery manufacturers which will lead to the involvement of machinery manufacturers in collaborative R&D. Currently their is a limited market so machinery manufacturers are not interested (Catch-22 situation; need public funding push/incentives).

### Microbial control

In the short term the new aquaculture sector see a huge market opportunity to expand by identifying compounds with antimicrobial effect in seaweed.

### Sustainability of materials

There is a technical opportunity to create biodegradable and marine safe alternatives to polypropylene in the short term but R&D will be required to realise this important opportunity to the sector.
Opportunities: **Commercial**

**Sustainability**

Replacement of imported meal

**Automation**  Net-zero

Partnering with agri-food supply chain

Natural alternative

Valorise by-products

Scale

Market development
## New aquaculture and Insect

**Replacement of imported meal**
- current market conditions favourable for domestic supply

**Net-zero and Sustainability**
- environmental sustainability/ carbon mitigation
- the push for net-zero and phasing out of soya
- rewarding sustainable practices of using alt protein vs. staples
- feed for ruminants and non-monogastric animals

**Market development**
- enabling more companies to diversify into the sector
- insects as food (for humans)

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### Short term (1-2 years)

In the short term the current market conditions are making domestic supply relatively more favourable over imported meal. With high shipping costs making imported product more costly there is a commercial opportunity for farmers to try alternatives including protein produced from insects and seaweed to replace soya and fishmeal. Other opportunities for this sector were identified in the prework such as replacing meal worms with black soldier fly for wild bird feed. In order to make these current market conditions longer term the industry need to address technical challenges to enable cheaper production which should make insect protein more competitive on price against imported meal. Diversifying the range of fly species for protein production was discussed as a way to compete with imported meal, however, soldier flies are currently the best performing species. Different species often have specific diets, and these diets are not always available through the currently permitted/available feedstocks. R&D required here to develop alternative species to black soldier flies for protein production.

### Net-zero and Sustainability

There is a clear opportunity already being realised in utilising food-waste for insect production and in doing so helping towards net-zero and sustainability targets. In addition to use of waste streams to produce protein, the resulting protein is also displacing less environmentally sustainable soymeal from our food system. There is a big opportunity to expand on this however in order to realise this, more government support will be required through regulatory (and policy) support.

### Market development

There is huge potential for market development for the insect sector. This will be realised through the emergence of new companies in this space which will diversify the sector. In the medium term it is expected that insects will increasingly be used in food (for humans) but in order for this commercial opportunity to be realised then regulatory challenges will need to be addressed (e.g. making the novel food process more ‘sensible’, make it easier to make food grade insect, need to remove regulatory hurdles) There will also be a need to maintain Quality Assurance. In the longer term there is an opportunity to develop insect-based and seaweed-based feed for ruminants and non-monogastric animals – this will require collaborative, multi-disciplinary research.

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### Medium term (2-5 years)

### Longer term (5-10 years)

### Very long term (10 years +)
Opportunities: **Regulatory**

**Market development into food**

**New feedstocks**

**Market development in agriculture**

**Market development beyond feed and food**

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<th>Short term (1-2 years)</th>
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<tbody>
<tr>
<td>Market development</td>
<td>• poultry and pigs</td>
<td>• insects as food</td>
<td>• shampoos, fabrics or even energy</td>
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<td>New feedstocks</td>
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<td>• broadening substrates available</td>
<td>• animal manures</td>
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<td>Use of frass as fertilizer will...</td>
<td>• ...allow rapid scaling of operations</td>
<td>• ...improve consumer acceptance</td>
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The commercial opportunities for market development of the novel systems sub sector (as outlined above) are clear but will only be realised if regulatory opportunities are addressed. For poultry and pigs: regulatory changes are required to enable wider adoption, UK regulation needs to be updated, like it has been in the EU. For insects as food: consumer education and awareness is required. For shampoos, fabrics and energy: R&D required to find novel uses. Across all of these areas there is a need to conduct biosafety studies to support regulatory changes.

There is a clear opportunity to diversify the feedstocks that the insect sector are permitted to use. Biowastes, such as animal manures, represent a potential feedstock for insects. Regulatory changes and clarity on what sources of feedstocks would be acceptable would be required by the sector to utilise these biowastes. Non-food products (e.g. consumer products, fabrics or energy) could be an alternative market opportunity for these feedstock streams. Regulatory changes and clarity are required by the sector around feedstocks.

The insect sub sector call for regulatory changes and clarity around the use of frass as a fertiliser which will allow rapid scaling of operations (Frass is currently a waste product from the process which is associated with a cost to dispose of it) and improve consumer acceptance (as it provides another sustainability story to the consumer).
Opportunities: **Consumer**

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<tr>
<th></th>
<th>Short term (1-2 years)</th>
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<th>Very long term (10 years +)</th>
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<tr>
<td><strong>Net-zero</strong></td>
<td>• respond to consumer pressure</td>
<td>• labelling of products as insect-fed</td>
<td>• help to address issue of the high carbon footprint of animal protein</td>
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<tr>
<td><strong>Consumer engagement</strong></td>
<td>• media and advertisement campaigns to increase awareness</td>
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**New aquaculture and insect**

The retailers are already responding to consumer pressure for reduced carbon products (Egg suppliers for Morrison’s using insects fed from plant-based food waste produced in supply chain) and this will continue to gather pace in the short term. In the medium term there is an opportunity to develop clear labelling to communicate the net-zero credentials and will help inform consumer choice. In the very long term there is a consumer opportunity to help to address issues of the high carbon footprint of animal protein e.g. develop a feed for ruminants that is insect-based (reducing reliance on imported soymeal) and uses red seaweed as feed additive (for methane reduction).

As insect-based food becomes more available consumer engagement will become more important; insects are perceived as more natural than lab grown meat, but still a lot to do to improve the perception. Opportunity to start consumer engagement early with children at school, families to demonstrate the benefits, media, labelling all very important. Raising awareness of insects as feed and foodstuffs. Insect protein consumption will become “more normal” in future.
Recommendations and next steps

An output from the workshop were several recommendations that were shared across the sub-sectors:

- Development of an alternative protein implementation and action plan to coordinate interdisciplinarity, integrating research into the production, processing and onward product development.

- Provide sustainable sources of funding to explore disruptive research and innovation ideas.

- Strengthen capability in the UK to deliver purposeful technology solutions.

- Assessment of the UK landscape to facilitate early engagement and consortia building with suitable industry and academic partners.

- Develop mechanisms to successfully speed up pioneering innovations through the UK market including access to finance for scale-up.

- Develop a core team for coordinating and building the UK ecosystem, providing a centralised resource accessible to all UK stakeholders.
Building on the recommendations coming from this report, a significant next step would be to support the development of a UK Alternative Protein Innovation network. This would aim to advance research and innovation for alternative protein-based food, requiring an interdisciplinary approach to combine research into production, processing and onward product development. Currently, research in this area within the UK has been conducted in a largely organic fashion. There are some initiatives from food industries, but impactful research and innovation in alternative protein-based food via public-private partnerships are scarce in the UK relative to our international competitors.

The lack of a dedicated interdisciplinary research and innovation network makes it difficult for the interested UK cohort of research leaders and innovators to collaborate and deliver transformative impact. The network would drive discovery and strategic research into alternative protein-based food innovation in the UK by pushing the frontiers of related science and technologies, uniting the UKRI partners across the food value chain and ensuring that R&D addresses market and societal needs.

The network should work as a virtual UK ecosystem to lead transformative innovation through coalescing research efforts to focus on specific market needs and industry challenges. This would complement the development of relevant incubator and accelerator programmes across the UK, which would further drive the market acceleration for alternative protein-based foods.

Implementation of the recommendations would lead to the following outcomes:

- A connected research and innovation landscape, able to take forward the breadth of collaborative R&D opportunities that the UKRI system has to offer
- Accelerated research into alternative protein improvement, with greater focus on market needs and industry challenges
- UK gains recognition as an international centre of excellence that attracts foreign direct investment into our agri-food innovation ecosystem
- Green growth opportunities for the UK bioeconomy
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<tr>
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This report captures the collective feedback of group discussions and breakout sessions and therefore does not necessarily represent the opinions or strategic priorities of individuals, companies or organisations named.
Alternative Proteins Workshop
Identifying UK Priorities

Transforming Food Production programme
Catalysing the transition to net-zero food production systems

Tom Jenkins & Andrew McLay
Transforming Food Production: Overview

- £90m funding until March 2024 to enable food to be produced in more efficient, resilient and sustainable ways
- Accelerating the development and adoption of integrated precision approaches to improve agricultural production
- Driving economic growth across the UK

Towards net zero emissions productive food systems by 2040

Transforming Food Production: Delivery

- £50m Future Food Production Systems
  Creating disruptive solutions & high value production systems
- £10m Investor Partnership
  Building a vibrant UK Agri-Tech investment ecosystem
- £25m Science and Technology into Practice
  Strengthening connections between research and practice; enabling adoption through KE & demonstration
- £5m International
  Building opportunity in partnership and driving export growth in Asia & N. America
Investment to catalyse Agri-Tech SME growth & scale-up

Series A Investor Partnership Programme

• Established £30m+ Agri-tech ‘net-zero’ fund
• £10m TFP grant to be x2 matched with equity investment
• Series A deals from Round 1
  • £22.1m funding into 7 UK SMEs (£5.6m TFP grant)
  • Investment focus included cellular protein, automation & robotics, AI and data management for pests & diseases
• International investors can lead investment rounds and build syndicates through lead investor pool
• Round 2 now closed and new deals being finalised!

https://apply-for-innovation-funding.service.gov.uk/competition/1025/overview

Investment focus on UK AP company growth

Higher Steaks

£1.02m TFP grant to support the SME in developing the UK’s first pilot plant for cultivated meat

TFP project: pilot plant for cultivated pork for sustainable food systems

Lead investor: Dismatrix Group. Syndicate with five other investors with a total Series A deal of £2.5m

MILLTRUST INTERNATIONAL

£454k TFP grant to take the pluripotent stem cell technology to next stages to serve the burgeoning cellular agriculture industry

TFP project: leading the science of sustainable protein by developing tools for cellular agriculture

Lead Investor: Future Planet Capital’s British Innovation Fund (previously managed by Milltrust). Syndicate with 12 other investors with a total Series A deal of c.£1m
Funding to support development of the UK AP sector

- Insectrial Revolution – commercial-scale insect production, combining SME expertise with leading research institutions, end-users and the UK’s largest retailer
- AGRI-SATT – large-scale algae production on non-agricultural land, mimicking natural algal blooms to cultivate local algal species rich in protein and PUFAs (DHA & EPA)
- REACT-FIRST - commercialising CO₂-to-protein for sustainable livestock feed; recently secured €8m Series A investment round

Coordination activities to support UK AP sector
Coordination activities to support UK AP sector

Aims and objectives of workshop today

• Bring together leading scientific and commercial experts across the UK Alternative Protein sector
• Discuss issues and identify opportunities and barriers to creating a globally competitive Alternative Protein sector in the UK
• Identify areas of synergy across the research-base & industry and collaboration opportunities to create new partnerships
• Establish a forum for knowledge exchange to discuss issues including technical, commercial, regulatory and consumer for mutual benefit across the Alternative Protein sector
Plant-Based

Technical: Challenges

<table>
<thead>
<tr>
<th>Functionality</th>
<th>Short 1-2 yr</th>
<th>Medium 2-5 yr</th>
<th>Long 5-10 yr</th>
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<tr>
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<td>improve and adapt techno functionality</td>
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<td>Extraction</td>
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<tr>
<td>lack of suitable varieties</td>
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<tr>
<td>Processing</td>
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<tr>
<td>scalable facilities</td>
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</tbody>
</table>

- Domestic supply of protein source
- Genetics and breeding
- Agronomy
- Nutrition
- Texture
- Processing
- Agrobiodiversity
- Cost of protein source
- Environmental benefits
- Cost in use
- Dietary diversity
- Waste
- Clean processes
- Scalable
- Fundamental knowledge
- Diversity of protein source
Technical: Opportunities

<table>
<thead>
<tr>
<th></th>
<th>Short 1-2 yr</th>
<th>Medium 2-5 yr</th>
<th>Long 5-10 yr</th>
<th>V. long 10 yr+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genetics and breeding</td>
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<tr>
<td>gene editing</td>
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<tr>
<td>breed varieties with enhanced functionality</td>
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<tr>
<td>breed varieties with enhanced health properties</td>
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<tr>
<td>genome sequencing of crops</td>
<td></td>
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<tr>
<td>Circular economy</td>
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<tr>
<td>co-product market development</td>
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<tr>
<td>engineering design</td>
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<tr>
<td>utilising waste and underutilised resources</td>
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<tr>
<td>Differentiated characteristics</td>
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<tr>
<td>nutrition</td>
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<tr>
<td>functionality</td>
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<tr>
<td>protein ingredients with enhanced characteristics</td>
<td></td>
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<tr>
<td>Diversify protein source</td>
<td></td>
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<tr>
<td>different sources of proteins</td>
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<tr>
<td>Efficient extraction methods</td>
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<tr>
<td>lower environmental impact</td>
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<tr>
<td>higher extraction yields</td>
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</table>

Commercial: Challenges

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<thead>
<tr>
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<th>Short 1-2 yr</th>
<th>Medium 2-5 yr</th>
<th>Long 5-10 yr</th>
<th>V. long 10 yr+</th>
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<tbody>
<tr>
<td>Economically viable supply chain</td>
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<tr>
<td>high cost of raw materials</td>
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<tr>
<td>profitability of farming sector</td>
<td></td>
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<tr>
<td>government subsidies</td>
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<tr>
<td>Investment</td>
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<tr>
<td>ROI to Farmer</td>
<td></td>
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<tr>
<td>infrastructure investments - farmer</td>
<td></td>
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<tr>
<td>infrastructure investments - processor</td>
<td></td>
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<tr>
<td>Flavour taints</td>
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<tr>
<td>Reduce and/or eliminate beany/earthy flavours</td>
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<tr>
<td>High costs of masking flavors</td>
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<tr>
<td>Clean label</td>
<td></td>
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<tr>
<td>products with added ingredients</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Sustainable supply chain</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>access to UK sustainable protein sources</td>
<td></td>
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</tbody>
</table>
Commercial: Opportunities

**Consumer demand**
- Diversity protein source

**Dietary shift**
- New product development
- Flavour
- Enhanced nutrition
- Affordability
- Domestic supply chain

**Circular economy**
- Allergy-free
- New market development

**Sustainability**
- Differentiated characteristics
- Market development for waste fractions

**Net-zero**

---

**Regulatory: Challenges**

**Labelling**
- Allergen
- GM
- Genetic and breeding
- Agrochemicals
- Trade

**Novel food legislation**
- EFSA approvals for emerging plant proteins
- Uncertainty relating to novel foods labelled as "novel foods" but consumed elsewhere

**Standard of identity (naming of products)**
- e.g. milk vs "mylk" / m*ck
- Ice cream vs frozen dessert

**Net-zero**
- Opportunity to fix N and reduce artificial N input
- Help achieve climate targets

**Dietary shift**
- Shift toward vegan/vegetarian diets

---

**GROWING EAT & DELI**

---

ANNEX 2 – WORKSHOP PRESENTATION SLIDES
Regulatory: Opportunities

Genetics and breeding
- Genetically modified
- Gene editing
- Genetic modification
- Reduced allergenicity
- Food ingredients with reduced or none allergenicity

Consumer: Challenges
- Education
- Sensory acceptability
- Perceived as ultra-processed
- Consumer acceptance
- Engagement
- Meat imitation
- Supply
- Affordability
- Consumer behaviour
- Cost of protein source
- Availability
- Misinformation
- Perceived as ultra-processed
- Misinformation
- Change consumer mindset
- Consumer acceptance
- Willingness of consumers to try new products
- Reluctance of wider acceptance of plant-based diet away from current diet habits
- Consumer behaviour
- Improving engagement and education
- Drive demand for healthier and sustainable option
- Sensory acceptability
- Simulate organoleptic properties
- Affordability and availability
- Sourcing/supply chains
- Price of final product
Consumer: Opportunities

Dietary shift
- Favour

Lifestyle shift
- New-zeno
- Demand

Sustainability
- Shift towards plant-based diets
- New market development
- New product development

Fermentation

<table>
<thead>
<tr>
<th>Sustainability</th>
<th>Short 1-2 yr</th>
<th>Medium 2-5 yr</th>
<th>Long 5-10 yr</th>
<th>V. long 10 yr+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate benefits associated with plant-based diets increased awareness</td>
<td></td>
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<tr>
<td>Increased awareness of healthy lifestyle improved nutrition</td>
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<tr>
<td>Shift towards plant-based/flexitarian diets wider product range is inclusive of consumer diets</td>
<td></td>
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<tr>
<td>New product development satisfy new dietary trends targeting different sectors of the population utilise plant functionality to enhance consumer experience</td>
<td></td>
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</tr>
</tbody>
</table>
Technical: Challenges

**Robust cell lines**

**Alternative cell culture media**

- **Scale-up**
  - Scaffolding technologies
  - Cost parity
  - Fundamental R&D

<table>
<thead>
<tr>
<th>Scale up</th>
<th>Short</th>
<th>Medium</th>
<th>Long</th>
<th>V. long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sufficient biomass</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative cell culture media</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replacement of animal components</td>
<td></td>
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<tr>
<td>Serum-free, but not prohibitively expensive</td>
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<tr>
<td>Currently optimized for human or mouse, not livestock</td>
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<tr>
<td>Expensive components (e.g., growth factors)</td>
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</tbody>
</table>

**Cost parity**

Delivering price parity to traditional meat

**Technical: Opportunities**

**Bioprocess technology**

- Improving efficiency of suspension growth
- Semi-continuous bioprocess for whole-cut cultivated meat
- Computational modeling of perfusion flow through scaffolds
- Computational modeling or novel bioreactor designs

**Cell culture media formulations**

- Identify cheaper sources of amino acids, e.g., plant hydrolysates
- Identify cheaper sources of growth factors
- Systematic investigation of growth factor needs and effects
- Map secretome of animal myoblasts, adipocytes, etc.
- Put the box cheaper media component solutions

**Cell line development**

- Establishment of cell line repositories
- Standardized isolation protocols

**Technical: Challenges**

**Acellular:**

**Scale-up**

- Production Functionality
- Cost parity

<table>
<thead>
<tr>
<th>Scale-up and investment</th>
<th>Short</th>
<th>Medium</th>
<th>Long</th>
<th>V. long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expansion of fermentation capacity</td>
<td></td>
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</tr>
<tr>
<td>Economical extraction of protein</td>
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<tr>
<td>Integrated biorefineries for algae, fungi, etc.</td>
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<tr>
<td>Overcoming the ‘valley of death’</td>
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</tbody>
</table>

**Production optimisation**

- How to control cell structure/metabolism during fermentation
- Productivity
- Building of robust production processes

**Cellular:**

- Robust cell lines
- Alternative cell culture media
- Scale-up
- Scaffolding technologies
- Cost parity
- Fundamental R&D

**Technical: Opportunities**

**Bioprocess technology**

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**Cell line development**

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- Standardized isolation protocols
Technical: Opportunities

**Acellular:**

**New functionality**
- **Alternative feedstocks**
  - **Cost minimisation**
  - **Precision fermentation**

<table>
<thead>
<tr>
<th>New Functionality</th>
<th>1-2 yr</th>
<th>2-5 yr</th>
<th>5-10 yr</th>
<th>10 yr+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein ingredient to challenge dairy and egg protein market</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
<td></td>
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<tr>
<td>Other functionality...</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Alternative feedstocks</th>
<th>1-2 yr</th>
<th>2-5 yr</th>
<th>5-10 yr</th>
<th>10 yr+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrates with increased sustainability and reduced cost</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>Remove dependency on corn, beet etc as source of carbon</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Precision fermentation</th>
<th>1-2 yr</th>
<th>2-5 yr</th>
<th>5-10 yr</th>
<th>10 yr+</th>
</tr>
</thead>
<tbody>
<tr>
<td>For animal-identical dairy, egg and meat proteins</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
</tr>
</tbody>
</table>

Commercial: Challenges

**Cellular:**

**Scale up**
- Cost parity
- Consumer acceptance
- Regulatory approval

<table>
<thead>
<tr>
<th>Cost parity with alternatives</th>
<th>1-2 yr</th>
<th>2-5 yr</th>
<th>5-10 yr</th>
<th>10 yr+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency/economies of scale</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scale up</th>
<th>1-2 yr</th>
<th>2-5 yr</th>
<th>5-10 yr</th>
<th>10 yr+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of capacity for demo-scale and mid-scale co-manufacturing</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
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<tr>
<td>Lack of model production facility blueprints</td>
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<tr>
<td>Lack of data sharing to inform process improvement</td>
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</tbody>
</table>

**Acellular:**

**Scale up**
- Product safety
- Lack of B2B

<table>
<thead>
<tr>
<th>Competition</th>
<th>1-2 yr</th>
<th>2-5 yr</th>
<th>5-10 yr</th>
<th>10 yr+</th>
</tr>
</thead>
<tbody>
<tr>
<td>From new alternative protein sources</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>Plant based meat alternatives competing for space</td>
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<tr>
<td>Lack of B2B options</td>
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<table>
<thead>
<tr>
<th>Scale up</th>
<th>1-2 yr</th>
<th>2-5 yr</th>
<th>5-10 yr</th>
<th>10 yr+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital investment for commercial-scale facilities</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td></td>
</tr>
<tr>
<td>Needs economies of scale to hit mainstream</td>
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</tbody>
</table>
### Commercial: Opportunities

**Cellular:** Open-access facility blueprints  
IP pooling frameworks

**Acellular:**

<table>
<thead>
<tr>
<th>Sustainable</th>
<th>Process innovations</th>
<th>High quality</th>
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<tr>
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</table>

<table>
<thead>
<tr>
<th>Process innovations</th>
<th>Developing open-access model production facility blueprints</th>
<th>Expand capacity for demo-scale and mid-scale co-manufacturing</th>
<th>Data lake for aggregating process data and informing process improvements</th>
<th>High quality and Sustainable protein for feed growing global population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>1-2 yr</td>
<td>2-5 yr</td>
<td>5-10 yr</td>
<td>10 yr+</td>
</tr>
<tr>
<td>Medium</td>
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<tr>
<td>V. long</td>
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**New product development**  
**Product innovation**

- **Creation of new supply chains**
- **Protein ingredients**
- **Beverage development**
- **Protein ingredients**
- **Consumer driven desire for alternative products**
- **Using unique characteristics to diversify products**

<table>
<thead>
<tr>
<th>Short</th>
<th>Medium</th>
<th>Long</th>
<th>V. long</th>
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</table>

### Regulatory: Challenges

**Cellular & Acellular:**

- Nutritional profile
- Freedom to operate in R&D space
- Demonstrate robust & reproducible process
- Time
- Novel food regulation
- Demonstrate food safety
- Cost
- Lack of clarity
- GM legislation

<table>
<thead>
<tr>
<th>Novel food regulation</th>
<th>Navigating approval process is time consuming</th>
<th>Cost of registration and getting new foods approved for SMEs</th>
<th>Demonstrate robust &amp; reproducible process</th>
<th>Cell derivation methods</th>
<th>Manufacturing process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>1-2 yr</td>
<td>2-5 yr</td>
<td>5-10 yr</td>
<td>10 yr+</td>
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<td>Medium</td>
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<td>V. long</td>
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</tbody>
</table>

- **Demonstrate food safety**
- Food-safe reagents used in manufacturing process
- Safety of the final formulated product

<table>
<thead>
<tr>
<th>Freedom to operate in the R&amp;D space</th>
<th>Separate regulation for testing products in R&amp;D context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>1-2 yr</td>
</tr>
<tr>
<td>Medium</td>
<td>2-5 yr</td>
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<tr>
<td>Long</td>
<td>5-10 yr</td>
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<tr>
<td>V. long</td>
<td>10 yr+</td>
</tr>
</tbody>
</table>
Regulatory: Opportunities

**Cellular & Acellular:**

Easing GMO regulations
Work with regulators

**Easing novel food regulations**

**Post Brexit opportunities**

**Easing gene editing regulations**

Clear path to market

<table>
<thead>
<tr>
<th>Post Brexit opportunities</th>
<th>Short 1-2 yr</th>
<th>Medium 2.5 yr</th>
<th>Long 5-10 yr</th>
<th>V. Long 10 yr+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freedom from EU regulation</td>
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</table>

**Easing novel food regulations**

- Make registration easy
- Use lessons learnt in other countries
- Provide clear guidance

**Easing gene editing regulations**

- Accelerate approval process of gene editing techniques

---

Consumer: Challenges

**Cellular & Acellular:**

**Consumer acceptance**

- Low acceptance of meat alternatives
- Suspicion of authenticity and likeness to existing products
- Perceptions of cultivated meat as ‘unnatural’
- Continued preference for real meat products

**Education**

- Benefits of mycoprotein over other meat alternatives
- Will consumers understand precision fermentation?
- Perception that alt. prot. is antithesis of regen ag and organics

---

**Appearance**

Nutritional equivalence
Transparency
Affordability Flavour
Consumer: Opportunities

Cellular & Acellular:

- Differentiation from highly processed alternatives
- Consumer engagement
- Labelling
- Net-zero
- Increased B2B
- Dietary shift
- Sustainability
- Health benefits
  - Improved organoleptic properties

- Consumer engagement
  - Transparency about the production process
  - Health benefits
  - Increased awareness of healthy lifestyle

<table>
<thead>
<tr>
<th></th>
<th>Short</th>
<th>Medium</th>
<th>Long</th>
<th>V. long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net zero</td>
<td></td>
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<tr>
<td>Major factor in engaging consumers</td>
<td></td>
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<tr>
<td>Consumer engagement</td>
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<tr>
<td>Transparency about the production process</td>
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<td>Health benefits</td>
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<tr>
<td>Increased awareness of healthy lifestyle</td>
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</tbody>
</table>

Novel Systems
Technical Challenges

Scale up
- Breeding expertise
- Feedstock meeting demand
- Variability of input
- Automation: Quality
- Scale-up: High Capex

Competitive on price
- Consistency of product
- Standardised processing methods
- Processing, farming & production equipment
- Knowledge

Production
- New Aquaculture Specific:
  1 - cultivation of some species (1-2yrs)
  2 - scientific trials (2-5 yrs)
  3 - alternatives to use of polypropylene in cultivation (1-2 yrs)

<table>
<thead>
<tr>
<th>Scale up</th>
<th>Short</th>
<th>Medium</th>
<th>Long</th>
<th>V. long</th>
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</thead>
<tbody>
<tr>
<td>Lack of expertise in breeding</td>
<td>1-2 yr</td>
<td>2.5 yr</td>
<td>5-10 yr</td>
<td>10 yr+</td>
</tr>
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<table>
<thead>
<tr>
<th>Competitive on price</th>
<th>Short</th>
<th>Medium</th>
<th>Long</th>
<th>V. long</th>
</tr>
</thead>
<tbody>
<tr>
<td>High capital expenditure</td>
<td>1-2 yr</td>
<td>2.5 yr</td>
<td>5-10 yr</td>
<td>10 yr+</td>
</tr>
<tr>
<td>Achieving low cost points of production needs to be price competitive to replace soy/fishmeal</td>
<td>1-2 yr</td>
<td>2.5 yr</td>
<td>5-10 yr</td>
<td>10 yr+</td>
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</table>

<table>
<thead>
<tr>
<th>Production</th>
<th>Short</th>
<th>Medium</th>
<th>Long</th>
<th>V. long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of automation</td>
<td>1-2 yr</td>
<td>2.5 yr</td>
<td>5-10 yr</td>
<td>10 yr+</td>
</tr>
<tr>
<td>Lack of available, tested machinery</td>
<td>1-2 yr</td>
<td>2.5 yr</td>
<td>5-10 yr</td>
<td>10 yr+</td>
</tr>
</tbody>
</table>

Technical Opportunities

Diversify feedstocks
- Net-zero meat
- Carbon neutral egg
- Existing technology

Bespoke technology
- Specialisation
- Fully automated production

<table>
<thead>
<tr>
<th>Diversify feedstocks</th>
<th>Short</th>
<th>Medium</th>
<th>Long</th>
<th>V. long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using all organic waste types as substrate e.g lignocellulose waste</td>
<td>1-2 yr</td>
<td>2.5 yr</td>
<td>5-10 yr</td>
<td>10 yr+</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology</th>
<th>Short</th>
<th>Medium</th>
<th>Long</th>
<th>V. long</th>
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</thead>
<tbody>
<tr>
<td>Fully automated production implementing already tested technology into the process designing bespoke solutions and equipment company specialisation to address hardware market off the shelf hardware</td>
<td>1-2 yr</td>
<td>2.5 yr</td>
<td>5-10 yr</td>
<td>10 yr+</td>
</tr>
</tbody>
</table>

New Aquaculture Specific:
1 - identify compounds with antimicrobial effect in seaweed (1-2 yrs)
2 - creating biodegradable and marine safe alternatives to polypropylene (1-2 yrs)
Commercial Challenges

Scale-up

Competing on price

| Low quality imports | Shipping costs | Unclear regulation | Government incentives | Commercialisation |

Consumer awareness

| Short (1-2 yr) | Medium (2-5 yr) | Long (5-10 yr) | Very long (10 yr+) |

Competing on price

- with existing protein sources i.e. soya
- achieving low cost points of production

Scale up

- reducing per unit cost (through high scale)
- limited by technical challenges
- commercialise

Consumer awareness

- novelty/lack of track record
- low consumer acceptance

Commercial Opportunities

Replacement of imported meal

| Natural alternative | Valorize byproducts | Sustainability | Automation |

Net-zero

Market development

Partnering with agri-food supply chain

| Short (1-2 yr) | Medium (2-5 yr) | Long (5-10 yr) | Very long (10 yr+) |

Replacement of imported meal

- high shipping costs making imported product more costly
- protein produced from insects replacing soya and fishmeal
- replacing meal worms with black soldier fly for wild bird feed

Net-zero and Sustainability

- environmental sustainability / carbon mitigation
- rewarding sustainable practices of using alt protein vs. staples
- the push for net zero and phasing out of soya

Market development

- feed for ruminants and non-monogastric animals
- enabling more companies to diversify into the sector

ANNEX 2 – WORKSHOP PRESENTATION SLIDES
Regulatory Challenges

Approval of additional feedstocks

UK regulation of protein for poultry & swine feed

ABPs

Regulatory clarity for frass use

<table>
<thead>
<tr>
<th></th>
<th>Short</th>
<th>Medium</th>
<th>Long</th>
<th>V. long</th>
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</thead>
<tbody>
<tr>
<td>insect protein to poultry &amp; pigs currently not permitted in the UK</td>
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<tr>
<td>insect processing regulated as a ABP activity</td>
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<tr>
<td>&quot;vertebrate-centric&quot; regulatory framework</td>
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<tr>
<td>approving a wider range of substrates</td>
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<tr>
<td>animal by-products (ABPs)</td>
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<tr>
<td>Regulatory clarity for frass use</td>
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<tr>
<td>lack of regulator clarity on by product</td>
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<tr>
<td>registering frass as a fertilizer</td>
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<tr>
<td>currently a waste product - with cost associated to dispose</td>
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</table>

Regulatory Opportunities

New feedstocks

Market development into food

Market development in agriculture

Market development beyond feed & food

Use of frass

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<thead>
<tr>
<th></th>
<th>Short</th>
<th>Medium</th>
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<tbody>
<tr>
<td>poultry &amp; pigs</td>
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<tr>
<td>insects as food</td>
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<tr>
<td>shampoos, fabrics or even energy</td>
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<tr>
<td>challenging polluting substrates like animal manures</td>
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<tr>
<td>regulating the end use depending on what the insect was grown on</td>
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<tr>
<td>regulatory clarity will allow rapid scaling of operations</td>
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<tr>
<td>use of frass as a fertilizer will improve consumer acceptance</td>
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</table>
Consumer Challenges

Affordability

Consumer acceptance

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<tr>
<th></th>
<th>Short (1-2 yr)</th>
<th>Medium (2-5 yr)</th>
<th>Long (5-10 yr)</th>
<th>V. long (10 yr+)</th>
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<tbody>
<tr>
<td>Consumer acceptance</td>
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<tr>
<td>consumer perception</td>
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<tr>
<td>of novel ingredients</td>
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<tr>
<td>consumer perception</td>
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<tr>
<td>of insects as feed</td>
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<td>stigma</td>
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<td>Affordability</td>
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<td>uptake will depend</td>
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<td>on price point</td>
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<td>(relative to other</td>
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<td>feed)</td>
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<td>impact on cost of</td>
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<td>final product</td>
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<tr>
<td>(soya fed vs. insect</td>
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<td>fed)</td>
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<tr>
<td>Consumer awareness</td>
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<tr>
<td>lack of consumer</td>
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<tr>
<td>awareness</td>
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Consumer Opportunities

Net-zero

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<tr>
<th></th>
<th>Short (1-2 yr)</th>
<th>Medium (2-5 yr)</th>
<th>Long (5-10 yr)</th>
<th>V. long (10 yr+)</th>
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<td>Net-zero</td>
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<td>alternative for</td>
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<tr>
<td>farmers/retailers</td>
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<td>in response to</td>
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<td>consumer pressure</td>
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<tr>
<td>opportunity for</td>
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<td>retailers to become</td>
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<td>pioneers/lead the</td>
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<td>field</td>
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<tr>
<td>labelling of products</td>
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<td>as insect-fed</td>
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<td>potential to be</td>
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<td>lowest footprint</td>
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<td>animal protein on</td>
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<td>the market</td>
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<td>Consumer engagement</td>
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<tr>
<td>Increasing consumer</td>
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<td>awareness through</td>
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<td>media and</td>
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<td>advertisements</td>
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</table>
Research capabilities and resources through Growing Kent & Medway

Supporting the UK alternative protein sector

Networking & research facilities - Growing Kent & Medway

University of Kent
School of Biosciences; Canterbury-Kent

**Fungal Biology**
(10 Research Groups)

- Human pathogens
- Saccharomyces cerevisiae
- Filamentous fungi
- Budding yeast
- Plant pathogens
- non-convivial

**Industrial Biotechnology**
(7 Research Groups)

- Antibody
- Fermentation
- Bio-Pharmaceutical
- Vaccine
- CHO Cell Culture
- Synthetic Biology
- Natural Products

https://www.kent.ac.uk/biosciences

A.Buscaino@kent.ac.uk
in/alessiabuscaino

Alessia Buscaino
University of Kent
School of Biosciences; Canterbury-Kent

Novel Fungal Strains Selection
Genomics
Proteomics
Metabolomics
Fermentation
Protein Expression and Purification

https://www.kent.ac.uk/biosciences
A.Buscaino@kent.ac.uk
in/alessiabuscaino

Yeast biocatalyst for safe, animal free high-value protein production

A.Buscaino@kent.ac.uk
in/alessiabuscaino
## Facilities

- 2 major research centres
- UK-wide field trials
- Glasshouses
- Growth rooms
- Cold stores
- Speed breeding
- GM containment
- Insectary
- Spore-proof pathology suite
- Analytical Services
- Molecular biology
- Fermentation facilities
- Barn 4 bio-incubator
- Eastern AgriTech Innovation Hub
- GreenTech Hub
- Crop Science Centre

### Protein4NetZero

#### NPD FACILITY (food grade)
- Air classified fractionator
- SCF extraction
- High pressure homogeniser
- Advanced drying facilities (SD, DD, FBD, VFD)
- Twin-screw extruder
- 3D printer
- Bioreactors & raceway ponds
- CEM Fat analyser
- Centri-GCxGC-ToF MS

#### Key equipment
- NPD FACILITY (food grade)
- ALGAE BIOTECHNOLOGY
- Flavour & sensory analysis
- Food accelerator programme
- New facilities are coming up

### Research focus

- Extraction
  - Eco-innovative extraction of plant and algal proteins

- Processing
  - Improved protein functions via sustainable processing

- Organoleptic
  - Science unlock to create optimal organoleptic attributes

- Clean label
  - Innovate clean label formulation for plant-based food

### Current projects (2021 –)

- **Algae**
  - Algae for taste
  - Seaweed protein extraction

- **Upcycled**
  - Upcycled plant proteins for meat and cheese alternatives

- **Legume**
  - Improving quality of fava bean protein concentrate

Contact: p.acharya@greenwich.ac.uk
ANNEX 3 – RESEARCH CAPABILITIES AND RESOURCES THROUGH GROWING KENT & MEDWAY

### Capabilities

- Trait discovery / prebreeding / breeding
- Pathology & entomology
- Crop modelling & physiology
- Genomics & bioinformatics
- Quantitative genetics & statistics
- Biochemistry
- GM & gene editing
- Micropropagation
- Remote phenotyping
- Image analysis & machine learning
- Agronomy & Farming Systems
- Contract trials
- Training
- Knowledge exchange & outreach
- Statutory work: variety testing, seed certification, seed testing

### Crops

**Legumes**
- Faba bean
- Pea
- Grasspea
- Chickpea
- Lentils
- Soybean
- Phaseolus

**Others**
- Wheat
- Oilseed rape
- Barley
- Potato

**Mycoprotein**
References


4. UK Health Alliance (2020) ALL-CONSUMING: BUILDING A HEALTHIER FOOD SYSTEM FOR PEOPLE AND PLANET. All-Consuming Build a Heal food Syst people planet

5. Geijer T, Gammoudy A (2020) Growth of meat and dairy alternatives is stirring up the European food industry. ING Res 20

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