Industrial biotechnology

Strategic roadmap for standards and regulations

Report

Industrial Biotechnology Leadership Forum

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Introduction

This report by the British Standards Institution (BSI) presents a strategic roadmap for the development of standards and regulations as an enabling framework for UK Industrial Biotechnology (IB). It has been commissioned by Innovate UK in consultation with the Industrial Biotechnology Leadership Forum (IBLF) in order to support the acceleration of IB as a contributor to CO_2 emissions reduction and to attaining the UK's legislated target of net zero greenhouse emissions by 2050.

The focus of the roadmap is on opportunities for action and results in the short to medium term, which is defined here as the next 3-5 years. Opportunities include those in sectors and applications which hold the greatest potential for IB-enabled CO_2 reduction within this short timeframe. The roadmap also addresses the imperatives for achieving greater traction for IB as a whole in the next few years, including where more material results and impacts in terms of CO_2 reduction and economic value are likely to require a longer horizon. Much is achievable in 3-5 years that will lay the foundations for the UK's ability to capitalize on its world class science and optimize innovation and value from IB as a pivot towards a more sustainable economy.

Five key sectors of IB application were covered in the scope of this project as a lens for exploring opportunities and challenges: agritech, biofuels, fine and speciality chemicals, plastics and textiles.

The findings and recommendations are based on primary research conducted between April and August 2020, in combination with desk research on the relevant standards and regulatory landscape. In-depth interviews were conducted with IB stakeholders and subject matter experts from over 50 organizations, representing a cross-section of sectors, technologies, maturity stages and domain expertise. These explored the opportunities for IB growth, the challenges faced, and the potential role of standards and regulations in overcoming roadblocks and as a lever for IB momentum. The list of organizations which participated in in-depth interviews is shown in the appendix to this report.

The roadmap sets out recommended action areas for standards and regulations within an overarching strategic framework for the development of industrial biotechnology, with consideration given to the surrounding context, benefits, implementation paths and timescales.

Objectives and method

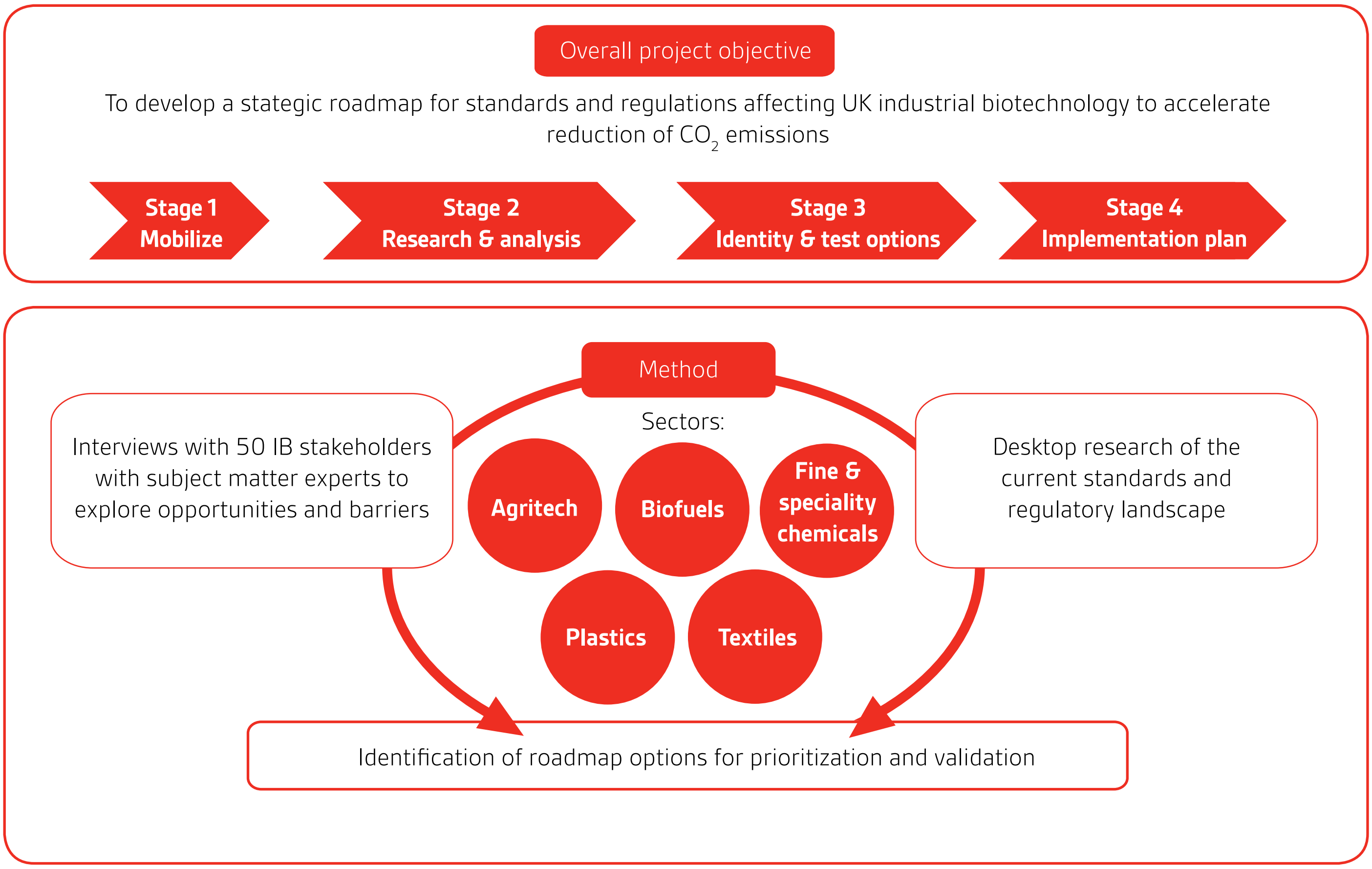


Figure 1

Industrial biotechnology

Industrial biotechnology involves the exploitation of biological resources for the processing and production of enzymes, chemicals, materials and energy. It is recognized as a key enabling technology that can contribute to addressing major societal challenges, through the use of sustainable alternatives to fossil fuels for the manufacture of everyday products, as well as for the discovery of breakthrough methods and pathways to achieving entirely new functionalities and performance. IB has already delivered considerable benefits to the UK through products ranging from antibiotics and vaccines, to biofuels, food and feed, and plastics, as well as through recycling of wastes and reduced energy consumption for the manufacture of chemicals and other materials.

In recent years, the development of synthetic biology to further drive novel solutions and provide platform technologies to enable IB has seen significant interest and gains in commercial potential. Synthetic biology is an interdisciplinary scientific field that is considerably synergistic with industrial biotechnology, and IB users will undoubtedly benefit as early adopters of this nascent industry. The hallmark of synthetic biology is its application of engineering principles to biology in order to enable the design and synthesis of biologically based parts, novel devices and biological systems, all of which are today underpinned by rapid advances in genetic and computational technologies, which are boosting development of powerful gene engineering capabilities, while lowering the costs of DNA synthesis and sequencing. It creates step changes in the development of products to keep pace with socioeconomic needs and add value to current IB offerings – and for this reason, the opportunities and development needs for synthetic biology are integral to the IB roadmap.

The breadth of products and markets where IB can be deployed is a defining strength, yet IB is seldom recognized by consumers and stakeholders outside its immediate value chains or user markets, due to its status of an underpinning technology than an end product. This profile makes the impact of IB to the UK economy hard to quantify, as it is embedded in the toolkits of manufacturing industries. Its value is, however, potentially much higher than the £3.7bn of revenue estimated in 2017 [1], which contrasts with the £17.2bn 2014 turnover for industrial biotechnology and bioenergy estimated in the 2016 **Evidencing the Bioeconomy**[2] report. Whatever the actual figure may be, the UK has for decades been a global leader in investing and excelling in the discovery of IB technologies, as well as in the development of an active, connected and collaborative industry-academic community needed to speed up innovation and commercialization.

So, where are IB products found in our everyday lives? One of the biggest areas is biofuels. These are fuels derived from renewable resources, such as sugars (ethanol) and vegetable or animal oils and fats (diesel), which are then blended into regular fuel, which is why they largely go unseen by those who use them. Another large-scale application is in the production of biological washing powders and liquids. Here, it is the inclusion of enzymes such as proteases that breakdown proteinaceous materials, lipases that degrade fats, amylases for starch, and cellulases that get to work on a grass stain that together give rise to the 'biological' descriptor. And it is thanks to new enzymes (biocatalysts) that can work at much lower temperatures, such as 15oC, that we no longer need a 40oC + wash to get clothes clean.

"Industrial biotechnology has been in use for literally centuries. But it is the last few decades where it has been used to great effect, to make medicines, fuels, food, chemicals and much more. Certainly, IB is ubiquitous in industry nowadays, but it can be difficult to quantify the value of IB to the UK and showcase the benefits of the technology when it is simply one tool in a company's toolbox of technologies."

[1] http://carbonrecycling.net/wp-content/uploads/2018/04/RSM-Industrial-Biotechnology-Landscape-Report-Summary.pdf

[2] https://bbsrc.ukri.org/documents/1607-evidencing-the-bioeconomy-report/

Increasingly, IB is set to become part of our daily lives, whether in:

- The specialty enzymes used in our food and beverages
- The biopharmaceuticals that are increasingly being used to treat a range of illnesses including cancers, arthritis and dermatological conditions
- The alternative raw materials and chemistries in our personal care products, or
- The bio-based technologies that sustain our agri-food production chains.

Industrial biotechnology is strategically important as a key enabler and integral component of a vibrant UK economy. The bioeconomy, which in 2014 was estimated to contribute £220bn GVA to the UK economy and support over 5 million jobs[3], represents the economic potential of using the power of bioscience, biotechnology and renewable biological resources to replace fossil derived feedstocks in the development of innovative products, processes and services. IB is a linchpin of this, with its expanding suite of novel platform technologies that offer alternative routes to producing existing chemicals or materials, as well as to creating entirely new products with superior performance and properties. IB technologies will therefore be critical to achieving the ambitious target of doubling the bioeconomy between 2018 and 2030, by delivering step change innovations and attracting inward investment through leveraging the UK's world class research capabilities.

IB is an area of truly transformative opportunity, with far-reaching impacts and benefits. It has the potential to remodel entire supply chains. It opens a new window to the future for industries where the UK is already strong, such as fine and specialty chemicals, while its disruptive solutions in areas from agritech to aviation fuels provide foundations on which innovative new industries can evolve.

Its strategic value also lies in its ability to be deployed across all regions of the UK where there is evidence of the bioeconomy, including rural and coastal areas, as a leveller of economic growth.

It is no exaggeration to say that industrial biotechnology is poised for expansion that will grow the economy, create high value jobs, contribute to net zero targets and deliver new solutions for some of our most pressing global issues. But at the same time, there is a risk of being too easily swept along by a compelling, positive narrative. **The ability of UK IB to capitalize on its position of relative strength and opportunity is no foregone conclusion, as many obstacles still remain.** IB is a glass half full, an industry on the cusp – but equally one with much to lose if the moment is not seized now.

The **National Industrial Biotechnology Strategy to 2030**[4], which was published in 2018, recognized that there are a number of challenges in policy, innovation, infrastructure, skills and communication in particular that need addressing in order to secure the UK's position at the vanguard of adopting IB as 'Business as Usual' across a wide range of sectors. One of these is the need to develop and implement standards and regulations that support high risk innovation by providing confidence to researchers, manufacturers and consumers, and by creating the frameworks for market uptake. This roadmap in this report places its recommended actions for standards and regulation in the context of the strategic imperatives that will together secure future UK IB success.

Industrial biotechnology towards net zero

Industrial biotechnology is a key enabler of decarbonization and the driving force for a strong and vibrant bioeconomy. Its transformative technologies have the potential to change our relationship with the resources we use and to open up entirely new headroom for inspiring solutions that improve our lives. **IB can reroute our untenable linear patterns of extraction, manufacture and consumption, which are today based largely on fossil fuels, into new paradigms of circularity, resource conservation and emissions reduction that are both economically and environmentally sustainable.** By so doing, it provides the responsible answer to some of society's most pressing challenges and expectations. Just as vehicle electrification and renewable energy are transforming their respective areas, industrial biotechnology reimagines the way we make things; and we are today still only witnessing the beginning of the step changes in manufacturing that it makes possible.

When we leave fossil carbon undisturbed and underground, by switching to the use of alternative, renewable bio-based feedstocks from plants or waste, we move to shorter carbon cycles without introducing new CO_2 into our atmosphere. By extending this benefit using biotransformation in industrial processes, our production of materials becomes less energy-and emissions-intensive. And once those materials can themselves be biologically recycled, we further reinforce a virtuous circular loop. Across its diversity of technologies and processes, industrial biotechnology is capable of achieving all of these things. Furthermore, IB not only helps reduce greenhouse gases (GHGs) up to the factory gate, but over the entire cradle-to-grave, or indeed cradle-to-cradle life cycle of products in use, in a way that amplifies the environmental benefits. And with IB-enabled technologies that are able to provide for carbon sinks and sequestration, another key piece of the toolkit for reducing our overall net GHG emissions falls into place. All of these make IB integral to the net zero arsenal.

[3] https://bbsrc.ukri.org/documents/1607-evidencing-the-bioeconomy-report/

[4] https://www.bioindustry.org/uploads/assets/uploaded/d390c237-04b3-4f2d-be5e776124b3640e.pdf

This roadmap does not offer a quantified, sequenced prediction of the overall CO_2 reduction that is achievable through industrial biotechnology, as comprehensive data simply is not available right now. Despite its millennia of history, IB is still characterized as an emerging space across the plethora of uses which have appeared only since the twentieth century, since it has expanded beyond its footprint of previous centuries in food and drink production. This early maturity stage is reflected in a relative absence of empirical evidence frameworks and collated impact measurements at an overarching or sector level. Indeed, developing these tools and methods is one key area of focus in the recommendations in this roadmap. In the absence of available, readable data at an overarching level, the opportunities for industrial biotechnology to support CO_2 reduction are evaluated across the five sectors included in the scope of this project on a relative and comparative basis, informed by desk research, industry sources, and the extensive analysis and qualitative feedback from many stakeholders and subject matter experts.

IB sector CO_2 reduction opportunity in 3-5 years

Biofuels and agritech hold the most prospect for CO_2e reduction in 3-5 years, but other sectors can also gain important traction

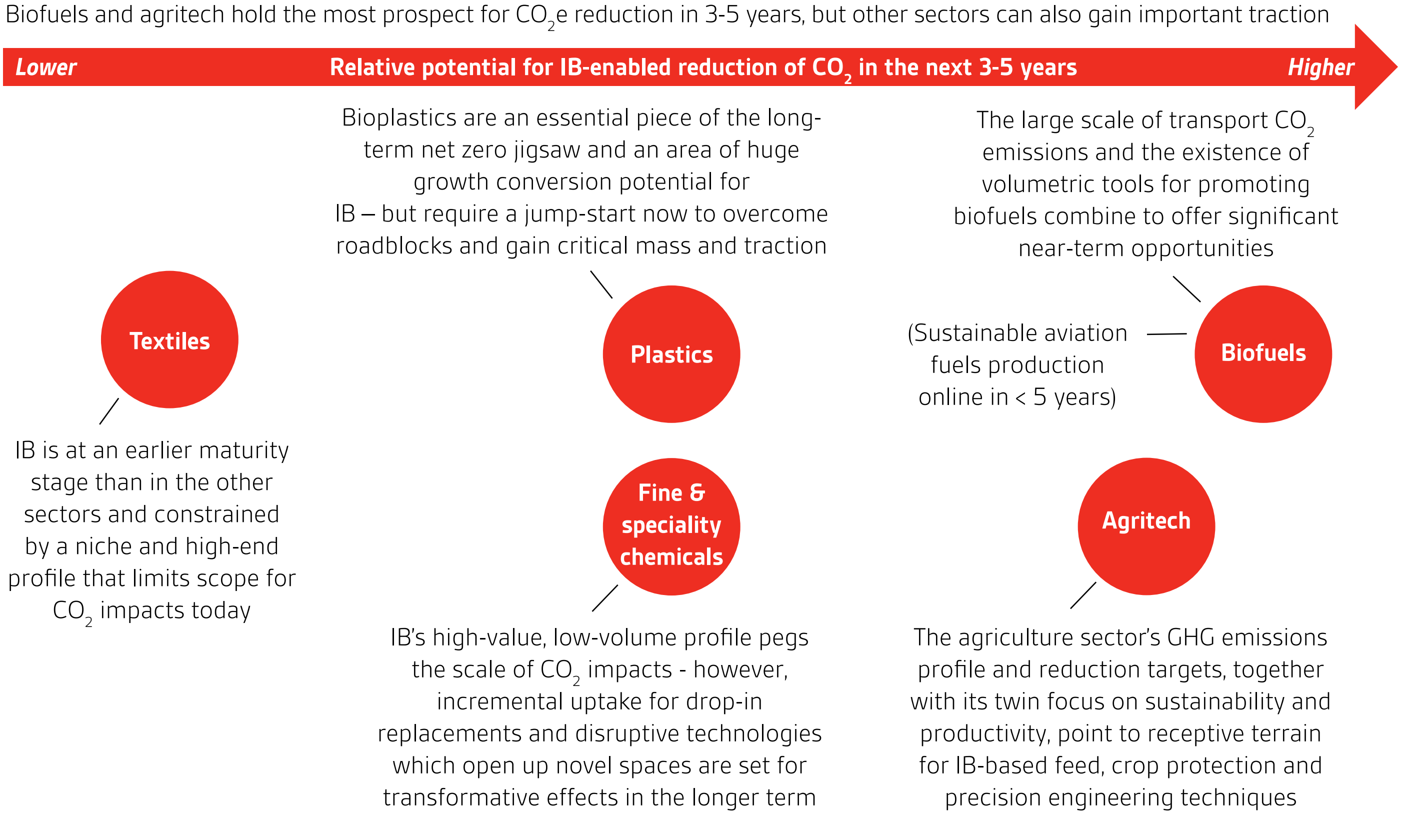


Figure 2

"The expectation of huge greenhouse gas reductions from a single technology is out of kilter with what actually is seen. The way that this is going to happen is a whole scale change of small tunings or processes that individually appear to make a small change, yet overall make a significant difference."

Industrial biotechnology and the UN Sustainable Development Goals

UK industrial biotechnology activities support the wide range of social, environmental, and economic needs defined by the UN Sustainable Development Goals (SDGs). The SDGs are described as "the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including those related to poverty, inequality, climate, environmental degradation, prosperity, and peace and justice." A significant number of multinational businesses and governments use the SDGs as the basis for their action plans and sustainability programs, as they are endorsed by a wide range of credible stakeholders and incorporate impact areas that intersect with the organizational activities of businesses and government bodies globally. The range of impacts that the UK IB arena has the potential to help advance are outlined in the following table:

Opportunities to advance development goals

	Contributing sectors	Opportunities to advance development goals	Impacted targets
2 ZERO HUNGER	Agriculture	• Contributions to agritech support improved crop yields and efficacy of animal feeds giving rise to improved livestock health. • IB enables the use of waste as feedstock for bio-based products reducing pressure on natural resources.	2.1, 2.2, 2.3, 2.4,
3 GOOD HEALTH AND WELL-BEING	Fine & Specialty Chemicals, Agriculture, Fuels, Plastics	• Creation of new medicines, vaccines and healthcare products • Reduced reliance on petroleum-derived fuels, chemicals and plastics reduces pollution and improves environmental impact on human health • Climate impact improves health outcomes of vulnerable populations	3.9
6 CLEAN WATER AND SANITATION	Fine & Specialty Chemicals, Agriculture, Plastics	• Reduced petroleum-derived plastic waste in waterways improves access to clean water • Reduced water consumption through use of enzymes and IB products resulting in less processing steps and less hazardous by-products in agriculture, chemicals and textiles • Bio-based chemicals replace persistent petroleum-derived chemicals that persist in watersheds	6.1, 6.3, 6.6, 6.B
7 AFFORDABLE AND CLEAN ENERGY	Fuels	• Biofuels support displacement of carbon-intensive petroleum-derived sources of energy, reducing greenhouse gas emissions	7.1, 7.2, 7.A, 7.B
8 DECENT WORK AND ECONOMIC GROWTH	Fine & Specialty Chemicals, Agriculture, Fuels, Plastics	• Supporting growth of emerging new innovation and startup companies creates high value UK jobs in emerging industries and fosters ongoing skills development	8.1, 8.2, 8.3, 8.4, 8.5
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Fine & Specialty Chemicals, Agriculture, Fuels, Plastics	• Supports investment and development of new scientific innovations to create a circular economy based on IB solutions • Supports development of municipal and private-sector infrastructure needed to capture value and resources from waste with long-term ambition for fossil carbon free and net zero	9.1, 9.2, 9.3, 9.4, 9.5, 9.B
11 SUSTAINABLE CITIES AND COMMUNITIES	Fine & Specialty Chemicals, Agriculture, Fuels, Plastics	• Supports symbiotic relationships between communities and local ecosystems, providing IB solutions for municipal solid waste management • Enables local value production, clean energy production, renewable materials, and protected environmental resources through local economic activity	11.3, 11.5, 11.6, 11.A, 11.B
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Agriculture, Plastics	• Embeds circular economy principles into multiple sectors, municipal activity, economic activity to enable significant capture of resources from waste • Reduces biological sources of waste, such as food, municipal, agricultural and industrial waste, and their associated GHG emissions • Bio-based products have the novel properties consumers seek with reduced environmental impact	12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.C

Agriculture   Fine & Specialty Chemicals   Fuels   Plastics

13 CLIMATE ACTION	• Reduces GHG emissions through multiple pathways, supporting UK's Net Zero goal • Improves environmental resilience, soil health and water retention by displacing overuse of petroleum-derived fertilizers and chemicals with bio-based alternatives and naturally-derived compost	13.1, 13.2
14 LIFE BELOW WATER	• Reduced petroleum-derived plastic waste in waterways improves water health and impact on aquatic life • Reduced introduction of petroleum-derived chemicals into waterways reduces presence of long-term persistence of harmful substances that damage aquatic life	14.1, 14.2, 14.3
15 LIFE ON LAND	• Supports biodiverse ecosystems by reducing introduction of harmful petroleum-derived materials and chemicals • Contribution to GHG reduction reduces extreme climate impact to biodiverse ecosystems • Supports biodiversity through displacement of petroleum-derived chemicals with bio-based alternatives and naturally-derived compost	14.1, 14.2, 14.3
17 PARTNERSHIPS FOR THE GOALS	• Provokes collaboration to develop multi-sectoral systems supported by a diverse range of local and global communities, companies, governments, and civil-society organizations. • IB provides solutions to increase resource efficiency and productivity and will contribute significantly to sustainable development.	17.1

Figure 3

Sector profile: biofuels

Biofuels are essentially liquid or gaseous fuels derived from biomass. The most widely produced are biodiesel and bioethanol, with others including methanol, dimethyl ether and liquid synthetic hydrocarbons. Biofuels are further characterized by generation: first-generation fuels are made from sugar, starch or vegetable oils; second-generation or advanced biofuels are manufactured from non-food sources of biomass, such as agricultural and forestry residues, material crops, municipal solid waste or algae.

The UK's biofuels production landscape currently comprises six biodiesel plants, three bioethanol sites, and several early-stage projects that use a gasification route from municipal or industrial waste to produce advanced fuels, such as aviation fuels, or that make biofuels from plant and forestry biomass. In addition, research is well underway to look at milder processing and enzymatic conversion of biomass.

Biofuels production peaked in 2017 at 742 thousand metric tons of oil equivalent[5]. And although the sector holds strong potential, it is regarded as having historically under-delivered against early expectations: a combination of policy effects and uncompetitive pricing versus crude oil and international fuels producers is today seen to be reflected in mothballed plants and import reliance.

Of the sectors covered in this roadmap, biofuels are widely viewed as offering the most significant near-term opportunity to leverage UK industrial biotechnology capabilities to advance net zero goals. This stems from a combination of, firstly, the scale of the emissions reduction opportunity – since road transport accounts for around a fifth of total UK GHG emission[6], and secondly, the availability of volumetric tools for developing the market through the Renewable Transport Fuels Obligation (RTFO) and the specified blend levels of biodiesel and ethanol used in diesel and petrol. It is estimated, for example,

[5] https://www.statista.com/statistics/332504/biofuels-production-in-the-united-kingdom-uk/

[6] https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/ukenvironmentalaccounts/2020

that moving to E10 petrol (containing up to 10% ethanol), in conjunction with an increase to the RTFO's biofuel supply targets, could cut overall transport CO_2 emissions by a further 750,000 tonnes per year – the equivalent to taking around 350,000 cars off the road[7]. And while the main opportunities are for biofuels in on-road vehicles, these same tools can drive GHG reduction across other categories including agricultural equipment and inland waterway vessels.

The impact of biofuels in terms of CO_2 reduction is well-recognized and is reflected in government data collected as part of the RTFO, which shows that biofuels offered an average GHG savings of 82%, when compared to fossil fuel use (and 77% when accounting for indirect land-use change)[8].

A longer-term and enduring contribution to UK net zero goals is also achievable via sustainable aviation fuels (SAFs) produced for the UK aviation sector, whose gross emissions accounted for 7% of the total UK carbon emissions in 2017[9]. While technically challenging to produce at scale, these development fuels fit the UK's long-term strategic needs and are an area warranting support, particularly as the aviation sector is an intrinsically harder decarbonization target, with less headroom for electrification than automotive. In 2020, Sustainable Aviation created the **Sustainable Aviation Fuels Road-map**[10], which showed that UK aviation can accommodate significant growth to 2050, without a substantial rise in CO_2, through an increase in aircraft standards and sustainable fuels. Although SAFs will make a smaller contribution to net zero within an immediate 3-5-year timeline, the first plants with significant capacity have the potential to be online and producing within this period. The strategic value of supporting this sector is also as an early move towards the UK's own greater fuel resilience and reduced reliance on jet fuel imports, which currently make up 70% of volumes. In addition, investing in SAF capability offers significant economic prospects. Sustainable Aviation have estimated that, in 2035, there may be between 14.5 and 30.9 million tonnes per year of SAF produced globally, and that the development of domestic production capacity could generate a gross value added (GVA) of up to £742m annually and support up 5,200 UK jobs by 2035.

Biofuels companies experience many of the challenges seen across other industrial biotechnology application areas, but with prominent concerns focusing on suitable large volume feedstock access, high development and infrastructure costs, and uncertainty in a market where the fluctuating crude oil price impacts on commercial viability. The advancement of UK biofuels production and market adoption is dependent on a commercial environment supported by targeted regulations, standards, tax policy and investment. In particular, the areas for action outlined in this roadmap for the growth of biofuels include a move to progressively higher biofuels blend levels, and further supportive interventions through the RTFO. They also address the need to facilitate access to feedstocks with the volumes, quality and characteristics that are essential to achieving the sector's potential, whether from crops, municipal waste or other sources of biomass. Across all biofuels, and notably for aviation fuels, the recommendations further include targeted support to de-risk technology through open-access pilot capabilities and demonstration facilities at scale.

Concerted initiatives that optimize the potential of UK biofuels production towards net zero goals do so by creating the headroom for capacity recommissioning and the conditions for investment in new routes to production. For industrial biotechnology, the strategic value of this goes beyond the fuels themselves: in a supply and value chain that somewhat mimics the petroleum industry, **a thriving UK biofuels production sector will also help to create the valuable by-products and intermediates that are the backbone of a sustainable IB capability in value-added chemicals manufacture**.

"The biggest CO_2 savings on paper in 3-5 years are going to be from biofuels just because of the speed at which you can ramp up the inclusion of both biodiesel and bioethanol."

[7] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/876383/introducing-e10-petrol-consultation.pdf

[8] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/782482/rtfo-year-10-report-6.pdf

[9] https://www.sustainableaviation.co.uk/wp-content/uploads/2020/02/SustainableAviation_CarbonReport_20200203.pdf

[10] https://www.sustainableaviation.co.uk/wp-content/uploads/2020/02/SustainableAviation_FuelReport_20200231.pdf

Sector profile: agritech

Simply put, agritech is defined as technologies used in primary food production to improve productivity and efficiency. industrial biotechnology and synthetic biology form part of a suite of technologies that are shaping the sector of the future, where their opportunity for contribution centres on the three key areas of:

- Bio-based crop protection solutions that displace conventional technologies in applications such as herbicides, insecticides, fungicides, adjuvants, growth stimulators and fertilizers
- Innovative IB-based animal feeds and feed additives such as novel proteins (especially single-cell proteins), probiotics and feed enzymes, which substitute traditional feed types and sources
- Use of precision biology techniques, such as genome editing, for the engineering of new crops strains with targeted benefits supporting innovative farming systems and productivity

Production of alternative food types via bioprocesses for human consumption is an additional strategic direction in the long-term but falls outside the boundaries of agritech, since it circumvents the actual farm gate.

The agritech space represents a prime area of opportunity for IB to contribute to CO_2 reduction, and with good traction achievable in the next 3-5 years. This is firstly a reflection of the overall GHG emissions profile of the farming sector. It accounts for 10% of the country's total emissions, producing 45.6 million tonnes of carbon dioxide equivalent (CO2e) a year, of which half is methane[11]. Across its three key areas on contribution, IB has the potential to reduce this significantly through a combination of impacts which include the displacement of traditional fertilizer technologies, a reduction in methane from ruminants, improved carbon sequestration performance and the supplanting of carbon-intensive feeds such as soya and fishmeal, which are mostly imported materials. The opportunity is amplified by the fact that IB-enabled benefits align squarely with the agriculture sector's productivity challenge, making it integral to the sector's ability to address its climate targets without compromising domestic production, and to the establishing of a credible narrative for agricultural best practice.

[11] https://www.nfuonline.com/nfu-online/business/regulation/achieving-net-zero-farmings-2040-goal/

Innovative IB-based animal feeds and feed additives, for example, can bring multiple advantages in terms of feed conversion rates and better animal health, which improve farming productivity alongside the optimization of land use and a lowering of both direct and indirect GHG impacts. They therefore support an overall strategy for UK producers to benefit from the value-added attributes of sustainable meat, as a means of differentiation and alignment with changing consumer preference.

Gene editing is today an untapped technology for UK agriculture, yet one which also plays strongly to the sector's twin productivity and environmental goals. It offers a route for speed and precision in the development of crops with characteristics that raise yields, while simultaneously reducing requirements for conventional crop protection chemicals and fertilizers. Its potential to drive wide-reaching innovation in farming systems is further seen in crop strains that can be developed to grow on marginal land, improve rates of atmospheric carbon sequestration, enhance the quality of the soil microbiome, or provide biogenic feedstocks for the production of biofuels and the next-generation of bio-based chemicals. However, while gene editing technology aligns with the GHG reduction and commercial agendas of the UK agricultural sector, it remains a latent resource since the practice was blocked in the EU, including the UK, following a Court of Justice of the European Union ruling in 2018.

The agriculture sector's early adopter profile, combined with its productivity drive, make for a receptive target for industrial biotechnology and synthetic biology. Further positive momentum for both technologies is provided by the goal set in 2019 by The National Farmers Union (NFU) of reaching net zero GHG emissions across the whole of agriculture in England and Wales by 2040[12], and where the bioeconomy contributes to one of the three strategy pillars for achieving this.

The way forward for IB in the agritech sector is addressed across many of the action areas presented in this roadmap, including those which aim to accelerate innovation and uptake through adaptive approval processes, tools for validating impacts, and evolving standards portfolios that are frameworks for future growth. In addition, the major current obstacle for synthetic biology is considered, reflecting the strong case for taking gene-editing techniques out of the scope of future UK GM regulation, subject to a detailed consultation, in order to unlock this key area of potential for expediting new technologies to improve UK agriculture outputs.

"So, what you're actually looking at is a full sustainability argument that says not only are we actually reducing net emissions, we're also contributing to stopping unsustainable practices in terms of intensive farming or damaging the environment."

[12] https://www.nfuonline.com/nfu-online/business/regulation/achieving-net-zero-farmings-2040-goal/

Sector profile: plastics

Bioplastics encompass a range of materials which differ from conventional plastics by being either bio-based, biodegradable, or featuring both properties in combination. Bio-based plastics are those made partly, or more pertinently entirely from materials derived from biogenic feedstock sources, including corn, sugarcane/beet, or lignocellulose. It is these bio-based plastics that define the sector from an IB perspective:

- Plastics that are both bio-based and biodegradable, such as polylactic acid (PLA) and polyhydroxyalkanoates (PHA), can be organically recycled using industrial anaerobic digestion and/or composting. There are significant opportunities for compostable bioplastic materials to be used in packaging/products that are in contact with food, since they can be collected and organically recycled together with food waste in a recovery solution that minimizes residual waste streams.
- Bio-based or partially bio-based non-biodegradable plastics, such as bio-polyethylene (bio-PE) and bio-polyethylene terephthalate (bio-PET), are drop-in replacements with properties that match their fossil fuel-based counterparts found in high-volume applications. They are technically equivalent and are suitable for use in the same applications, and for mechanical recycling via existing recycling streams.

Despite their variety, technical performance and potential benefits, bioplastics have so far globally only made a very small dent in the overall dominant position of fossil-derived polymer technologies. Although global production capacity of bioplastics stood at 2.11 million tonnes in 2019, the bioplastics sector still only represents less than 1%[13] of all plastics produced and is consequently still characterized as a nascent sector. Its strategic importance for industrial biotechnology is therefore in terms of the huge conversion growth potential. As the global sector approaches an inflection point, it is essential that the UK rapidly consolidates and then expands its footprint in the emerging bioplastics space, in order not to lose out in the technology ownership race, and to future proof a UK plastics industry which in 2017 had turnover of £27 billion and employed 170,000 people[14].

The priority of the plastics sector as a decarbonization target is borne out by its global scale and an ongoing level of dependency. If the current strong growth of plastics usage continues as expected, plastics will account for 20% of total global oil consumption and 15% of the global annual carbon budget by 2050 (the budget that must be adhered to in order to achieve the internationally accepted goal to remain below a 2°C increase in global warming)[15]. In 2019, global production and incineration of petroleum-derived plastics was estimated to be adding more than 850 million metric tons of GHGs annually to the atmosphere—equal to 189 five-hundred-megawatt coal power plants[16].

While comparison of the life cycle GHG emissions performance of bioplastics versus conventional plastics remains challenging due to inevitable differences in scale and infrastructure, and although there is variability by feedstock, product and application type, a number of life cycle assessments have shown bio-based plastics to feature significant CO_2 advantages. Bio-based plastics save fossil resources by using biomass which regenerates and provides unique potential of carbon neutrality. They can also require less energy-intensive processes for their production. Replacing fossil fuel feedstock with biomass is therefore one strand of an overall plastics sector mitigation strategy, along with renewable energy, recycling and demand-management. Furthermore, bioplastics that can be bio-degraded or composted are able to support the organic recycling of a greater proportion of biological waste, as an alternative to landfill or incineration, and therefore a further reduction in GHGs in the form of methane emitted from biological wastes and emissions from incineration. Bio-based plastics are an innovative industry that has the potential to decouple economic growth from resource depletion and adverse environmental impacts, and, as such, they can offer a key element of the net zero formula for the plastics sector, for overall waste and resource strategy, and the circular bioeconomy.

Single-use packaging, films, bin liners and catering disposables are the mainstay of bioplastics in the UK today, where the sector is represented by a small number of companies involved in polymer, compound and film development, and is weighted more to technology supply than production at world industrial scale. The balance of the UK bioplastics community comprises converters and single-use plastics distributors, but with a marked absence of momentum and investment from multinationals.

[13] https://www.european-bioplastics.org/market/

[14] https://www.bpf.co.uk/plastics-strategy/sources.aspx

[15] http://www3.weforum.org/docs/WEF_The_New_Plastics_Economy.pdf

[16] https://www.ciel.org/wp-content/uploads/2019/05/Plastic-and-Climate-Executive-Summary-2019.pdf

A growth strategy for UK bioplastics in support of net zero goals requires a jump start to reach the critical mass at which the market becomes more attractive for investment, and to achieve the commercial foundation that supports innovation and value-added diversification. Compostable bioplastics, which already have a market foothold, represent the best route for consolidating this foundation. Beyond this, a longer-term horizon is required. Changes at greater scale are complex, impact many stakeholders, and must address potential resistance by incumbent businesses and investors defending legacy investments and assets, or who now lack a commercial incentive to change. An important focus here will be on the high-volume but as yet untapped opportunity to supplant fossil-derived feedstocks on the existing manufacturing assets of major polymer manufacturers.

Equitable tax policies, targeted market interventions to increase bio-based uptake, tools for leveraging environmental benefits, and supportive structures for testing and development, are among the action areas in this roadmap which impact on the bioplastics sector. There is also a need for solutions that promote circularity and adjust the ecosystem to improve capture of biological resources from waste. Bio-based plastics contribute to these solutions and benefit from them. The self-reinforcing cycle that can be created by adopting circularity will drive down GHG emissions and push investment into industrial biotechnology as a solution provider. In this way, the success and adoption of bio-based plastics becomes a force multiplier for broader IB growth and a key component of net zero.

"We're talking packaging and bin liners and collection systems having a big impact. Those are the reality today. Bioplastics can dramatically reduce CO_2 emissions, dramatically increase the amount of food waste you collect and intercept, and dramatically improve the quality of that going to soil."

Sector profile: fine and speciality chemicals

Fine and speciality chemicals (F&S Chemicals), which are often known as performance or effect chemicals, are mainly differentiated from bulk/commodity chemicals by volume and price. Speciality chemicals are used as ingredients in finished products and formulations, where they are added in relatively small amounts to, for example, home and personal care products, plastics, coatings and adhesives. Fine chemicals are high value organic chemicals produced in much lower volumes, often using multi-step syntheses to high specifications; they include intermediates, active pharmaceutical ingredients, some agrochemicals such as biocides, flavours and fragrances, as well as pigments.

According to a strategy produced by the Chemistry Council in 2018, the UK chemicals sector had an annual turnover of £48.7 bn with a gross value added of £17.8 bn in 2016[17]. It is an industry that invests significantly in science and engineering research and innovation, and whose strategy has at its core the desire to develop sustainable processes and materials with a 'create and make' ethos. Within this strategy, IB is recognized as having a key part to play in achieving the chemical industry's ambitions of facilitating a move towards net zero and delivering a 50% increase in turnover by 2030.

While IB is already finding applications in the production of a wide range of chemicals, these are predominantly at the high-value but lower-volume end of the market. Consumer products, and notably the personal care category, are important innovation and demand drivers – for example for bio surfactants and other bioactives and bio-derived novel products which offer beneficial skincare properties. Enzymatic routes for the production of flavours and fragrances are a further dynamic area in which the UK is establishing a strong position, with opportunities across an array of uses.

IB achieves CO_2 reduction by avoiding use of permanently fixed carbon, as well as through lower-temperature processing that is less energy intensive, and the ability to recycle material (that is left after the bioprocess) into feedstock or reuse. Beyond internal processing and manufacturing, the scope of GHG emissions effects is increasingly being articulated in terms of cradle-to-grave life cycles which extend the boundaries to include the often much greater environmental impact associated with the consumer's use of products, and which leading consumer companies are now using to drive change.

[17] http://ukchemistrygrowth.com/wp-content/uploads/2019/11/Chemistry-Council-Sector-Deal-041119-1.pdf

While potential for IB to reduce CO_2 in a short 3-5-year time frame is constrained by its low-volume sector profile, its contribution is poised to grow significantly over a longer horizon, as both drop-in replacements and new products are developed and utilized. In particular, the potential to disrupt conventional chemistry will stem from the ability of IB technologies to open up novel spaces that are inaccessible to synthetic chemistry, or from the ability to reduce the number of processing steps through the use of biocatalysts, in combination with performance and processing benefits.

Consumer pull is key for IB in the sector, with growing demand seen for products that are of natural, sustainably sourced bio-origin and which can also offer superior properties. This explains why the acceleration curve for IB ingredients in consumer-facing sectors is already approaching an inflection point, in contrast to where IB is used as a process intermediate or processing aid, where the disruption of conventional chemistries is set at a slower pace. Here, change will depend on a progressive, knock-on displacement along value chains, but faces a headwind from a primary focus on cost more often being the rule among B2B customers today, other than where bio-based technology offers competitive advantages and fits with the broader sustainability goals of individual companies..

Outside the very niche end of the market, new IB companies seeking commercialization and scale often struggle with the dual challenge of developing technology platforms and routes into established markets. The high cost of early technologies at lower scale is a barrier, particularly where technologies cannot be overlaid on existing assets, and where incumbent fossil-derived technologies, with their capital investments already behind them, are difficult to displace and themselves disinclined to transition to bio-based approaches. The recommendations in this roadmap seek to address these challenges by leveraging the benefits of IB at all links in the chain and through initiatives to optimize value derived from biomaterial feedstocks. They identify areas of opportunity for more assertive policies to accelerate technology transformation, initiatives that mitigate the inhibitory burden placed on start-ups and SMEs in registering new chemical entities, as well as for new traction from the standardization of a bedrock catalogue of IB-derived chemical alternatives.

"Potentially every single product that we have which involves chemicals is a target for a bio-based manufacturing process."

In order to build on existing capability and strength, the UK needs to have clearly defined target bio-based chemicals that can be both developed and manufactured here. Through extensive consultation and evaluation of both research expertise and manufacturing know-how, a list of the UKBioChem10[18] was identified in a 2018 report produced by the BBSRC funded LBNet. These are the top ten bioderived chemicals on which the UK could focus resources in order to provide a range of building blocks on which multiple other intermediates and end use products could be realized. This would in turn provide the platform for further related chemicals being developed as a pipeline for numerous value chains, capitalizing on domestic supply of existing and novel chemicals with more attractive environmental credentials. The recommended actions in this roadmap therefore reflect the need for concerted efforts to realize the potential for the UK to have a leading position through the synthesis and use of the UKBioChem10.

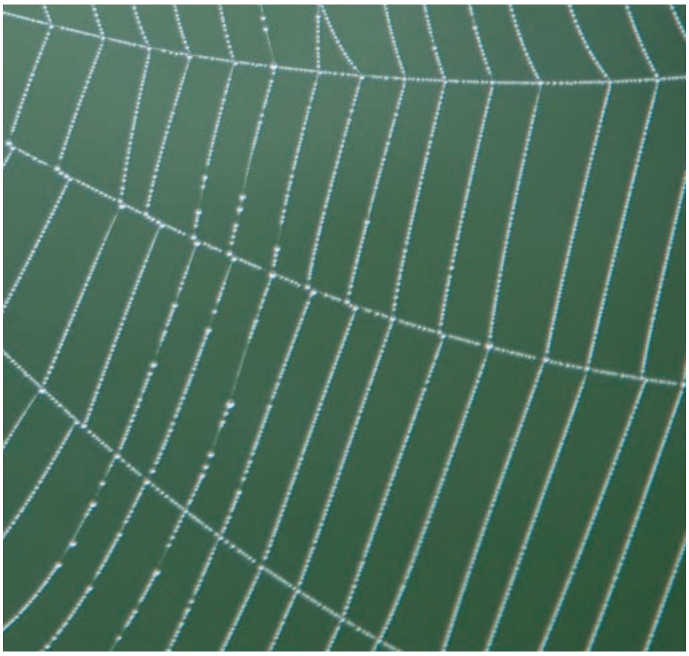
Irrespective of the current low volumes, fine and speciality chemicals are a valuable IB sector from an industrial strategy perspective, where the UK has the opportunity to innovate and expand from its strong technology and skills base in traditional synthetic organic chemistry and engineering. They are an exciting area where IB has a central role to play, and therefore one that warrants the full-fledged support and collaborative funding required to ensure their smoother development and commercialization.

Sector profile: textiles

Industrial biotechnology in the UK textiles sector is at an earlier stage than in the other sectors covered in the scope of this project. It currently consists of small-scale and highly targeted use, where the cross-over between IB-enabled textiles and both plastics and fine chemicals further shrinks the understood boundaries of textiles as a standalone IB space. Developments at present focus on speciality textiles at the novel end of the market and at limited industrial scale, as well as on bio-based approaches to the manufacture of process chemicals, dyes and fixing chemicals.

The Accenture **Made Smarter** report published in 2020 shows that emissions from the manufacturing of textiles, apparel and leather represent 2% of GHG emissions from UK manufacturing, with manufacturing overall accounting for 15% of the country's total. Two key drivers of emissions are noted: high energy requirements for certain manufacturing processes (such as spinning and dyeing) and high volumes of waste from over-supply at manufacturing.

Opportunities for IB-enabled CO_2 reduction are through the replacements of materials with high levels of embedded GHG content, as well as bio-based process chemicals that lower energy and water requirements. A further route for exploration is the recycling of cotton and other textile materials to produce new thread, which would avoid the atmospheric release of CO_2 from materials that are otherwise incinerated or sent to landfill. In the case of cotton, for example, this would also cut the offshored carbon footprint from the use of non-renewable fertilizers to grow the cotton.



The pace of commercialization in textiles is dependent on fashion brands scrutinising supply chains and evaluating how they can transition to circular economy principles, in part as a response to consumer pressure. While textiles rank lower than the other four sectors as an area for IB-enabled CO_2 reduction in a close 3-5-year timeframe and is therefore not a primary shaper of recommended actions in this roadmap, it nonetheless stands to benefit from the range of IB cross-sector initiatives.

[18] http://ukbiochem10.co.uk/wp/wp-content/uploads/2019/01/UKBioChem10_Report.pdf

Executive summary: roadmap and recommendations

Meeting the UK net zero target by 2050 will require efforts and action by the full range of stakeholders, including all those whose work intersects with the UK industrial biotechnology arena. Expanding UK industrial biotechnology capabilities, along with the surrounding infrastructure and behaviours that will support its success, opens a range of opportunities to reduce GHG emissions, sequester carbon, and advance positive economic opportunities. The actions outlined in the following roadmap and recommendations have been identified to create the stepwise path to make a future where UK industrial biotechnology companies play a significant role in supporting a prosperous and environmentally sustainable future.

Companies, regulatory agencies, individuals, processes, materials, and municipalities all coexist and operate interdependently. Large-scale permanent change cannot take place without acknowledging the interrelated nature of the many discrete, and sometimes seemingly unrelated or contradictory, elements and actors operating across complex, adaptive systems. There are a number of overarching challenges that exist within, and across, these systems that are significant barriers to early stage companies in the UK IB community. These include entry into existing markets that are dominated by legacy incumbents, within regulatory regimes designed around existing infrastructure, business models and technology. In concert, these inhibitors cut across multiple sectors of IB application, and are illustrated by eight overarching gaps illustrated below:

Gaps

Eight overarching gaps will inform the approach to optimising IB and its contribution to CO_2 reduction across the sectors

The barriers and challenges to IB innovation and commercial scale up point to 8 overarching areas of gap	Priority sectors for IB-enabled CO_2 reduction in 3-5 years			Foundation sectors for IB-enabled CO_2 reduction	
	Biofuels	Aviation fuels	Agritech	Plastics	Fine & speciality chemicals
Technology de-risking	●	●	●	●	●
Cost competitiveness vs. incumbents	●	●	●	●	●
Feedstock access and security	●	●	○	●	○
Adaptive evidence frameworks		●	●	○	●
Compelling public profile	○		●	●	●
Leveraged envionmental benefits	○		●	●	●
Alternative to EU GM regulations			●		
Viable end-of-life solutions				●	

● Recurrent gap ○ Variable gap

Figure 4

Each of the overarching gaps that have been identified are addressed by a directional framework grouped along four pathways. Each pathway is supported by action areas that are described in detail throughout the recommendations section of this report. The action areas, and the corresponding roadmap, have been identified with the understanding that the scale and complexity of the challenges require a holistic, systems-thinking approach. The pathways and action areas address a range of points related to infrastructure, tax policy, regulations and standards, infrastructure, perceptions and behaviours, and a host of other areas. The pathways are as follows:

Pathway 1: circular resources - This pathway envisions UK industrial biotechnology capabilities as the linchpin to establishing a circular economy that captures value where there was once waste or overlooked agricultural capacity, creating new sources of feedstock and a virtuous cycle that stimulates investment.

Pathway 2: communication tools - This pathway focuses on creating awareness and a shared understanding of the potential and benefits of industrial biotechnology, which will drive investment, adoption, and scale

Pathway 3: informed science-led approach - These recommendations create momentum toward a more agile operating environment that aligns with science, yet also lowers legacy hurdles to developing and producing innovative bio-based products and materials

Pathway 4: supportive level playing field - This pathway offers recommended actions related to funding, infrastructure, government interventions, and tax policy that have been chosen to support UK industrial biotechnology companies' ability to compete with fossil fuel-derived technologies on a more equitable footing.

Recommendation overview: roadmap pathways and action areas

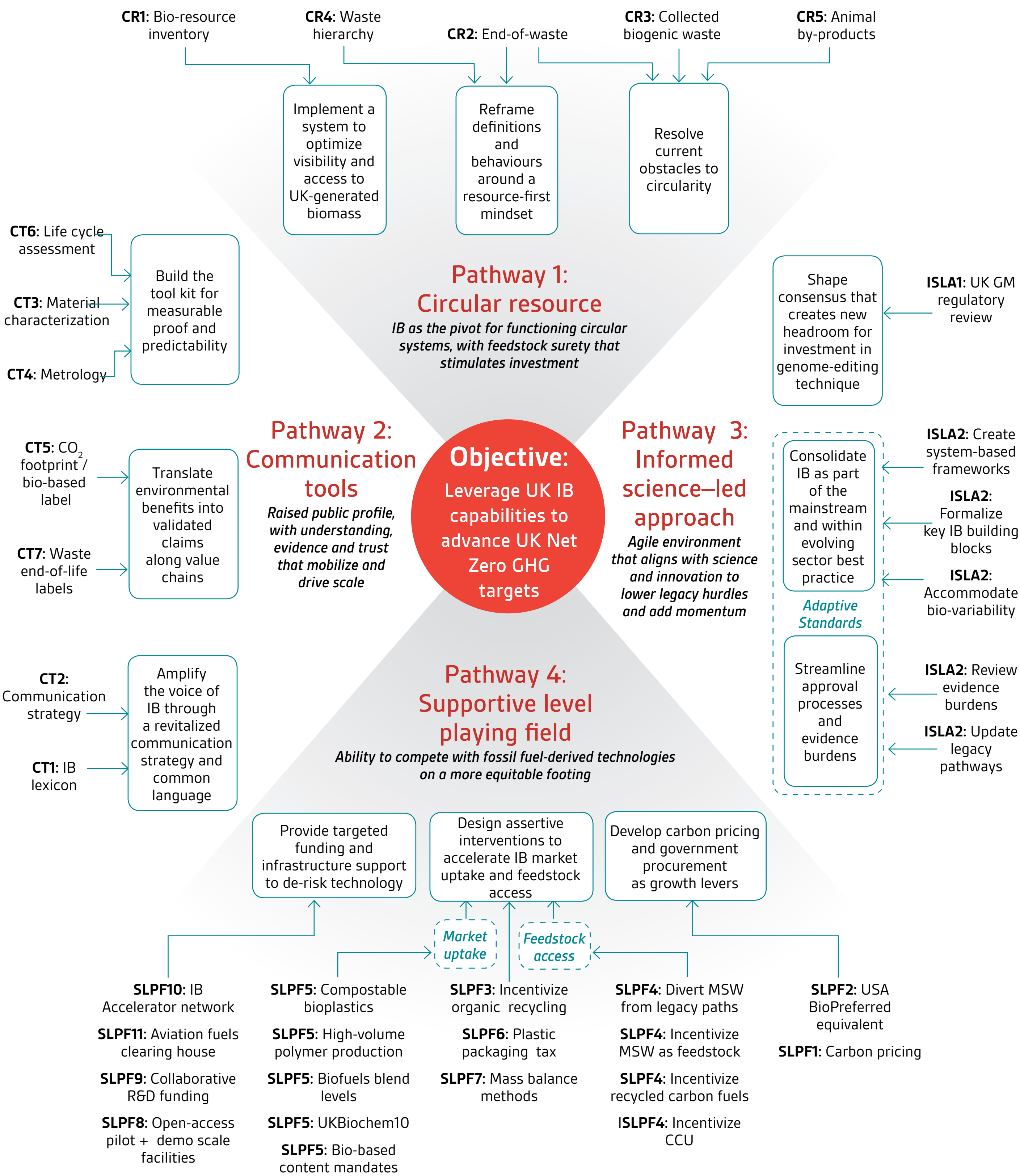


Figure 5

The roadmap to coordinate relevant activity and deploy the strategy is laid out over a three-year indicative timeline, with key responsibilities held by the UK Government, UKRI, and industry stakeholders.

Roadmap

Pathways	ID	Funding	Actions & Time frame (2021 / 2022 / 2023)	
Circular Resource Pathway: IB as the pivot for functioning circular systems, with feedstock surety that stimulates investment	CR2	£	End-of-waste	
	CR4	£	Waste hierarchy	
	CR5	£	Animal by-products	
	CR1	£££	Bioresource inventory	Ongoing
	CR3	££	Collected biogenic waste	
Communication Tools Pathway: Raised public profile, with understanding, evidence and trust that mobilize and drive scale	CT1	£	IB lexicon	
	CT2	£	Communication strategy	
	CT3	££	Material characterization	Ongoing
	CT4	££	Metrology	Ongoing
	CT6	££	Life cycle assessment	
	CT5	£££	CO2 Footprint / Bio-based label	
	CT7	£££	Waste end-of-life labels	
Informed Science-Led Approach Pathway: Agile environment that aligns with science and innovation to lower legacy hurdles and add momentum	ISLA1	£	Genome editing	
	ISLA2	£	Adaptive standards	Ongoing
Supportive Level Playing Field Pathway: Actions to enable IB to compete with fossil fuel-derived technologies on a more equitable footing	SLPF6	£	Plastic Packaging Tax	
	SLPF9	££	Collaborative R&D funding	
	SLPF10	££	IB Accelerator network	
	SLPF8	£££	Pilot and demonstration facilities	
	SLPF11	£££	Aviation fuels clearing house	
	SLPF7	£	Mass balance methods	
	SLPF3	£	Incentivization of organic recycling	
	SLPF4	£	Optimization of IB feedstock access	
	SLPF1	££	Carbon pricing	
	SLPF2	£	USA Biopreferred equivalent	
	SLPF5	£	Interventions to accelerate IB uptake	

Key - Owners

- Owned by UK Government
- Owned by Industry
- Owned by UKRI

Projected Funding Requirements

£	Low
££	Medium
£££	High

Figure 6

Recommendations

= Elements for turnaround in 12 months or less

= Involves standards development and best practice

= Involves regulation

= Agritech

= Biofuels

= Fine and speciality chemicals

= Plastics

= Creation of systems-based frameworks

= Updates to legacy pathways

= Accommodating 'bio-variability'

= Formalization of key IB building blocks

= Review of evidence burdens

Pathway 1: circular resource

The present moment holds a unique opportunity for the UK to leverage its industrial biotechnology (IB) capability and engage its citizens to significantly advance towards its net zero target by 2050. At the heart of this opportunity is an embrace of a functioning circular bioeconomy, which requires change across multiple, interconnected systems in order to tap into latent sources of value while reducing greenhouse gases and material waste.

The Ellen MacArthur Foundation defines the circular economy as such:

"A circular economy is a systemic approach to economic development designed to benefit businesses, society, and the environment. In contrast to the 'take-make-waste' linear model, a circular economy is regenerative by design and aims to gradually decouple growth from the consumption of finite resources."

Circular economy principles assume value in materials and seek to exhaust opportunities to keep them in use, before discarding them as waste. The counter to this approach is a misperception that positive environmental impacts must always require a reduction in product or service quality, or an inherent increase in costs. That assumption is based, in part, on an inability to see the untapped value hidden in the waste generated by our modern economic system. In that view, waste is something to be hidden or destroyed, buried in landfills or incinerated to emissions and ash. It has only been quite recently that we have begun to understand the impacts, limits and hidden costs of the linear take-make-waste economic model. Although those costs are yet to be consistently captured in most corporate or governmental budgets, we are beginning to understand the impacts of a warming planet and oceans increasingly polluted with single use plastics. Solutions to these and other global challenges, and to support net zero ambitions, must account for the complex, adaptive, interdependent nature of large-scale systems, since small-scale solutions within individual silos will only yield small-scale gains around the edges.

IB is on the frontline of this change as the anchor of the **UK Bioeconomy Strategy**[19] and its goal of a more circular, low-carbon economy – one shaped by solutions that are environmentally sustainable as well as resource efficient. Its transformative remit also aligns squarely with the Resource and Waste Strategy's objective to demonstrate international leadership in circularity[20], as well as with the aspiration set out in both the Industrial[21] and Clean Growth Strategies[22] to double UK resource productivity and eliminate avoidable waste by 2050.

[19] https://www.gov.uk/government/publications/bioeconomy-strategy-2018-to-2030

[20] https://www.gov.uk/government/publications/resources-and-waste-strategy-for-england

[21] https://www.gov.uk/government/topical-events/the-uks-industrial-strategy

[22] https://www.gov.uk/government/publications/clean-growth-strategy

Industrial biotechnology as the pivot for a functioning circular system

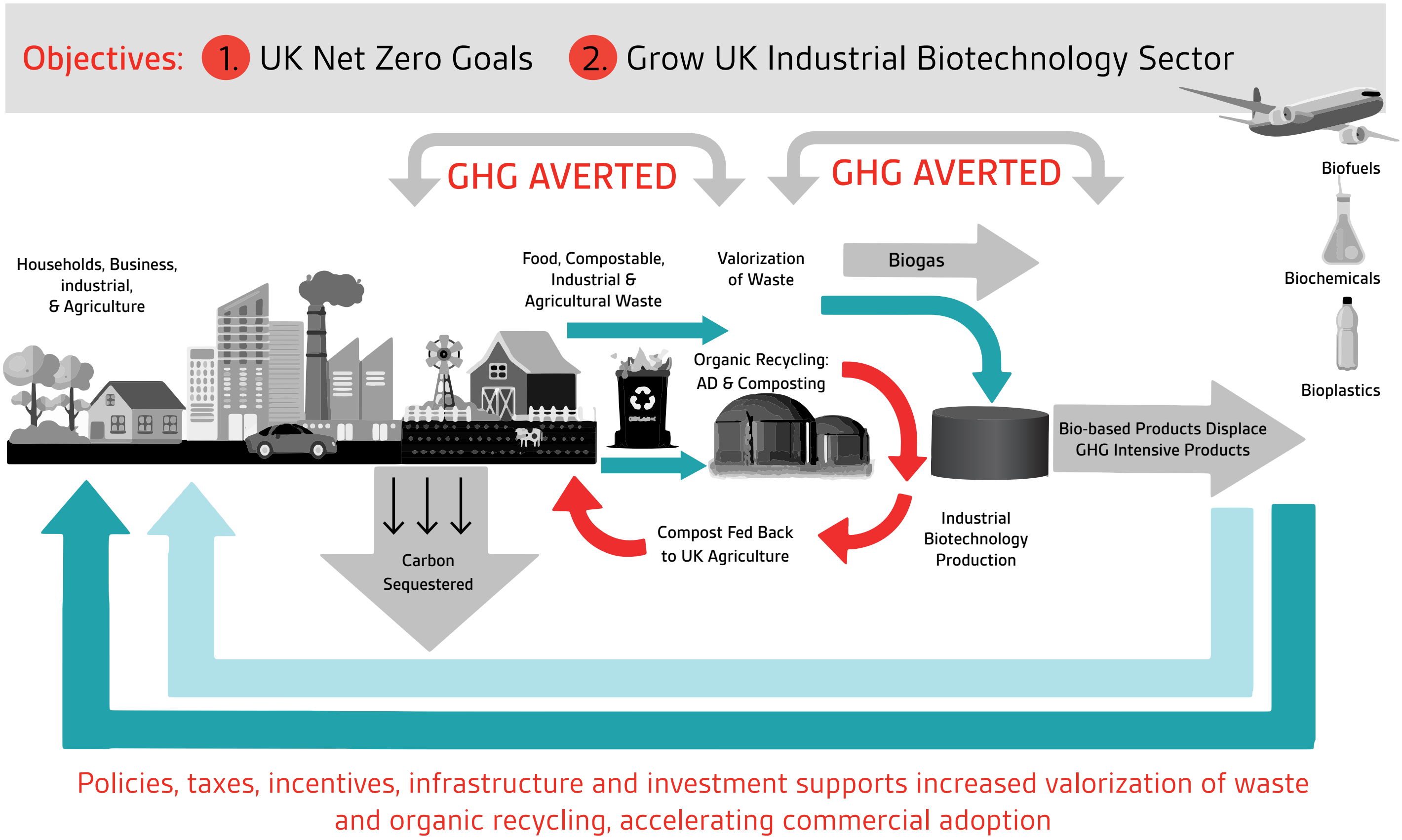


Figure 7

This resource productivity can be driven by capture of a wide variety of the biogenic resources that are essential feedstocks into industrial biotechnology processes. These range from agricultural and forestry waste to crops grown specifically with resource capture in mind, either on primary farmland dedicated to agricultural production or on marginal lands that had not previously generated value. These also include the different wastes produced by industries and households. **Each of these materials hold the potential to be valorized through innovative biotransformation processes to create new products and materials, enabling a reduction in net GHG emissions through their circular recapture of value.**

The opportunity for IB to act as the pivot for innovative circular systems that reduce, replace or sequester GHG emissions exists at multiple points across the life cycles of industrial, agricultural and municipal activity , as illustrated in figure 7.

Considering that the UK generated 221 million tonnes of total waste in 2016[23], there are potentially significant opportunities to reduce GHG emissions by avoiding the landfill and incineration of this waste, and to capture material and value from it. More specifically, opportunities for GHG reduction and waste valorization can apply to a portion of the 14.5 million tonnes of household waste, certainly most of the 7.8 million tonnes of biodegradable municipal waste, and an indeterminate volume of the 39.8 million tonnes of commercial and industrial waste, all of which were sent to landfill or incineration. Repurposing of this waste through an IB route is an opportunity to prevent or capture methane emissions emitted from biological wastes, displace the CO_2 emissions of petroleum-derived feedstocks, and avoid emissions from incineration. **A reframing of definitions of waste and resource is therefore at the heart of adopting circular economy principles that align with the growth opportunities for IB.**

A functioning circular system also creates a force-multiplier that builds momentum and stimulates market demand for bio-based materials. Compostable bioplastics, for example, are at present hindered by the prevailing approaches to organic recycling, yet stand to gain much greater traction if this roadblock can be addressed so that there is confidence in these plastics being organically recycled as they were designed to be.

Maximising the potential of circular resources, with IB as a linchpin in the capture and retention of the embodied value and energy in renewable materials, is an ambitious task. It is, however, one where economic development and climate action justify the near-term effort, funding and coordination needed. The following recommendations are designed to support a circular system in which IB can achieve its potential: they address the need for data on and sufficient access to biogenic resources, systems and practices that enable valorization of non-virgin materials, as well as policies and behaviours that foster circularity of materials and energy, rather than the creation of waste and untapped value of linear end-of-life practices.

[23] Defra UK Statistics on Waste, March 2020; https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/874265/UK_Statistics_on_Waste_statistical_notice_March_2020_accessible_FINAL_rev_v0.5.pdf

Circular resource recommendation 1 (CR1) – bioresource inventory

Develop a comprehensive bioresource inventory and online user interface to meet the need of IB technology developers for visibility of and access to UK-generated biomass

S

Stakeholders have identified that a lack of visibility, consistent classification, and reporting of data related to the type and availability of materials has been a significant constraint that inhibits the success of various UK strategies, including the UK industrial, clean growth, circular economy, bioeconomy, and resources and waste strategies.

The 2016 scoping study **Materials Flow Planning**, commissioned by BEIS (then BIS) confirmed that a lack of coordinated and usable data on the availability of material resources in, and to, the UK makes the identification of secure and reliable domestic feedstock supply difficult, inhibiting investment, clean growth, competitiveness, and the industrial transformations required to deliver against the above mentioned government strategies. In addition, Resource Recovery from Waste (RRfW), in concert with the UK Office for National Statistics (ONS), Defra and BEIS, have made the case that **circular economy policies cannot be effectively implemented without access to current data on stocks, flows, characteristics and uses of materials**. Furthermore, IB stakeholders interviewed for this project have expressed the need to secure consistent sources of feedstock to support the commercial viability of their investments and the effectiveness of their biorefining operations.

In response, the UK Office for National Statistics (ONS) has led efforts to establish the means to make UK resource stocks and flows visible to support impacted industries, environmental objectives, and the broader UK economy. These efforts have been focused on early stage research into the development of a National Materials Datahub (NMDHub), which would provide a view of an interconnected resource economy and the ability to map material resource stocks and flows. The NMDHub would, in addition, provide the ability to model options for economic forecasts, capital investment decisions or policy interventions, including visibility of their impact. This proposed system holds the potential to significantly create both much needed stable supply and inherent demand of viable feedstock, supporting and stimulating growth in sectors impacted by UK industrial biotechnology.

During interviews, IB stakeholders indicated that there is strong demand for this type of inventory or resource map and the need becomes more urgent as innovation in new products and processes drives an increasing need. ONS has identified three areas that need addressing to successfully develop a datahub of UK material resource streams. These include:

- Standardization and protocols
- Data sharing, collaboration and cross-sector engagement
- Data linking across industry and government sectors

The opportunity that is presented by making this type of feedstock information current and visible not only improves efficiency in supporting existing production needs, but also leverages available resources to stimulate new investment, start-ups, and innovation clusters by identifying where resource exists that could serve new, yet-to-be-discovered biorefining opportunities. This becomes another force-multiplier that creates its own momentum by enticing investors, driving greater innovation focus and encouraging new production capacity. By identifying and capitalising on new uses of existing resources, it further strengthens the bioeconomy, which creates high value desirable jobs across the UK and supports UK net zero goals.

The following points are specific actions to advance the aforementioned ONS recommendations related to standardization and development of agreed-upon protocols, which are needed to support the development of a publicly available bioresource inventory:

1. Development of agreed-upon standards defining consistent terminology and classification of common materials. This should include all primary sources of biomass, such as suitable agricultural crops, and secondary sources, such as biological waste that can be valorized as inputs into the biorefining process.
2. Development of user protocols and agreed-upon data standards to enable consistent and harmonized recording of waste data: Development of the NMDHub will require an understanding of data structure and relationships, waste producer/processor/consumer use cases, etc., all of which requires facilitation of dialogue across impacted, knowledgeable stakeholders across sectors.

"You can't have a bio economy without the bio"

3. Development of agreed-upon standards defining specifications and use of primary/raw materials and secondary waste/materials: standards designed to classify primary or secondary materials to support use or reuse will require valid data on their chemical composition, material characteristics and hazard status, and suitability against production process requirements. Developing agreed-upon standards and specifications will increase speed, efficiency, and quality in industrial biotechnology uptake and production. Businesses will also benefit from development of specifications of secondary materials, such as food waste, compostable materials, industrial waste, and agricultural biomass (See more detailed listing in accompanying table 'Breakdown of feeds and waste streams'). This can also include future secondary materials where technologies are still in earlier stages of development, such as carbon capture and utilization technology. Secondary materials hold the potential to be valuable sources of raw materials in the IB value chain, provided that their potential uses can be consistently defined. The consistency that standards bring strengthens market confidence. This will create a vibrant market for secondary waste and incentivize investment into additional uses of secondary waste for IB production. The effectiveness of the force-multiplier described earlier is dependent on investors and stakeholders being able to make confident decisions based on current and accurate information, all of which relies on standards to define agreed-upon meaning to the data.

A relevant example to support ongoing development of the inventory can be found in earlier work undertaken by Zero Waste Scotland, Scottish Enterprise, and the Scottish Industrial Biotechnology Development Group (SIBDG), which includes **The Biorefinery Roadmap for Scotland**[24], and **The Biorefining Potential for Scotland**[25] reports. The first identified actions required to identify the barriers and risks faced by companies and potential investors to enable the more established biorefinery technologies. Those efforts confirmed that sufficient feedstock exists that could be valorized to become inputs to support biorefining, converting sustainable feedstocks into high value bio-based products and materials. The reports also came to the same conclusion stated here; that the greatest chances of success were dependent on mapping wastes, by-products, crops, and agricultural residues that had the potential to be repurposed as feedstock for biorefining (see example below). The evolution and deployment of initiatives such as these must be towards a resource inventory that is not only as comprehensive as possible but also maintained on a live and dynamic basis and synchronized with industry's needs – all of which is reliant on significant ongoing funding.

Case study: IAR – the French bioeconomy cluster

IAR consists of members from across the bio-based value chain, working on initiatives which range from harnessing regional strengths in agricultural inputs to the marketing of final products generated by industry partners, as well as research capability and engagement with public stakeholders. The cluster was developed in order to provide critical mass of interested stakeholders, develop innovative projects and initiatives, leverage funding, and provide end-to-end supply chains based on bioderived feedstocks. IAR provides market intelligence, especially into biomass as a feedstock that support its utilization in industry value chains.

Breakdown of feeds and waste streams

Feed	Waste & biomass stream
Commercial & industrial wastes	Paper and cardboard wastes; rubber wastes; wood wastes; household mixed food waste; animal waste; household garden waste
Agriculture	Agricultural wastes (agricultural and processing residues, straw, residual root vegetables, etc.); forestry biomass and waste (thinnings, harvest residues, diseased wood, etc.), non-food crops (starch, oil, fibre, novel crops, etc.)
Marine biomass	Macro (seaweed) and microalgae
Food & drink	Food & drink (including by-products, co-products and non-captured wastes); dairy; distillery by-products; brewing by-products; coffee grounds; fish processing by-product; abattoir by-product
Sludges	Wastewater sludge

From 'Biorefining Potential for Scotland' report[26]

Figure 8

[24] https://www.sdi.co.uk/media/2092/biorefinery-roadmap-for-scotland-building-a-sustainable-future.pdf

[25] https://www.zerowastescotland.org.uk/sites/default/files/Biorefining%20Potential%20for%20Scotland%20Final%20report.pdf

[26] https://www.zerowastescotland.org.uk/sites/default/files/Biorefining%20Potential%20for%20Scotland%20Final%20report.pdf

Case study: Resource Exchange Network For Eliminating Waste (RENEW)

An analogous example of a platform designed to support exchange of available materials to reduce waste and meet industrial needs is the Resource Exchange Network for Eliminating Waste (RENEW). This is a free materials-exchange network established by the Texas Legislature in 1987 to promote the reuse or recycling of industrial wastes. The network is a marketing channel for industries, businesses, and governmental units who wish to sell surplus materials, by-products, and wastes to those who will reclaim or reuse them. The RENEW platform (http://renewtx.net) provides inventories to enable facilities to exchange materials that would otherwise be disposed of as waste, enabling organizations to search for available materials or post their own. Facilities who post materials can avoid disposal costs, and potentially reduce regulatory costs and efforts. Consumers of available materials find usable materials at a reduced cost, often free.

Exchanges within the network have resulted in:

- **Diversion of more than one billion pounds of materials for reuse or recycling by industries**
- **Savings of more than $27 million USD in disposal costs and**
- **Earnings of ~$15 million USD from the sale of recyclable materials.**

The needs that have been highlighted by IB stakeholders, in addition to work carried out to date by similar initiatives, point to the opportunity to create value and utility by establishing visibility, consistent meaning, and usability out of existing information. From a planning perspective, it is relevant to note that the aims of the NMDHub are wholly consistent with the efforts led by the ONS to bring an Integrated Data Platform (IDP) programme for government. The IDP is designed to provide the opportunity to unlock the vast potential of linked data to enhance decision making for the public good, providing a quality evidence base on which to improve the lives of citizens. While the NMDHub and IDP are not the only possible means to develop a publicly available bioresource inventory to meet the requirements of industrial biotechnology, these efforts may present the best opportunities to leverage existing efforts and develop this type of centralized collective dataset. This does, however, entail possible risks associated with an increase in scope of any project, in this case, the potential to slow progress and dilute focus from IB-specific needs. The NMDHub proposal, for example, originally indicated a possible 10-year timeline, although it is clear that if it is incorporated within the IDP programme this time horizon could be accelerated. One way to potentially accelerate progress on developing a usable dataset focused on biogenic materials for IB may be to work with ONS to develop a Bioeconomy pilot for inclusion within the first stage (1-2 years) of the IDP programme once it is approved. Alternatively, there is the option to initiate an independent and less ambitious data gathering exercise focused on those materials, while maintaining visibility and input into the broader NMDHub/ IDP project, in order to align near-term activity wherever possible. If this latter option is selected, the less ambitious near-term objective could be the development of a smaller scale set of data and a simple exchange, similar to the Texas RENEW example (see inset), for a smaller set of users for the near term, while designing ultimately for IDP alignment.

"We've got lots of companies that are looking at valorizing waste streams. When the information is there and people know what the chemical composition is and the availability, they can actually get quite creative"

Circular resource recommendation 2 (CR2) – end-of-waste

Adapt Environment Agency processes for end-of-waste and develop the resource-first mindsets to better support capture, valorization and re-use of waste in IB processes

An inhibitor to circularity remains the regulatory requirements of how 'end-of-waste' is defined, and more specifically, the regulatory process related to making that determination, particularly for less common materials or uses. 'End-of-waste' refers to the criteria that defines when waste materials cease to be classified and regulated as waste and can instead be used or sold as products in their own right.

The **BS 8001 Standard Framework for implementing the principles of the circular economy in organizations** describes the current regulatory landscape as such:

"The prevailing regulatory framework is usually fit for purpose for waste management, but it is currently unlikely to be favourable for secondary raw materials ... the recycling and reuse of items that could remain in the economic chain of utility without increased risk of harm to human health and/or the environment has sometimes been hindered. For example, used electrical items provided by third parties to an organization to be repaired or refurbished and then sold to the public might be viewed as waste by regulatory authorities. Regulations also exist to restrict and manage the shipping of waste for reuse, recycling and disposal to other countries. The existence of different interpretations especially on how waste is classified can make it problematic for organizations to use their resources in the most optimal way."

At present, the regulatory framework and accompanying process related to determining end-of-waste is as follows:

- **Compliance with end-of-waste regulations**: end of waste regulations are defined by the EU Waste Framework Directive, which is administered by the UK Environment Agency (EA) on behalf of DEFRA; according to the European Waste commission, 'end-of-waste' criteria specify when certain waste ceases to be waste and obtains a status of a product (or a secondary raw material) when it fulfils the technical requirements applicable to products.
- **Meeting the requirements of a quality protocol**: quality protocols have been developed for 13 material categories, for which they define technical requirements and if/how secondary materials can be viably reused and cease to be classified as waste.
- **Through an end-of-waste request, submitted to the EA by the waste producer seeking a secondary use**: producers of waste materials that have the potential to be used as a secondary raw material, but which are not specified in end-of-waste regulations or quality protocols, are required to make a submission for an end-of-waste assessment to the EA for an opinion on the waste status of their material.

It is this case-by-case assessment that has been identified by IB stakeholders as problematic and inhibitory to reuse of waste as a resource for IB production. This translates to a much lower volume of reusable material being captured. Interviewed IB stakeholders have described their frustration with the current process, expressing the following areas of concern:

- The process unduly inhibits adoption of circular economy principles and does not reflect the potential of available resources from an IB perspective
- The process used to determine whether waste can be repurposed is too lengthy
- Capacity constraints at the EA have created delays in completion of assessments, which increase financial pressure on stakeholders and inhibit innovation
- They feel there is a lack of transparency on the status of the assessments, and that communication with the EA can be difficult
- The process is rigid, with a lack of knowledge about the potential for waste use in IB processes resulting in an overly cautious mindset

"Getting an end of waste application approved is second only to seeing the golden unicorn flying underneath the rainbow"

The following recommendations are presented to increase reuse of secondary materials and better support industrial biotechnology development.

Update the EA process and protocols to regulate the characteristics of potential resources, as opposed to defining what is or isn't to be classified as waste. For example, a current characteristic of waste is that it does not have a current market for it. This assumes that a material that has not been assigned a value must be waste. This overlooks future yet-to-be-determined uses of waste. This also assigns a default definition on a potential resource as waste, versus starting with the challenge of finding a suitable reuse for the material as the default and deeming it as waste as a final determination only after all possibilities have been exhausted. The better approach may be to start with the intent of finding a viable use for a resource first, and only determine characteristics of the waste that would deem it unsuitable for future uses as a resource (e.g. toxicity, environmental impact, etc.). In the United States, the Resource Conservation and Recovery Act (RCRA) provides waste producers a higher degree of control over determination of secondary use, provided the producer meets with environmental compliance. This reduces drag in the process, reduces material waste, and increases access to secondary materials, as described in the accompanying example.

Develop standard(s) that specifically define how an organization should evaluate a range of waste materials primarily for the purpose of identifying opportunities to manage them as resources that add value inside or outside of the organization. For example, although the **ISO 14001 Environmental Management System** standard requires that organizations determine aspects that have significant environmental impacts, there are only brief mentions of identifying opportunities for repurposing waste, and little guidance on how to put that into practice. This type of guidance will enable producers of potentially reusable materials to more quickly identify new ways of identifying value, and confidently incorporate those opportunities into investments and business operations. This also enables them to embed these practices further upstream in their product development process, choice of materials, process design, etc. In addition, this also serves to lift some burden from the EA in the evaluation of more novel materials and/or use cases. An even more targeted approach would be to develop a standard specific to reclassifying biogenic wastes as viable resources that can be used as inputs into industrial biotechnology production processes (in concert with relevant regulatory changes). The provision of worked exemplars and case studies could be developed and made available to ensure the full spectrum of evaluation is carried out, including the IB processes themselves characterizing the end of pipe outputs..

Ensure adequate staffing levels at the EA, and explore opportunities to assign specific individuals within the EA to a designated licensing team responsible for evaluating novel materials and secondary use cases. These 'bio-champions' can be specially designated to support evaluation of innovative materials and use cases with a resource-first mindset focused on actively developing potential secondary materials in line with the UK bioeconomy strategy.

Further develop and extend the scope of quality protocols to account for different types of materials and more secondary use cases that can best support the range of industrial biotechnology requirements.

Example: US Resource Conservation and Recovery Act (RCRA)

Some aspects of the Resource Conservation and Recovery Act (RCRA)[27] may be useful in accelerating the current EA end-of-waste evaluation process and enabling a higher volume of waste to be repurposed as secondary materials. RCRA defines criteria for waste and hazardous waste, but also when a material may not be considered a waste (and therefore not subject to the requirements of RCRA). Material is not considered waste if it:

- Is explicitly cited by the US Environmental Protection Agency (EPA) as exempt from the RCRA requirements
- Can be considered a "by-product". By-products are defined as a material that is not one of the primary products of a production process and is not solely or separately produced by the production process and can be found to have another use. Examples include molasses, which is a byproduct of refining sugar, and sawdust, which is a byproduct of the lumber industry, and feathers, which are a byproduct of poultry processing.
- Can be "reclaimed", such as if it is processed to recover a usable product, or regenerated. Examples include recovery of lead values from spent batteries and regeneration of spent solvents, which can be used by another entity or organization.
- Can be "used or reused" such as:
  - Being employed as an ingredient (including use as an intermediate) in an industrial process to make a product (for example, distillation bottoms from one process used as feedstock in another process).
  - Being employed in a particular function or application as an effective substitute for a commercial product (for example, spent pickle liquor used as phosphorous precipitant and sludge conditioner in wastewater treatment).

A generator of waste is required to make a determination and document of whether the material is/isn't waste or hazardous waste. These determinations are left up to the generator organization, provided they follow the RCRA conditions, which supports a faster evaluation process and secondary use of a higher volume of materials.

[27] https://www.epa.gov/rcra/resource-conservation-and-recovery-act-rcra-regulations

Circular resource recommendation 3 (CR3) – collected biogenic waste

Establish standards, guidelines, and infrastructure to support UK adoption of segregation, capture, and valorization of collected biogenic waste at source

S

One inhibitor to consistent, large-scale capture of value from biogenic waste is the fragmented, local responsibility for waste management, which lies with hundreds of local councils, each operating within a range of practices. At present, practices range from comingled food/garden waste collection, separate food waste collection, to no collection of organically recyclable waste (e.g. compostable, anaerobically digestible) at all. The government has committed to roll out segregated food waste collection from households and businesses across the country by 2023, as part of the Environment Bill. **In concert with the lead-up to implementation, central government can support the transition by providing direction, support and funding for the changes needed to coordinate activity, which will enable local councils to focus on adoption and execution of context-based programmes that best support local household, business and agricultural site needs.**

With landfill capacity at a premium and costs continuing to rise, local councils will also derive benefits from the opportunity to divert a higher volume of waste from increasingly expensive landfills and incineration. The needs of industrial biotechnology production for local, low emission, cost-effective feedstock inputs create the additional stream to divert waste, reducing those pressures. Assured access to these resources will equally be critical to giving IB investors the confidence they require for their planned production and capacity increases.

Council-level ownership, within a consistent range of options identified by central government, will enable and empower local councils to choose which waste processing path is most suitable based on available options and local infrastructure. These choices can be impacted by type, availability, and location of MRF (Material Recovery Facility) and biorefinery processing infrastructure, the type and volume of waste, and the mix of household, commercial, industrial and agricultural sites within a municipality. This level of flexibility will reduce local resistance, empower local councils to make context-based decisions, and account for uneven distribution of processing facilities. This approach is also recommended by the Biobased and Biodegradable Industries Association (BBIA).

Coordination by central government can be supported by development, issuance, and support on use of consistent guidelines and standards that address elements to include the following:

- **Bin characteristics**: the **BS EN 840-1:2020** standard was introduced to create a basic standard for the regulation of the design of mobile waste containers. The standard should be reviewed to assess any additional needs required of bins to accommodate the unique characteristics of food and compostable waste, particularly weight, volume, moisture and odour.

"The waste management system is in need of an overhaul and funding support. So, I would say it's not the disposal, it's the whole system: it's the collection, the disposal, the treatment, the soil segregation."

- **Material Recovery Facility (MRF) practices**: at present, standards related to MRFs have been developed that relate to output quality of compost, **PAS 100:2018**, quality of digestate, **PAS 110:2014**, equipment, waste containers, and lifting devices; but none have been developed to provide guidance to MRFs that supports consistent and scalable capture of biogenic recyclable waste to capture value. A standard to define and align MRF practices that connects and underpins the corresponding elements described throughout this report (e.g. labelling, communication, etc.) should be developed as a blueprint for how MRFs should operate, and how they should work in concert with council efforts to capture value from waste with a resource-first mindset and set of operating principles. These guidelines should address requirements across the entire value chain, from kerbside pickup, to sorting, processing, recovery of resources, etc. The standard should also be flexible to account for the local context and relative maturity of the MRF and be seen as a stepping-stone towards the more consistent national capability that is needed. In addition, guidelines should also account for historical MRF practices, particularly in light of the existing BS EN 13432 standard, which defines criteria for compostability. Since that standard is focused on product decomposition, as opposed to MRF practices, it is not resulting in consistent application on the part of MRFs, who may divert more compostable material to landfill than was intended when the standard was drafted. MRFs under financial pressure have also resorted to accelerating the time to compost material, resulting in poorer quality output. According to stakeholder input, MRF practices have diverged from anticipated practices since the standard was developed, so an updated assessment of MRF methods paired with a realignment to the standard will improve consistency of practices.

- **Municipal practices & decision-making**: the factors and municipal decision-making process related to capture and diversion of organically recyclable waste can be standardized in the form of guidelines. If done correctly, standardized yet flexible guidelines can balance scale versus context, enabling context-based design and decisions within a consistent framework based on the needs and infrastructure of specific municipalities. Effective guidelines to support municipal programs can include:
  - Sorting and processing systems/technology by material stream: these guidelines can define necessary capabilities of equipment, municipal processes, etc. This will provide a model blueprint that also enables municipalities to flex up or down, based on local context.
  - Communication: see recommendations in 'Communication tools – ('IB Lexicon')
  - Measurement: types of measurements can be established by a standard that enable municipalities to set and track progress to local and country-wide goals. Based on the baseline maturity level of the municipality, measurements can be developed along a continuum, which can support a range of entry points, while driving continuous improvement. Different types of measurements can also be established based on process, output, outcome or impact. Also, measurements can potentially be tied to incentivizes to drive necessary behavioural changes at the level of household, business, municipality, MRF, etc.
  - Impacts/constraints/capabilities: In order to enable a wide range of municipalities with varied entrypoints to adopt consistent practices that are also flexible and context-based, other factors to consider in developing a standard include:
    - Determination of frequency of kerbside pickup.
    - Population demographics
    - Site type: businesses, schools, households, agricultural sites, etc.
    - Type and volumes of waste

A consultation is recommended to explore these opportunities and agree upon the most effective standards and measurements. This should include Industry, in order to ensure that a new coordinated approach is designed to process waste in ways that best align with requirements of those who represent its market.

Circular resource recommendation 4 (CR4) – waste hierarchy

Update end-of life (EOL) path with an agreed-upon standard hierarchy and guidelines that prioritize and facilitate the capture of value from biogenic resources for IB development

At the heart of UK adoption of circularity is the need to move away from the concept of 'waste management', and instead to embrace a mindset of 'resource efficiency'. The successful adoption of this mindset requires consistent understanding and practices. **An agreed-upon standard hierarchy that defines how to capture value from resources, particularly organic waste such as food waste, compostables, agricultural and industrial biomass, is essential to adopting efficient, effective and scalable systems to capture resources, boost UK IB development, and support UK net zero targets.** In addition to this hierarchy, a framework of guidelines and standards will support the creation of shared meaning and consistent application of the EOL/resource hierarchy.

Since collection and sorting largely determine the efficiency and effectiveness of waste management systems, the further upstream that materials can be correctly segregated into optimal paths for processing, the better the system's performance. Therefore, the support systems and behaviours of consumers, businesses, industry and the agricultural sector are crucial factors in the success of diverting and processing waste that consistently captures value. This consistent understanding and action by such a wide range of stakeholders can be best supported by the EOL/Resource hierarchy, accompanying standards, and clearly visible and understood iconography that instructs stakeholders at multiple points of the value chain, including industry and downstream Material Recovery Facilities (MRFs).

The current EOL hierarchy published by the UK government for most waste, which defines the preferred path to process waste to enable maximum capture of materials and energy from materials, is shown in figure 9.[28]:

The current hierarchy was developed under assumptions of continued overreliance on petroleum-centric economies, in addition to less-mature understandings of potential IB applications and scale. The update to this hierarchy that will increase value capture and improved alignment with the UK Bioeconomy Strategy is to emphasize and prioritize capture of biogenic resources through valorization of waste as feedstock and through organic recycling (anaerobic digestion and composting), which are also aligned with more recent guidance developed by WRAP[29]. The benefits of increasing valorization of waste and organic recycling include:

- Increased capture of energy and the associated reduction in GHG emissions
- Increased capture of materials
- Reduced toxicity

Current end-of-life/resource hierarchy

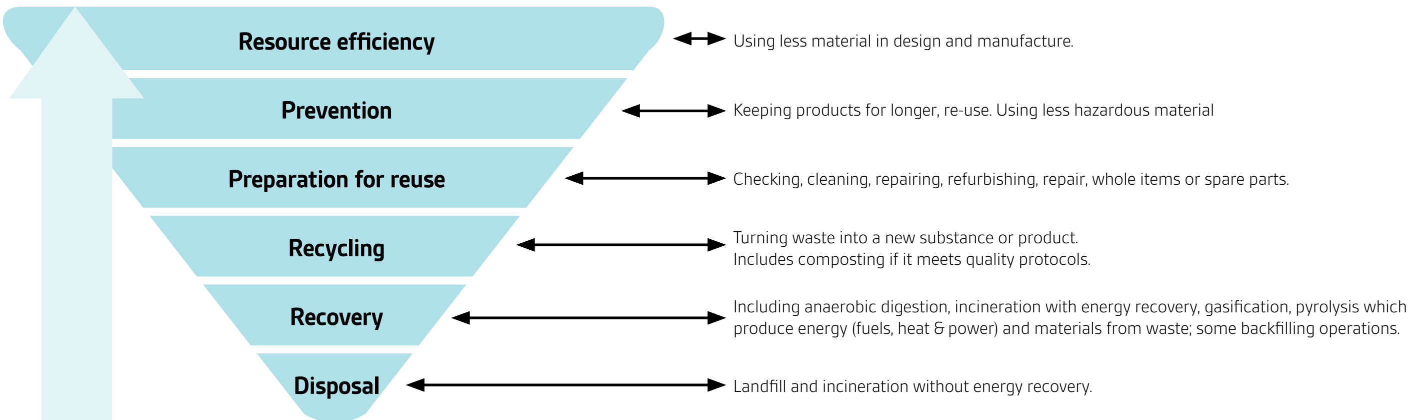


Figure 9

[28] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69403/pb13530-waste-hierarchy-guidance.pdf

[29] http://www.wmba.co.uk/app/uploads/2017/06/wrap-applying-wastehierarchy.pdf

- Elimination of inefficiencies related to food contamination of petroleum-derived plastics: At present, petroleum-derived materials contaminated with food are primarily sent to landfill - just 12-15% of mixed plastics are currently recycled in the UK. Bio-based materials potentially resolve this issue and increase value capture, as compostable bioplastic and accompanying food waste can both be diverted to the organic recycling path, either via composting or anaerobic digestion. The extent of the waste and inefficiency associated with attempts to recycle petroleum-derived plastics will grow increasingly visible as organic recycling practices and infrastructure mature. As households, businesses, and municipalities grow comfortable with disposing of bio-based plastics 'contaminated' with food waste in a single bin or organic recycling container, the futility of washing petroleum-derived plastics that will still likely end up in a landfill becomes apparent. This creates a pathway for increasing displacement of petroleum-derived plastics, starting with single use food containers and similar products, with organically recyclable bio-based plastics.

The recommended EOL/resource hierarchy that follows better accounts for capture of biogenic resources by prioritising bio recycling routes for the repurposing of these wastes, as feedstocks or through organic recycling:

- Resource efficiency: using less material in design and manufacture. Keeping products for longer; re use. Using less hazardous materials
- Prevention
- Bio recycling, consisting of:
  - Valorization of secondary waste into biogenic feedstock: convert biogenic resources into feedstock for IB-enabled production. This is an underutilized opportunity at present, which can expand to fuel the scaling up of biorefining technologies that require this waste. It addresses IB stakeholder concerns related to security of domestic biomass inputs to support consistency, quality and scale, while supporting the development of a virtuous economic and environmental cycle.
  - Organic recycling, consisting of:
    - Recovery via anaerobic digestion (AD) – capture embedded energy through anaerobic digestion. This path captures both energy (in the form of biogas) and material recovery (in the form of digestate, which can improve soil health and displace petroleum-derived fertilizer). This path is suitable for biological wastes and some bio-based plastics, at present.
    - Composting – this path captures biological nutrients and embedded carbon in the form of compost that is fed back into soil. Similar to digestate, this improves soil health and can displace energy-intensive petroleum-derived fertilizers. Bioplastics, garden waste and food are suitable for composting.
- Other recycling (mechanical or thermochemical) – e.g. for of glass, aluminium, traditional petroleum-derived plastics, or types of chemicals and other waste streams which are incompatible with bio recycling
- Incineration to energy
- Landfill

"And really what I think we need is a review of the way we think about waste to try and make it easier to do what we want to do, which is basically repurpose waste for something useful, something good. And that seems to be the fundamental block."

Recommended end-of-life/resource hierarchy

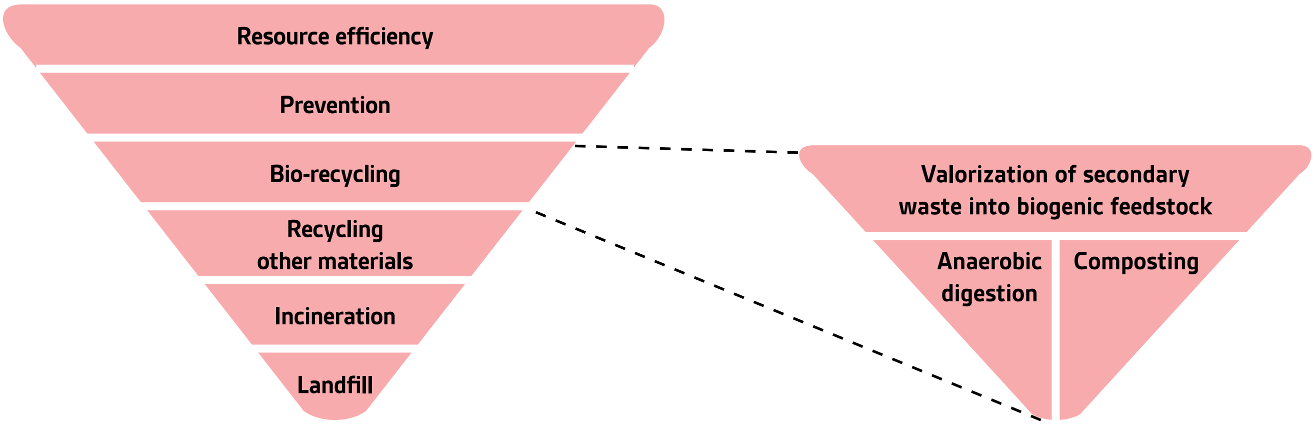


Figure 10

Circular resource recommendation 5 (CR5)– animal by-products

Review animal by-product (ABP) regulations and identify opportunities for improving access to ABPs as a feedstock for IB applications through regulatory change and standards

Animal by-products (ABPs) are animal carcasses, parts of animals, or other materials which come from animals but are not meant for humans to eat. They are a valuable potential source of feedstock for IB-enabled processes, yet the current regulatory framework can be an obstacle to their use. This framework is defined in **EU Regulation (EC) No 1069/2009 Health rules as regards to animal by-products and derived products not intended for human consumption** and is administered in the UK by the Animal and Plant Health Agency (APHA). It is designed to protect human and animal health, with ABPs divided into three categories based on level of health risk - with one the highest and three the lowest level of risk. Sites that process, store or transport ABPs must be approved by or registered with the APHA.

Several IB stakeholders commented on the complexity on these regulations and on their being unreflective of actual levels of risk in instances where ABPs are completely transformed through biorefining processes, for example into bio-based fuels, plastics and speciality chemicals. Fallen stock are category 2 animal by-products as defined in article 9 of the ABP regulation EC1069/2009: 'animals and parts of animals, other than those referred to in Article 8 or Article 10 that died other than by being slaughtered or killed for human consumption'. These, in particular, were noted as an area for possible regulatory change. In some cases, for example, the current system can require pre-treatment mechanisms that add a cost burden to the IB technology user that makes secondary use of such materials commercially unviable, yet which may not be necessary from a health risk perspective. Fallen fish stock was cited as an example: it has potential as an energy-rich feedstock for biofuels – but despite this potential reuse, it is likely instead to end up incinerated as waste.

There is likely merit in exploring opportunities to introduce new risk management practices that take greater account of IB technology applications on an individual basis, or that make greater use of actual detection of contaminants. Similar and related issues are seen to exist in the context surrounding the use of kitchen and catering waste, and notably in the field of insect biotechnology – where insects are used as nutrient recyclers in innovative chemical production chains - and in insect biomass conversion for the production of feed protein. These areas are also seen to warrant clarification of the UK regulatory framework, with revisions or new legislation, as well as alignment with trading standards authorities, in order to ensure that the UK does not lose out on these areas of emerging market opportunity.

Any regulatory revisions should also include accompanying standards and guidelines for impacted parties, points of the value chain, ABP type/category, and intended secondary uses, materials, and products. These overall changes would further align with a resource-first mindset needed to support the valorization of waste and circular economy principles.

Pathway 2: communication tools

Effective communication is a vital part of the toolkit for fostering and giving meaning to game-changing innovation. For industrial biotechnology, this opportunity for traction touches many areas on different levels and for varied reasons - yet despite having a powerful story to tell, communication today remains something of an underutilized asset.

As a field that encompasses a myriad of technologies derived from harnessing bio-based products and processes, **the headline challenge for IB is to sharpen a compelling overall identity and for this to be supported by a unifying purpose and meaning that is accessible to those outside the immediate community**. This facilitated understanding is required on a technology level, as well as through messaging that translates the technology into value propositions and trusted benefits. These in turn must place IB centre-stage within unfolding narratives that align with the needs and expectations of stakeholders from investors to consumers. Without this, IB lacks an optimal framework around which to rally and mobilize, or a platform from which to claim its warranted place in the spotlight on the frontline of decarbonization – and on equal terms with vehicle electrification and renewable energy.

If communication is key to creating consumer pull and the confidence that investors are seeking, it is equally important from a more functional perspective. Communication is also about developing the systems for evidence, measurement, predictability and interoperability that are essential enablers of faster scale up and internal systems that work smoothly. Beyond this, the scope of communication extends to conveying meaning that enables scalable and consistent adoption of new practices, by clarifying confusion and methods so that businesses and consumers are enlisted to support large-scale change.

The following recommendations reflect the IB community's long recognized need for an ambitious communication strategy and set out the potential role that standards can play in achieving definition and alignment, and garnering trust, within a well-designed system.

Communication tools recommendation 1 (CT1) – IB lexicon

Develop a standardized lexicon of industrial biotechnology that establishes a common language and terminology and is accessible to audiences outside the IB community

The development of a lexicon is recommended to define concepts and terminology necessary for in-depth understanding and communication of the materials, technologies and processes that constitute industrial biotechnology and synthetic biology. This will be framed by an overarching profile of IB and a delimitation of the processes inside its boundaries. It will provide (and rationalize where helpful) naming conventions for use across all areas of the IB technology environment and manufacturing lifecycle, spanning raw materials, microbial contributions and all aspects of bioprocessing and equipment.

To maximize relevance and utility, the lexicon will also profile individual key technologies, methodologies and chemicals that are the backbone of IB today, together with their applications and uses by sector. More than being a vocabulary, the lexicon will be designed as a reference for understanding and communicating the range of environmental, performance and socio-economic benefits that are attributable to IB. It will therefore include coverage of methods that may be used to validate benefits and impact, so that it serves as a robust foundation for claims that can help drive further commercialization.

By cross-referencing other standards, the lexicon will also establish the interrelationship of IB and other standardized nomenclature (e.g. 'bio-based'). Sector-specific thematics may also be included where these are central to understanding the surrounding context in which IB must evolve. In the case of bioplastics, for example, this would provide a guide to the interpretation of terms such as bio-based plastic, biodegradable, compostable and drop-in.

Consideration will also be given to the language that will be most effective in encouraging households and businesses to embrace their role in change. A glossary of IB and bio-based terms will be developed and how they are to be communicated to a number of audiences. Using the example of bioplastics again, this might include an understandable vernacular that streamlines current terminology (bioplastic, bio-based plastic, biodegradable plastic, compostable plastic etc.) into an end-user language that is meaningful for municipalities, businesses and households. In addition, standards to define this agreed-upon glossary may consider eliminating particularly confusing terms - such as 'biodegradable' - from use in consumer-facing claims, on product descriptions or on packaging. This best practice for terminology would extend beyond material composition to include the language of required action, through the association of materials with their preferable waste diversion stream, including visible end-of-life marks and instructions. In this way, the lexicon would support leveraging the role of end-users, through a combination of better-informed purchase decision-making and more responsible waste segregation and disposal behaviour.

"I think one of the things that we've struggled with as a community is reaching for words to describe what it is we're talking about. And I think defining that common language is something standards do really well."

Two alternative routes are available for the development lexicon:

- **BSI PAS (Publicly Available Specification) Standard**: a fast-track standardization document which is developed by a steering group of stakeholders, selected from relevant fields and led by BSI. It offers rapid initiation and turnaround, usually in a twelve-month timeframe

or

- **BSI Flex Standard:** an approach suited to emerging practices which offers a dynamic and iterative approach for developing the lexicon. A Flex standard creates content in a flexible timeframe measured in weeks or months that is shorter than for a PAS. Once developed, it can then be progressed as a PAS or a seed document for a BS/EN/ISO standard. From an IB perspective, it is a route for maximising stakeholder engagement in the lexicon and well-suited to the need for an agile, incremental approach to its collaborative design

It is noteworthy that the American Society for Testing and Materials (ASTM) has developed **ASTM E 3072: 2019 Standard Terminology for Industrial Biotechnology**. The standard is intended to support the design and performance evaluation of fuel ethanol manufacturing facilities and biopharmaceutical facilities, and the possible applications of proteins, DNA, RNA, biomolecules, viruses, fungi, and bacteria in biotechnology research. The standard also accounts for biomass properties such as density, moisture content, ash content, carbohydrate content, and acid-insoluble residue content. ASTM had been seeking additional task group members earlier in 2020 to further develop the current terminology. Another potentially useful standard may be **ANSI/ASABE S 593.1 Terminology & Definitions for Biomass Production, Harvesting and Collection, Storage, Processing, Conversion and Utilization**. This provides terminologies that are used in biomass feedstock production, harvesting, collection, handling, storage, processing and conversion, bioenergy, biofuels, biopower, and bioproducts. In addition, **PAS 600, the Biobased Products Guide to Standards and Claims**, also provides guidance that can be brought to bear when seeking out existing thinking on the subject. Each of these standards, and any ongoing updates, may be the fastest logical starting point for UK IB companies to either adopt existing sets of terminology, and/or jump start a similar standard that addresses any other unique needs of the UK IB community.

Communication tools recommendation 2 (CT2) – communication strategy

Formulate a communication strategy to raise the public profile of IB and enlist advocacy and funding, with targeted messaging by audience type

The lexicon described above will be one element of an overall communications strategy that has the objective of increasing the public profile of industrial biotechnology, as set out in the **National Industrial Biotechnology Strategy to 2030**, which was launched in 2018.

The primary aim of the communications strategy will be to develop a louder voice that enlists the support of policy makers for IB's ambitious long-term development horizons, through a combination of advocacy, funding and supportive policy measures that create certainty, longevity and confidence. In addition, the strategy will be designed to maximize the effective reach of IB at all levels across other key target stakeholder groups, including government departments, investors, businesses, local authorities and consumers.

The shaping of a revitalized communications strategy presents an opportunity to first consider the question of identity. The term industrial biotechnology is obviously an accurate statement of fact, yet for many it is hardly suggestive of the new possibilities for far-reaching change that these technologies open up, or compelling as a consumer or employer brand. Industrial biotechnology, synthetic biology and engineering biology are all terms that currently co-exist and, while they are not necessarily synonymous, this further points to a possible opportunity to forge a stronger common narrative under a future-proof identity.

Through whatever mechanism is finally chosen, **industrial biotechnology requires the concepts of bold vision, ground-breaking reach and transformative benefits to be embedded in its philosophy and deployed around a unifying purpose that can be defined across its areas of application through adapted narrative for highly targeted resonance**.

As an adjunct to the lexicon, it is therefore recommended that tailored messaging frameworks are developed for key target groups by industry sector and audience type. The messaging will need to position IB as a cornerstone in the shaping of new sector practices that address megatrends at play on global markets, so that IB is understood as a prominent and integral part of world-leading best practice for entire ecosystems. This narrative development can best be undertaken in parallel with the initiative to craft new adaptive standards (which is a recommendation in the "informed science led approach" section of this report). These include standards which take a holistic ecosystem services-led view in a way that opens up new opportunities for the recognition of IB within value-adding toolkits.

While narratives will be tailored to individual key area of opportunity, they are likely to be underpinned by a consistent set of core IB thematics, which, for example, may include:

Key messaging themes

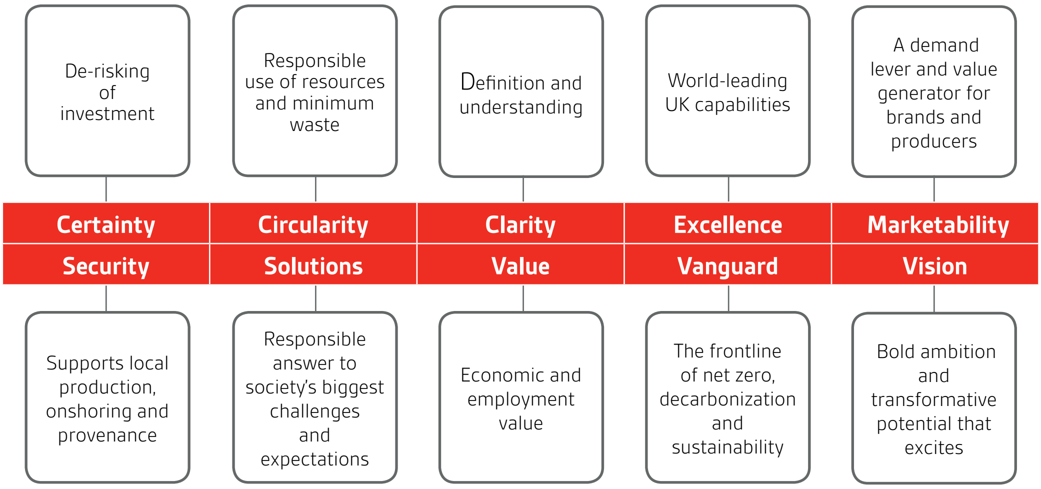


Figure 11

A key narrative strand will be to reinforce the essential role that each stakeholder group plays in advancing industrial biotechnology as the pivot of the UK bioeconomy and at its intersection with other key national strategies for economic growth and safeguarding of the environment.

Specific messaging will also need to be developed on the subject of gene editing, and more generally GM, to inform a balanced debate as the UK evaluates its regulatory future outside the EU. This must seek to provide the public with clarification, understanding and evidence that addresses consumer concern where this currently exists, and as a counterweight to misperceptions shaped by historical media coverage. Specifically, this should unpick unhelpful amalgamations under the banner of GM. It should also allow the public to reach its own conclusion, by highlighting the evidence that, rather than being a focal point for concern, gene editing might better be seen as a solution to many of the world's problems.

"We (the IB community) have been talking about this for so long now; we just need to get on and do it and start socialising it and testing out our comms. There is no better time than right now for us to promote the benefits of IB to everyone."

Communication tools recommendation 3 (CT3) – material characterization

Develop standards for the characterization of feedstocks and microbial host systems based on properties and process suitability, to build system predictability across the IB life cycle

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Analytical characterization, which is the process by which a material's structure and properties are probed, measured, and classified, has an important role to play in supporting the optimization of biomass conversion processes. There is seen to be an opportunity for new standards in this area, where characterization of feedstocks based on their mechanical, physical and chemical properties – and defining parameters for allowable variations - would mean greater control over feedstock sourcing and fewer issues related to quality variability.

These standards, which would serve as a basis for feedstock specifications, would help support optimal performance, processing and operations - allowing the use of potentially heterogeneous feedstocks that are currently considered problematic due to their inherent variability. **They would offer a valuable procurement tool for biorefineries and biofuels producers using 'feedstock-agnostic' processes, by streamlining feedstock selection against operating requirements and entailing greater flexibility and more control over sourcing.**

As a first step, a scope will need to be developed for properties and parameters for inclusion in the characterization, as well as for the categories of biomass to be characterized. A prioritization can be established across sub-sets of agricultural residues, wood waste, other cellulosic and fibrous materials, municipal solid waste and additional biogenic sources.

Beyond biomass feedstocks, the potential benefits of characterization standards are likely to extend to other aspects of the IB technology platform too. This should include standards for the profiling and description of generic and specific microbial host systems and their suitability for certain IB processes to aid selection for the user. For example, standards for the profiling and grading of microorganisms would facilitate their selection and transferability based on proven use and suitability for specific types of IB processes.

The common denominator of these initiatives is being part of a toolkit to build the process predictability, supply confidence and control needed for increasing acceleration at scale.

"And we've got problems at the moment because what some of the commercial guys agreed to is 'oh well, you make that for us.' But what are they making? What are we getting? We haven't actually defined it in terms of strength, activity, end use or whatever. We end up having a lot of debate about what's good, what's bad and what's appropriate."

Communication tools recommendation 4 (CT4) – metrology

Explore opportunities for metrology to help translate innovation into reproducible applications across a wider range of IB-using sectors

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Metrology is the scientific study of measurements and therefore closely related to physical and functional characterization, which requires metrology standards for collecting test results. It serves as a framework for the referencing of new products and materials to standards, and, as such, provides a gateway for innovation into uptake and commercialization by industry. The opportunities for metrology to help translate innovation into reproducible applications extend across a wide range of biotechnology-using sectors and applications, making it an important focus area for investment and development.

The Centre for Engineering Biology, Metrology and Standards was established in 2017 to help the UK synthetic biology industry improve the investigation, manufacturing and adoption of new products, through the development of metrology standards. This is a centre of excellence and resources that should be further leveraged to support the IB community and enable the design aspect of synthetic biology's engineering approach which relies on simulation - and therefore also on digital biological information and the data collection methods that are needed to capture it.

"We can actually streamline those processes into readily identifiable and specific activities that produce the same thing again and again. And that is dependent on metrology and the ability to show repeatability and sustainability around the production of materials."

Communication tools recommendation 5 (CT5) – CO_2 footprint or bio-based labels

Explore best option for a universal standardized and mandatory labelling system that is based on GHG potential (CO2 footprint or carbon neutrality) and/or bio-based content

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Today, consumers are faced with an array of product claims that can often confuse more than clarify product impacts and attributes. This is exacerbated by the range of potential sustainability-related aspects that can be impacted throughout the life cycle of a product. **A streamlined labelling landscape would help consumers who are receptive to buying products with minimal environmental impacts, but who do not have the time or expertise needed to navigate through what can appear to be contradictory claims by similar products.**

From the perspective of industrial biotechnology, the development of standardized approaches to labelling presents an opportunity for greater traction across its sectors of application. In particular, there is a strong body of opinion that mandatory labelling using a standardized protocol should be introduced across all products. This would not be exclusively for consumer products but should include B2B transactions as well, so that impacts are known and can be authenticated along the supply chain. Labelling would increase the weight of IB-derived sustainability benefits by enforcing transparency and comparison between competing products on the market - as a basis for informed decision-making. It was also mentioned that a standard-backed system that is a universally understood benchmark across sectors has more weight than industry accreditation systems

By decluttering the existing labelling landscape with a clear unifying system, it is also expected that IB would further unlock the 'market pull' of consumer preference and gain momentum from brand owners who are confident in the robustness of the overall system.

A universal product labelling scheme of this type would require extensive consultation about which sustainability attributes to use and how.

Three potential approaches to communicating the environmental advantages, particularly related to the carbon intensity, of bio-based products are:

1. Focus simply on promoting whether a product is bio-based, and the percentage of bio-based content
2. Require mandatory disclosure of carbon footprints of all products, regardless of whether they are carbon neutral, as this inherently advantages most bio-based products
3. Focus on an IB-specific initiative for achieving, and aggressively communicating, carbon neutrality for bio-based products

Mandatory labelling on the level of bio-based content in a product would be feasible across a spectrum of plastics, packaging and other consumer goods, although it would need to be clear in the case of labelling of food, for example, that it relates to the packaging and not the food inside. Labelling based on the level of bio-based content could potentially be integrated with carbon footprinting into an aggregate rating or used independently as the metric for labelling. The practical advantage of selecting 'bio-based' as the measure is that it would be simpler to implement than a system that requires companies having to go through the typically costly and time-intensive process of getting their GHG emissions quantified through life cycle assessment, especially if this needs to be done on a product-by-product basis. For the purposes of measurement, bio-based content could be determined by the standard **BS EN 16785-1:2015** which involves a less complex process.

"And for me, that comes into ultimately that any consumer good should be traffic lighted in the way that fat, sugar and salt are for food."

While a bio-based label system would therefore offer practical benefits, bio-based and low carbon intensity are not in every case synonymous. The question is therefore whether bio-based is a good enough proxy for low carbon intensity, or whether a more empirical LCA approach is essential for a label to be equitable and meaningful from a carbon perspective. The BioPreferred Program in the USA was regarded by some as a possible model to investigate. It includes a product label to indicate bio-based content and has successfully stimulated the market for bio-based products through a federal procurement scheme. (See 'USA BioPreferred Equivalent' recommendation in the "Supportive level playing field" pathway.)

The lead scenario suggested by the IB community is for labelling to be based on the carbon footprint of a product, which requires detailed life-cycle assessments (LCAs) to be conducted by each IB company. (Details and relevant standards are described later in "Communication tools – recommendation 7). Carbon footprinting is, in fact, already an emerging trend among consumer goods companies, with Unilever having recently announced the introduction of carbon labels on 70,000 products, which show the quantity of GHG emitted in the process of manufacturing and shipping products to consumers. The dairy-free milk firm, Oatly, and Quorn, the meat substitute brand, have also introduced CO_2 emissions information on their labels.

A third option is for IB companies collectively to support the development, adoption and promotion of a single, targeted claim, such as carbon neutrality. This supports a consistent, focused message to the market. Since bio-based products are lower emitting than corresponding petroleum-derived products, the cost and effort to attain carbon neutrality are a significantly lower bar to clear than their higher impact counterparts. Collective commitment to carbon neutrality by producers of IB-enabled products highlights this advantage and creates a market differentiator. This path requires a high degree of collaboration, consultation and alignment within the IB community, including the setting of LCA boundaries that can be aligned with **PAS 2060**, the internationally applicable specification for the demonstration of carbon neutrality, if this claim option is selected.

Equally at the heart of this communication is the need for agreed-upon iconography – symbols or marks that can be easily interpreted and understood by a diverse range of stakeholders. Guidelines for the use of symbols or logos to communicate environmental benefits are provided by **BS EN ISO 14024: 2018 "Environmental labels and declarations —Type I environmental labelling —Principles and procedures"**.

A "traffic light" system is one option suggested by IB stakeholders, and while it is not a definitive recommendation it illustrates the principles of the labelling required: products are graded across a structure that is visual and intuitive, and that links to a call to action. Labels might further show GHG data in the same way that nutritional labels do for salt, fat and sugar; however, the level of detail incorporated needs to be weighed against the risks of complexity for consumers who may have difficulty putting the information into context.

From a practical usability perspective, the same label iconography would ideally integrate correct waste disposal practice for consumers and households and serve as a marker for waste handlers (These aspects of labelling are addressed in the next recommendation).

The expectation is that the development of a universal label would need to dovetail with a future fiscal landscape that recognizes the importance of the bioeconomy as a focus for targeted support. For example, many stakeholders envisage the label as part of an overall system involving either a carbon tax or mandated usage of materials that have a low carbon impact (these are addressed in the "Supportive level playing field" section of this report).

A public consultation is recommended on a future harmonized approach to labelling and fiscal landscape that will be most effective in fast-tracking IB and the bioeconomy overall.

A coordinated communication campaign would also be an essential element, in order to educate and familiarize the public with the meaning of iconography and data used on labels, as well as of the carbon footprint or bio-based terms and definitions that would underpin it.

Benefits and drawbacks of labelling approaches

	Benefits	Drawbacks
Bio-based content	Simpler to implement	Potentially less of a compelling consumer message as bio-based and low carbon intensity are not in every case synonymous
Carbon footprint	Increasing adoption & consumer interest	Higher costs to implement across products; footprint data may be too abstract for typical consumers
Carbon neutral	Most compelling to consumers; lends itself to IB advantages over comparable petroleum-derived products; simple message that most can understand	Aggressive target that some may not be able to meet in the near term, which may delay IB-wide consensus and adoption

Figure 12

Communication tools recommendation 6 (CT6) – life cycle assessment (LCA)

Align stakeholders on how to leverage LCA methods and environmental standards as a platform for promoting IB; sponsor LCAs for a set of flagship IB products and materials

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IB technologies have the potential to demonstrate clear and compelling environmental advantages over many of the products and materials against which they compete, particularly fossil-derived fuels, chemicals and plastics. Effective communication of these advantages to both consumers and B2B customers will therefore be key to accelerated market adoption, a sentiment echoed by most stakeholders interviewed for this project.

The challenge, as expressed by the community, is partly tied to a low level of common understanding of tools or standards that exist to calculate these impacts. In addition, stakeholders face an inherent disadvantage as pioneers in fields that are dominated by established businesses operating at far greater scale and with decades of data behind them. The challenge is further compounded by the need for a method to be consistently applied across IB and conventional chemistry routes in order to be an effective comparative tool.

Product life cycle assessments (LCAs) are a mature and commonly used method of calculating the carbon footprint of a portion, or the entirety, of the energy and materials consumed to produce a product. **ISO 14040: 2006 "Environmental management — Life cycle assessment — Principles and framework"**, **ISO 14044:2006 "Environmental management — Life cycle assessment — Requirements and guidelines"**, and **ISO/TS 14067 "Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification"** define methods to credibly conduct an LCA and understand associated GHG emissions. The **BS EN 16760:2015 standard "Bio-based products — Life Cycle Assessment"** has been developed specifically to calculate the material and energy consumption of products comprised of bio-based materials, making this a fit for products developed through industrial biotechnology production processes.

LCAs are seen as a credible means to measure environmental impacts, assuming they are conducted and documented by qualified practitioners using agreed-upon methods as defined by these nationally- or internationally accepted standards. Although standards that have been developed and committee-reviewed by this type of rigorous and transparent process are considered to be a credible set of protocols, some variability can exist in their use, simply due to the complexity of materials and production methods inherent in the making of most products. In order to enable as wide of an audience to use these methods against as many types of products and use-cases, LCAs typically enable the organization conducting the LCA to determine boundaries, within reasonable limits, based on significance. Examples include:

- **Cradle-to-gate studies**: these are assessments of a partial product life cycle from resource extraction (cradle) to the factory gate (e.g. before it is transported to the consumer).
- **Gate-to-gate studies**: these are partial LCAs looking at only one value-added process in the entire production chain. Gate-to-gate modules may also later be linked in their appropriate production chain to form a complete cradle-to-gate evaluation.
- **Cradle-to-grave**: the full LCA from resource extraction ('cradle') through use phase and to disposal phase ('grave').

The setting of boundaries is required to be determined based on the stated goals of the LCA as well as based on the significance of the impact to be included or excluded. Assumptions that go into determining boundaries must be clearly and explicitly stated.

Although this level of flexibility accommodates a wider range of materials, products, value chains and use cases, it may be one source of the frustration expressed by IB stakeholders who seek a simple, comparable measurement that can be easily communicated to a wide, potentially non-technical audience. It is therefore important for IB companies to understand how to establish LCA boundaries, and to collaborate on creating agreed-upon boundaries for chosen IB products and categories that simplify communication of environmental benefits to their customers.

It is not recommended to create new methods for conducting LCAs, as some interviewed stakeholders have suggested, but instead, consider best use of the valid, peer-reviewed methods that have already been developed. A suggested approach is to align IB stakeholders on the use of current, relevant environmental standards, in order to better use the tools that already exist. It is also important that IB companies understand how these standards are intended to work with one another to support the goal of creating a clear way to communicate environmental benefits to customers via product labels. For example, companies that choose to demonstrate a claim of carbon neutrality can follow a stepwise path defined by the following set of standards:

- **ISO 14040: 2006, ISO 14044:2006, ISO/TS 14067,** and **BS EN 16760:2015** provide guidance on gathering and analysing the data needed to understand energy and materials consumed in manufacturing a product, along with corresponding GHG emissions
- **PAS 2060** (addressing carbon neutrality) provides guidance on how that data should be used to support, communicate, and maintain a claim of carbon neutrality

- **BS EN ISO 14024: 2018 "Environmental labels and declarations —Type I environmental labelling —Principles and procedures**" provides guidance on how companies should affix marks on products to communicate that claim of carbon neutral.

Supporting a deeper understanding and harmonized use of these standards tools will enable consistent and credible claims that support IB messaging related to superior environmental impacts. This will require convening of IB stakeholders to establish agreed-upon, product- or segment-specific boundaries applicable to IB-enabled products or industry segments, including biofuels, bioplastics, speciality chemicals, and agritech. This agreement on boundaries is critical for consistency of messaging, as it limits misinterpretation and enables comparison of one product to another based on a single, consistent scope.

The following is an example of an action path that IB companies can follow that supports collective adoption, verification and declaration of carbon neutrality:

- Agreement on standardized approach: **PAS 2060** (Carbon Neutrality) is an internationally recognized standard defining how companies can go about achieving and demonstrating carbon neutrality and is one approach for supporting the objectives of the IB stakeholders.
- Commitment to carbon neutrality: this requires individual companies publicly commit to the goal and develop a plan to attain carbon neutrality. Some plans may require carbon offsets for the near-term in cases where companies cannot meet carbon neutrality solely through energy reduction, sequestration and transition to renewable sources.
- Determine agreed-upon boundaries for each IB product category or IB industrial segment: this enables IB producers and their customers to have a high degree of confidence in their claims, as it is based on a consistent process that addresses the same areas of the value chain to be chosen as in-scope for comparable products and materials. Although there is some latitude in the **PAS 2060** standard related to determining boundaries, it requires companies to include production sites or processes that are determined to be significant sources of emissions within the scope. Direct emissions (Scope 1) and indirect emissions (Scope 2 and 3) greater than 1% of the total carbon footprint are required to be in scope for product-specific claims, while those of lesser impact are permitted to be excluded. Although the standard provides specific guidelines and requirements related to choosing what is or is not in scope, participating IB companies should still determine agreed-upon points of their typical value chains that are significant enough to be deemed in-scope for their product type. That type of harmonization enables IB to promote, in specific and consistent terms, the preferred environmental impact of their products, which prevents critics from finding flaws due to seemingly inconsistent approaches. In addition, this also enables the calculation and establishment of consistent GHG emissions factors. Investment into calculating emissions factors for bio-based materials will also accelerate uptake by downstream customers seeking to calculate their own carbon footprints, which include the indirect Scope 3 emissions of upstream materials and activity.

"I think the trouble with LCA is a lot of people kind of do their own back of an envelope calculations."

The role of standards in measuring and communicating carbon neutrality claims

Companies that seek to communicate environmental benefits to customers via product labels should use methods that have been created via the consensus and scientific input of standards development process. Understanding and communicating environmental claims and their benefits are supported by a series of interdependent standards designed to work in concert.

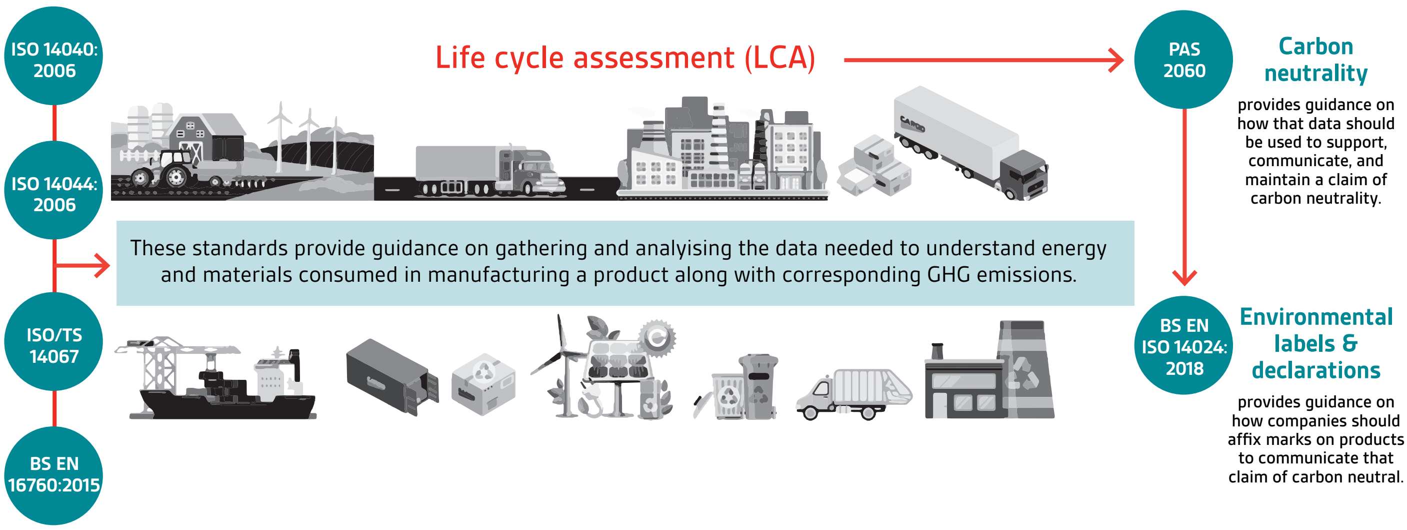

Figure 13

- Company implementation of carbon neutrality plans for in-scope products
- Validate carbon neutrality: Although companies can self-assess and declare carbon neutrality based on applying the methods of the standard themselves, it is recommended that qualified third-parties conduct this validation, in order to project the highest level of credibility and objectivity of the process.
- Declaration: companies can then publicly declare that their product has attained the status of carbon neutrality, which can be done, in part, through product labelling. In order to do so, companies should affix environmental marks according to the methods described in **BS EN ISO 14024: 2018 "Environmental labels and declarations —Type I environmental labelling — Principles and procedures"**, as **PAS 2060, ISO 14040**, and **ISO 14044** do not provide guidance on application of product logos or symbols related to environmental attributes.

A further option is to sponsor LCAs for a cross-section of IB-derived products and materials, in which all key IB end use sectors are represented. This would provide a powerful platform from which to promote a broad message of environmental superiority over legacy technologies that is backed by scientific data and by a consolidated body of evidence. It would help to kick start the promotion of bio-based products based on proven LCA advantage by being coordinated across products, rather than just a one-by-one approach.

Communication tools recommendation 7 (CT7) – waste end-of-life labels

Explore best options for a new mandatory and standardized labelling system on products, bins and liners to instruct on correct end-of-life path and maximize capture of resources

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At present, a typical household or business is presented with a myriad of options related to how they dispose of waste, which varies from region-to-region in the UK. **If households and businesses are to play their part in segregation of waste and resource capture, they will need to be better supported in understanding the impact of their actions, how resources are captured from waste, and simply – what goes in which bin?**

On product iconography/communication

Simple, clear communication at the point of waste separation is essential to successful adoption of these new practices and their resultant benefits. For example, end users responsible for upstream segregation of waste should not be expected to discern which types of plastics can be disposed via which paths. Therefore, clear, direct instructions are essential, with on-product iconography that consistently maps material type to bin, or path type.

The optimal path for compostable bio-based plastics is via organic recycling, which consists of anaerobic digestion and composting. On-product/package marks can therefore also provide clear direction to waste producers in order to maximize this resource capture. They will further ensure that appropriate waste can be leveraged as a feedstock for IB processes.

Bin iconography/communication

In addition to on-product/package marking, a key point of end user interaction, and instruction, is directly on the disposal bins. Considerations should include:

- Consistent iconography: on product icons must be consistent with those displayed on associated bins to indicate the type of material and EOL path.
- Bin colour: bins should be assigned with separate colours to further emphasize the differing EOL paths. If possible, on product markings and communication should also create associations with each particular bin colour to further reinforce appropriate EOL paths for each material.
- Explicit instructions: unlike products, disposal bins are not limited in size (as it relates to iconography). This offers a unique opportunity to provide more detailed instructions to end users related to materials and EOL paths. Direct written messages will reinforce icons assigned to each EOL path (e.g. 'This bin is only to be used for food and compostable waste.') It may also be possible to provide additional information, written or graphical, to end users about the actual process ('Your food waste will produce environmentally-friendly energy.') Care must be taken not to overwhelm the end user, as essential messages can become diluted.

"People just want and need a consistent system. Right now, we have different rules which is just not helpful"

Pathway 3: informed science-led approach

Industrial biotechnology is a fast-moving field of action that requires an equally dynamic evolution of standards and regulations in order to realize the economic and environmental potential of its transformative innovation. This pathway sets out initiatives which seek to unlock this potential by addressing headwinds and reframing best practice in order to achieve greater momentum. It is underpinned by the rationale that regulations and standards must be agile enough to reflect scientific expertise and evidence, particularly where this is currently a roadblock that limits access to whole areas of opportunity. The same agility must drive a new adaptive approach to standardization: while the current standards landscape is not inherently a barrier for much of IB, neither is it actively enabling. Vision is required to adapt and create new standards tool kits that actively lend momentum.

Informed science-led approach recommendation 1 (ISLA1) - genome editing

Shape consensus and determine potential approach for removing gene-editing from the scope of future UK GM regulation, in order to create new headroom for innovation and investment; develop a PAS covering genome-editing techniques as a best-practice support

The European Union's legal framework for genetically modified organisms (GMOs) currently blocks gene-editing techniques such as the much publicized Crispr-Cas9 – which enable alterations or changes to the genome within the same organism using enzymes as 'molecular scissors'. Although gene editing is distinct from genetic modification, which inserts genetic material (DNA) from one organism into a different one, both practices are effectively currently inhibited in the EU and the UK following a Court of Justice of the European Union ruling in 2018, which treats the two as effectively the same.

The case for a regulatory review of gene editing as a tool is a strong one as it allows very specific changes to the DNA and can have many useful applications. It centres around the scientific principle that gene editing is comparable to existing selective breeding practices, insofar as it is in effect a more precise and targeted method for the formation of new combinations of genetic material that would occur through such breeding programmes.

Compared to alternatives, gene editing is therefore an efficient route offering greater speed and precision in the development of crops with the characteristics needed to make a targeted contribution towards the agriculture sector's twin objectives of improving productivity and reducing overall GHG impacts. Strains can be developed with enhanced stress tolerance, pest and disease resistance or improved nutritional quality, which raise yield and optimize land utilization, while simultaneously reducing requirements for conventional crop protection chemicals and fertilizer. Similarly, gene editing has significant potential to support innovation in farming systems, for example through new crop strains that are adapted to grow on marginal land, improve rates of atmospheric carbon sequestration, enhance the quality of the soil microbiome, or provide new and more efficient types of biogenic feedstock to produce biofuels and next-generation bio-based chemicals. Impacts are also achievable towards a reduction in CO_2 created by food waste, for example where crops such as potatoes can be developed which have extended shelf-life.

At present, the EU regulatory framework preventing gene editing in crops and farm animal results in the UK being out of step with countries such as the USA, Argentina, Brazil, Australia and Japan. **A more enabling UK regulatory environment, that gives access to best available technologies, proven solutions and the same tools as producers elsewhere, could unlock the world-leading potential of UK scientists to support a more competitive and sustainable food and farming sector at home, as well as more productive and climate-friendly farming systems in developing countries, through use of fewer resources while maintaining or increasing quality and yields.** The UK's synthetic biology and IB communities are therefore strongly supportive of a comprehensive regulatory review, for which there is also backing across the farming, plant breeding and international development sectors.

Europabio.org, one of the most respected authorities on genome issues, is also notable for having highlighted the unique opportunity to create headroom for innovation and continued future investment by fostering and guiding breakthroughs for genome editing.

This roadmap aligns with the recently announced plan for a consultation on the UK's post-Brexit regulation of precision engineering techniques, which the government has tabled for Autumn 2020. The opportunity for societal and economic benefits from taking gene-editing techniques out of the scope of future GM regulation will need be weighed carefully against the potential risks, which include repercussions on EU trade from regulatory divergence. In addition, the science-based case that organisms developed through genome editing should not be subject to disproportionate regulatory requirements will need to be made as part of an inclusive debate that engages with the range of opposing concerns, for example across potential risks to the farmed and natural environment, animal welfare and biodiversity.

In parallel, and extending beyond the consultation, a wide-reaching communication programme is recommended that informs citizens and fosters greater clarity, so that gene editing has the opportunity to be understood as a solution to societal needs and problems. (This roadmap element is further detailed in the "communication tools" section of his report).

A complementary workstream is proposed to explore the opportunity to develop a PAS for genome-editing techniques, as a further technology enabler and a best-practice support.

"The UK needs to look at the question of gene editing independently, because there are other parts of the world that are storming ahead using that technology, and at the moment we're still kind of hamstrung and we haven't been able to do that."

Informed science-led approach recommendation 2 (ISLA2) - adaptive standards

Implement collaborative workstreams to agree and develop adaptive standards and guidelines that lighten evidence burdens and build momentum for IB opportunities

The opportunity exists to adjust and configure standards into a more powerful enabling framework – one that reflects the scientific evidence, innovation and growing maturity of industrial biotechnology, as well as its need, like any fast-moving technology area, for good practice definitions to dynamically evolve. The recommendation of this roadmap is to focus action around several overarching themes which shape an environment for acceleration:

Updating legacy pathways

IB technologies and products are typically evaluated against approval processes, standards and guidelines that apply equally to and were originally developed for their fossil-derived alternatives. There is a body of opinion among IB stakeholders that pathways largely conceived around conventional chemistries are therefore a sub-optimal mirror for the technologies, properties and possibilities that now underpin innovative bio-based solutions.

Reviewing evidence burdens

The approval and testing processes for placing new molecules, active ingredients and formulated products on the market can represent an insurmountable time and cost burden for the small starts-ups and spinouts on the frontline of IB innovation. While health and safety principles remain paramount, there are seen to be opportunities for science-based streamlining of approval and test data requirements into less onerous evidence sub-sets.

Creating system-based frameworks

While standards for individual products and methods play an essential role, there is an overlying opportunity to develop new sets of standards that take a more holistic view of ecosystems and of integrated management practices within a given sector. Vision will be required to develop such standards of dynamic good practice for a fast-changing world, as part of the toolkit for creating an environment suited to expedited implementation of IB.

Formalising key IB building blocks

The catalogue of IB-enabled drop-in chemical building blocks is now widely regarded as having reached a milestone of critical mass. This 'coming of age' offers the prospect of greater commercial momentum and scale for the IB space, with new standards having a potential role to play in further consolidating the credentials of IB inside the industrial mainstream. The community developed UKBioChem10[30] showcases this notion.

Accommodating 'bio-variability'

Use of heterogeneous biogenic feedstock inherently introduces a level of variability which is not the case in legacy fossil-derived chemistries which are mainly single highly characterized molecules and building blocks. Future systems are needed which are tolerant of this fact.

As a next step, it is recommended that collaborative workstreams, and (potentially) task and finish groups, are established to develop action plans and to provide an advisory steer for adaptive standards and approval processes. While this will require a high level of focus on individual sectors, consideration should also be given to complementary horizontal activity to aid cross-sectoral collaboration around common opportunities and challenges. Workstreams will need to involve representation of all stages of IB value chains and with the inclusion of the sector-relevant regulatory bodies.

The examples highlighted below are selected to illustrate the current challenges and opportunities, as a groundwork for this collaborative standards adaptation and innovation.

Impacted IB sectors

- Agritech
- Biofuels
- Fine and Speciality Chemicals
- Bio-based plastics

[30] http://ukbiochem10.co.uk/wp/wp-content/uploads/2019/01/UKBioChem10_Report.pdf

2a. Plant protection product (PPP) guidelines (ISLA2a)

Themes:

IB sectors:

The placing of plant protection products on the market is covered by EC regulation 1107, which governs the approval of all chemistries and microorganisms used in these applications and is therefore the key gateway for innovative biologicals into the crop protection space. Data requirements are set under this regulation for both active ingredients and formulated products, with the default requirement being a full data package that amounts to the entire arsenal of listed tests and studies. Dedicated OECD guideline documents have been developed for certain categories of semiochemicals and natural substances, which give more streamlined guidance about which data from the full list is actually relevant in their case and therefore required for their risk assessment. However, where no such guidance document exists, the full default requirement applies. This is the case, for example, with nature-inspired chemical substances produced by chemical or biological synthesis, which include peptides produced by insects or fungi, as well as antibodies and RNA-based products. These substances can be produced by insects, microorganisms or synthetic routes to be identical to a naturally extracted equivalent. The profile and hazard are the same as the natural source, and technology allows them to be manufactured in a way that limits chemical impurities and by-product synthesis. However, because they are not covered by a specific guidance document, the whole data requirement package must be applied to them, on the grounds that the molecule is produced synthetically. Stakeholders have noted, for example, that the relevance of testing the effects of these molecules on non-target species other than insects is limited for a species-specific peptide – however, this is the default regulatory requirement.

An opportunity is therefore identified for the UK to take the initiative in adapting lists of test and data requirements for each category of these classes of products in order to facilitate their deployment, while still maintaining a rigorous assessment process. A more bespoke and adaptive system would address a current roadblock whereby prohibitive costs prevent access for small companies and entail that only multinationals bring products to market.

2b. Soil microbiome standard (ISLA2b)

Themes:

IB sectors:

The soil microbiome refers to the diverse communities of bacteria, fungi and other microorganisms in soil habitats, which underpin key benefits that soils provide, such as nutrient recycling, the neutralization of pollutants, and aiding carbon storage in soil organic matter. The understanding and management of soil microbiomes is an opportunity for IB to develop as a foundation for regenerative agriculture and the reduction of GHG emissions, as for example through the use of organic fertilizer, which encourages beneficial microbes while inhibiting pathogens – and which displaces the carbon footprint of traditional fertilizer.

Soil microbiome research is an early-stage field that requires further knowledge and evidence in order to profile the composition of microbial consortia and the interrelationships of biological systems and their environments, as a platform for understanding the role that the soil microbiome performs and for developing integrated management techniques. As one example of this work, Strathclyde University is currently conducting a project to explore a framework for soil health metrics and measurement methods. Other proposed initiatives include research to characterize and map regional variations in microbiome composition (as they are doing in the USA). The results of such projects will be an important input to inform how standards development should evolve.

Current soil health standards include:

- **BS ISO 20295:2018 Soil quality. Determination of perchlorate in soil using ion chromatography**
- **BS ISO 20244:2018 Soil quality. Screening method for water content. Determination by refractometry**
- **BS ISO 19097-2:2018 Accelerated life test method of mixed metal oxide anodes for cathodic protection. Application in soils and natural waters**
- **BS ISO 18645:2016 Fertilizers and soil conditioners. Water soluble fertilizer. General requirements (from a committee - CII)**
- **BS 10176:2020 -Taking soil samples for determination of volatile organic compounds (VOCs). Specification**

Beyond the existing standards, which focus on specific testing methods, an opportunity exists to develop an overarching standard for microbiome health which sets quality benchmarks and is a framework for measurement, management and ongoing improvement.

2c. Integrated pest management (IPM) standard (ISLA2c)

Themes:

IB sectors:

The EU ban on most types of chemical pest control has created momentum for alternative and, particularly, integrated approaches to pest detection, prevention and control that offer a sustainable solution to the challenges faced by the agricultural sector. Potential exists for the development of a standard for IPM best practice, as a mode of agricultural operation in which biocontrol agents work synergistically with other methodologies (e.g. predictive tools, spraying methods, resistant crop varieties) across plant, soil and agroecosystem health.

2d. Sustainable meat production standards (ISLA2d)

Themes:

IB sectors:

Meat production contributes to a thriving food system, yet the industry needs to evolve to respond to the challenges and expectations of consumers and stakeholders in regard to its sustainability credentials. For example, potential approaches to more sustainable livestock farming methods that support regenerative agriculture are not widely known by most consumers. At the same time, producers stand to benefit through the value-added attributes of sustainable livestock farming methods and regenerative agriculture. A potential role therefore exists for new standards that help to better differentiate between meat production systems and to demonstrate their characteristics. While there are already a multitude of country-specific standards of different sorts (in the case of beef, for example, grass-fed, deforestation related, organic), their harmonization could facilitate trade by co-ordinating communication, education, product branding, trade and supply chain compliance. Such a standard could forge a narrative to educate, and also to brand and differentiate sustainably produced meat by highlighting the positive benefits across the spectrum of sustainability dimensions including welfare, health, GHG emissions, land use, environmental stewardship and product nutritional quality. Its potential relevance to industrial biotechnology would be in creating a stronger demand framework for innovative IB-enabled animal feeds and additives, by placing these within an unfolding narrative that defines world's best practice for meat.

2e. Ruminant methane standard (ISLA2e)

Themes:

IB sectors:

Innovative IB-based animal feeds and feed additives such as novel proteins, probiotics and feed enzymes to aid digestion combine multiple benefits which will enable the agricultural sector to address its climate change challenge without compromising domestic production.

These benefits can include higher productivity (feed conversion rates), better animal health and the displacement of more carbon-intensive feed sources such as soya. For the livestock sector, re-engineering of animal feeds using biotechnology also has impact potential in the area of rumen microbiome, where new feed types are able to significantly reduce livestock methane emissions. Methane accounts for half of total GHG emissions from the UK agricultural sector, making these technologies an important focus within the overall environmental equation. An opportunity exists for a standard and metrics that link feeds to emissions, as a tool to support their environmental case and validate their impacts, and as a platform for commercialization within overall best practice for livestock feed management.

2f. Sustainable bio-based standard (ISLA2f)

Themes:

IB sectors:

Standards for the measurement of bio-based content, notably BS EN 16785-1:2015 and BS ISO 16620-2:2019, are important elements of the IB development tool-kit which have considerable potential to be more actively leveraged to drive uptake, with several possible options for this highlighted in the "Supportive level playing field" section of this report. In addition, some IB stakeholders felt that scope may exist to augment these standards, by adding a further overlay of possible qualification for content that is not only bio-based but is moreover sustainably bio-based. This would require sustainable biomass certification of feedstocks originating from agricultural biomass and from various other types of circular resource. In the case of agricultural biomass, for example, this could be supported by a sustainable agriculture standard or certification of provenance from sustainable methods.

2g. Material crops standard (ISLA2g)

Themes:

IB sectors:

The cultivation of crops for biofuel production raises questions for policymakers and the agricultural sector, linked primarily to the 'food versus fuel' debate and a need for scrutiny of the lifecycle greenhouse gas emissions that the biofuels themselves may generate. Dedicated material crops, which are perennial crops grown for non-food production, have the potential to provide biomass with high energy yield and in large volumes. Research by Aberystwyth University[31], for example, has identified that planting the perennial biomass crop miscanthus in the UK could offset 2–13 Mt oil eq. yr, and contribute up to 10% of current energy use. For biofuels producers, crops such as miscanthus, willow and short rotation coppice, which can be grown in the UK, represent an important but as yet underdeveloped opportunity for a domestic feedstock supply solution. In addition, where appropriately managed, they offer important environmental benefits in that they can be grown on existing lower-grade agricultural land, are suited to reduced management intensity, and can contribute to improving soil microbiomes. A further key characteristic is their potential effectiveness as carbon sinks through the sequestration of carbon in soil, which is itself a prime factor in overall strategy for combating climate change. An opportunity exists to explore new standardization for these crop types that centres on their carbon sequestration performance and land use credentials. Setting the standard for carbon sequestration performance and optimal land use for these crops would provide a guide for the precision engineering of new crop strains, as well as a framework for validating and better differentiating the net GHG impacts of the biofuels that are produced from them.

2h. Biofuels standards (ISLA2h)

Themes:

IB sectors:

Standardization of biofuels across quality and test methods, as well as their use in petrol and diesel at different blend level, is usually regarded as an area that is adequately covered and subject to a level of review in line with regulations – for example, in preparation for future increases in bioethanol and biodiesel blends. Cited standards for automotive fuels include:

For petrol-

- **BS EN 228:2012+A1:2017Automotive fuels. Unleaded petrol. Requirements and test methods**
- **BS EN 15376:2014 Automotive fuels. Ethanol as a blending component for petrol. Requirements and test methods**

For diesel-

- **BS EN 590:2013+A1:2017 Automotive fuels. Diesel. Requirements and test methods**
- **BS EN 14214:2012+A2:2019 Liquid petroleum products. Fatty acid methyl esters (FAME) for use in diesel engines and heating applications. Requirements and test methods**

More than by standards, the pace of market growth for biofuels used in automotive diesel and petrol is determined by policy volumetric tools – and notably by a combination of the RTFO (Renewable Transport Fuels Obligation), which requires fuel suppliers to meet specific targets for renewable fuels, and measures for the progressive introduction of higher blend levels. Although these mechanisms are the primary lever, IB stakeholders see an opportunity for an evolution of standards to define and validate best practice in a way that helps to cut through potential misinformation surrounding the sustainability of biofuels. In particular, the life cycle assessment (LCA) attached to biofuels is an area warranting a more harmonized approach, which forms part of a cross-IB recommendation for LCA in the "Communications tools" section of this report. Further related initiatives that merit future exploration include new standards to support a tightening up of sustainability certification, as a shaper lens for discerning the sustainability profile of one biofuel versus another.

2i. Sustainable aviation fuels production pathways (ISLA2i)

Themes:

IB sectors:

ASTM International is the body that assures the testing and safety of new jet fuels, with the standard ASTM D4054 – 19 covering the evaluation and approval of new fuels and fuel additives for commercial and military aviation gas turbine engines. Where a new fuel does not fit an established production pathway, it must undergo stringent testing along four tiers, with each tier requiring a larger volume of fuel and higher costs, in order to establish a new alternative pathway. The advance of SAF development capability in the UK through use of novel technologies and feedstocks represents a seedbed of opportunity, yet the high costs of this testing are a significant blocker. A proposed future UK Clearing House that offers a comprehensive jet fuel testing service in the UK coupled with substantial development funding are the key roadmap elements for SAFs and will be important tools for establishing the new pathways that are essential to realising the potential of UK-led innovation. These elements are further highlighted in the "Supportive level playing field" section of this report.

[31] https://pure.aber.ac.uk/portal/files/6593598/McCalmont_et_al_2015_GCB_Bioenergy.pdf

2j. Reach (ISLA2j)

Themes:

IB sectors:

The main regulatory framework for all chemicals produced in the EU is REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) (EC 1907/2006), which was implemented in 2006. The key aim of REACH is to improve the protection of human health and the environment through better and earlier identification of the intrinsic properties of chemical substances. This is done by the four processes of REACH, embodied in the acronym. REACH has been designed to encourage industry to look at substituting hazardous chemicals with more benign molecules and the use of safer technologies where possible. Chemicals made via IB routes, as any other, fall within the scope of REACH regulations.

Often the goal of producing more environmentally friendly bio-based materials is one of the key drivers for companies to investigate IB products and processes in the first place. Thus, this is where IB products could offer advantages, with strong momentum from consumer facing markets for more sustainable products lending strength to their development. However, in order to best tap into this momentum, optimize alignment with REACH, and facilitate uptake, the provision of a standardized catalogue of IB-derived alternatives is needed, with transparency on how they are made and on their sustainability credentials.

While REACH provides a single regulatory framework for the control of chemicals and ensures information on the properties of chemicals enabling them to be safely handled, it is not an easy process for manufacturers, especially small companies with new and innovative products. An additional specific blocker can be the need for animal testing for new molecules, which is both costly and time consuming, especially for small companies and start-ups. Furthermore, animal testing runs contrary to the sensitivities of exactly those consumers who bring greatest market momentum for bio-friendly products. Although REACH has minimized animal testing by making it mandatory to share previous animal testing data, alternative approaches using the principles of the 3Rs – replace, reduce, refine – should be established as much as possible to reduce the burden of cost of testing and proof of safety. Sharing best practice for in vitro testing and in silico modelling and working with of the National Centre for the Replacement, Refinement and Reduction in Animals in Research to create and develop evidence based changes in policy and regulations would facilitate the smoother development and commercialization of entirely new molecules which are an exciting area where IB has a central role to play.

2k. UK biochem 10 (ISLA2k)

Themes:

IB sectors:

Although there is not much appetite for the UK to establish its own alternative to REACH, it was thought that there could be an opportunity for it to develop a model of manufacturing standards, integrating the relevant supporting evidence base and regulatory compliance.

It is recommended that this initiative focus initially on the UKBiochem10, which are the ten bio-based chemicals that were identified through extensive consultation with industry as being those on which the UK could focus resources for maximum impact, based on:

- Their commercial viability
- UK strength to exploit
- Functionality
- Sustainability

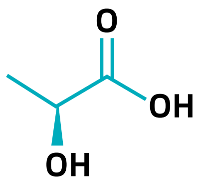
"It's around using the most appropriate and up-to-date standards to be able to determine the burden of evidence for proving safety."

They were agreed through multiple workshops with LBNet and other experts representing the chemicals industry, biotech start-ups, academia, government, biotechnology consultants and the Biotechnology and Biological Sciences Research Council. Each chemical was evaluated to present a clear long-term business opportunity for the UK, where there is already a strong foundation, and where the UK has the business and research infrastructure to develop and commercialize them.

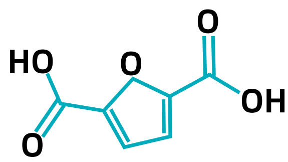
This core catalogue of bio-based chemicals, which include a proportion of so called 'drop in' replacements, could be used as a test bed to generate new streamlined standards of manufacturing due to their opportunity for the UK to show market penetration and impact.

One of the considerations highlighted in all IB sectors is the inherent variability of feedstocks which could carry over into the final products, together with the question of how this can best be managed and its impact in performance and safety. There is an opportunity for the UK to develop exemplar standards through investment in metrology techniques that can be used to characterize and apply statistical approaches to minimize unpredictability; something that again could be applied to the UKBioChem10 as exemplars.

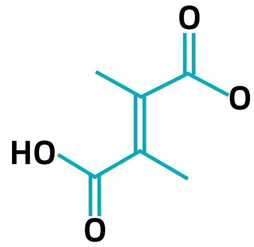
Biochem 10



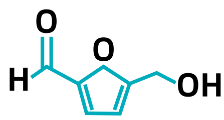
Lactic Acid



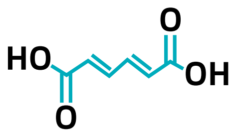
FDCA



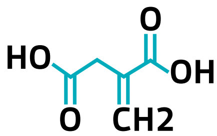
Levoglucosenome



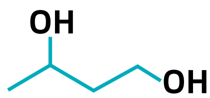
HMF



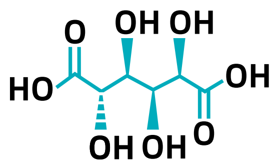
Muconic Acid



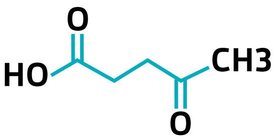
Itaconic Acid



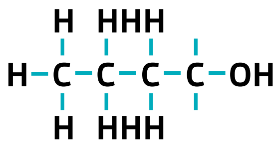
1,3-Butanediol



Glucaric Acid



Levulenic Acid



N-Butanol

Figure 14

" We have put a marker in the sand by identifying what we see as the top 10 chemicals we could be good at producing using bioroutes. Get this right and we have both our own routes as well as confidence to make other chemicals using IB".

Pathway 4: supportive level playing field

Although IB businesses hold great economic promise, they currently face an uphill climb to compete on what many IB stakeholders have described as an uneven playing field. Aside from the inherent challenges that technology disruptors or insurgents must overcome in any domain, IB has to contend with the added incline of operating within an overall market where the policy and tax environment continues to mean a home advantage for the higher emitting incumbents that IB aims to displace.

The following recommendations present a range of options to simultaneously level out the playing field and provide the additional support that IB requires to deliver on its economic and environmental potential. These solutions relate to policies the UK chooses to adopt, targets to which the UK commits, and how the UK incentivizes desired behaviours. They cover the opportunity to use carbon pricing as a lever for IB growth, the role of government procurement support, as well as the scope for more assertive interventions to drive market transformation and the ability of IB to develop at greater scale and speed. In addition, they reflect the need for targeted funding and infrastructure support which will be critical to bringing research projects through to commercialization, and to the embedding of IB technology as a mainstay, rather than a novelty, across its broad range of sectors of application.

Supportive level playing field recommendation 1 (SLPF1) – carbon pricing

Adopt carbon pricing, most likely through a carbon tax, that levels the competitive field and forces the pace of transition to IB and away from fossil fuel-dependent technologies

R

In order to enable industrial biotechnology and synthetic biology to scale more rapidly, the UK must adopt policies that boost their competitiveness with legacy products and materials, which continue to retain the lead in part due to a distorted marketplace. Fossil fuel-derived technologies hold a significant advantage in the form of scale, infrastructure, investment capital, and sheer incumbency. More so, these advantages are bolstered by significant subsidies to the fossil fuel industry. According to the IMF, the fossil fuel industry benefited from approximately $5.2 trillion in direct and indirect subsidies in 2017[32]. For IB start-ups, or even established businesses wishing to use cleaner, greener technologies in their operations, these factors create a more difficult environment for innovation to gain a foothold.

Stakeholders were of the opinion that effective carbon pricing is ultimately the best mechanism to redress this imbalance, and that without it the transition to IB solutions will be much slower. Economists also broadly consider a market-influencing mechanism such as a carbon tax to be the most efficient way to reduce emissions, as it encourages business and consumers to make purchasing and behavioural choices that reduce their own footprints. The same IMF report noted that efficient (equitable) fossil fuel pricing would have lowered global carbon emissions by 28 percent and fossil fuel air pollution deaths by 46 percent, and increased government revenue by 3.8 percent of GDP, at the time of the study[33].

In order for the UK to meet its net zero goals, it must take aggressive actions and adopt bold policy initiatives. Two potential paths include:

1. Adopt or adapt the current EU Emissions Trading System (ETS)
2. Adopt a carbon tax and redistribution scheme

Both paths are under consideration in the review of carbon pricing options following the UK's departure from the EU, which opens the door to alternatives to the existing EU Emissions Trading System (ETS).

The EU Emissions Trading System (EU ETS) is a cornerstone of the EU's policy to combat climate change and its key tool for reducing greenhouse gas emissions cost-effectively. A cap is set on the total amount of certain greenhouse gases that can be emitted by installations covered by the system. Within the cap, companies receive or buy emission allowances, which they can trade with one another as needed. They can also buy limited amounts of international credits from emission-saving projects around the world. The current ETS has been a contributor to the UK's ability to reduce GHG emissions by 29% over the past decade[34]. Following the UK's departure from the EU, proposals under consideration include introduction of the UK's own ETS, or a carbon tax, or for development of both in a conjoined carbon pricing strategy.

"The only way to drive the industry and make a real sustained impact is if everybody has to include a price for carbon in their economics. And I think when you have carbon included in the economics, it actually unleashes better innovation and opportunities for people to find ways to comply with and to benefit from it."

[32] https://www.imf.org/en/Publications/WP/Issues/2019/05/02/Global-Fossil-Fuel-Subsidies-Remain-Large-An-Update-Based-on-Country-Level-Estimates-46509
[33] Ibid
[34] https://www.carbonbrief.org/analysis-uks-co2-emissions-have-fallen-29-per-cent-over-the-past-decade

An approach that has been under consideration in proposals released in June 2020 is to establish a UK-specific trading system to replace the EU ETS system. The proposed plan reduces the existing emissions cap set in the current EU ETS by five percent. However, although the proposed further five percent reduction is an improvement, the tabled scheme is unlikely to be enough to enable the UK to achieve its net zero ambitions, according to research conducted by the London School of Economics[35]. This is in part, since the scope of the ETS cap-and-trade system only covers around 35% of UK GHG emissions[36].

Applying a price to a wider range of emissions will drive more GHG reductions. That is likely to be more effectively accomplished through adoption of a carbon tax and redistribution scheme, similar to the one adopted in the Canadian province of British Columbia (BC), which applies to about 70% of the province's GHG emissions through the taxation of the purchase and use of fossil fuels. BC redistributes the revenue collected from the tax to consumers, largely through the form of tax credits[37]. These tax credits aim to offset any adverse financial impacts of the tax, avoid tax increases, and generate economic stimulus.

Benefits that have been derived, in part, as a result of the policy include:

- Per capita CO_2 emissions declined up to 15% from 2008-2013
- From 2008-2011, BC had an approximate 10% greater reduction in vehicle fuel use as compared to the rest of Canada[38]
- Aggregate employment in the province has increased over the 2007-2013 period[39]
- Canada's overall emissions intensity for the economy has declined by 36% since 1990[40]
- Heavy industry GHG emissions have been reduced by 11 Mt CO_2E from 2005-2018[41]
- Between 2005 and 2018, GHG emissions from manufacturing industries have declined by 4 Mt CO_2E with a 12% decrease in energy use[42]

The United States is also considering a similar approach defined in a bill being advanced at present through the legislative process, titled the *Energy Innovation and Carbon Dividend Act*. The policy is projected to reduce America's emissions by at least 40% in the first 12 years and is expected to create 2.1 million new jobs[43]. The objectives of the legislation are described as follows by the advocacy group Citizens Climate Lobby, which engages communities and lawmakers for adoption of the bill:

The policy is carried out as follows:

- Carbon Fee: this policy puts a fee on fossil fuels like coal, oil, and gas. It starts low, and grows over time. It will drive down carbon pollution because energy companies, industries, and consumers will move toward cleaner, cheaper options.
- Carbon Dividend: the money collected from the carbon fee is allocated in equal shares every month to the American people to spend as they see fit. Programme costs are paid from the fees collected. The government does not keep any of the money from the carbon fee.
- Border Carbon Adjustment (BCA): to protect U.S. manufacturers and jobs, imported goods will be assessed a border carbon adjustment, and goods exported from the United States will receive a refund under this policy. The BCA is to be imposed on emissions-intensive trade-exposed (EITE) goods that are imported or exported. Imported goods under this EITE classification will pay a surcharge to account for the difference, and US EITE exports will receive a refund for the carbon fee associated with its carbon footprint. This prevents the carbon fee from putting US businesses at a competitive disadvantage in global markets and removes the incentive for those businesses to relocate to avoid the carbon fee. The carbon border fee adjustment is also specifically designed to comply with international trade law under the WTO.

The current consultation process being undertaken by the UK provides an opportunity for IB businesses to engage with policymakers and legislators in the shaping a well-designed carbon pricing approach that supports UK net zero goals and economic development, where IB technology is a strategic pillar of both.

[35] https://www.lse.ac.uk/GranthamInstitute/publication/how-to-price-carbon-to-reach-net-zero-emissions-in-the-uk/

[36] https://www.carbonbrief.org/guest-post-what-the-uk-can-learn-from-carbon-pricing-schemes-around-the-world

[37] https://nicholasinstitute.duke.edu/sites/default/files/publications/ni_wp_15-04_full.pdf

[38] https://institute.smartprosperity.ca/sites/default/files/publications/files/BC%27s%20Carbon%20Tax%20Shift%20after%205%20Years%20-%20Results.pdf

[39] https://institute.smartprosperity.ca/sites/default/files/jobs-and-bc-carbon-tax.pdf

[40] https://unfccc.int/documents/224829

[41] https://unfccc.int/documents/224829

[42] https://unfccc.int/documents/224829

[43] https://citizensclimatelobby.org/energy-innovation-and-carbon-dividend-act/

Supportive level playing field recommendation 2 (SLPF2) – USA BioPreferred equivalent

Explore the potential to implement a UK scheme modelled on the USA's BioPreferred Program to leverage government procurement and further drive market demand for IB

One path identified by interviewed IB stakeholders that is worth further exploration is the development and promotion of a UK scheme comparable to the BioPreferred Program managed by the United States Department of Agriculture (USDA). Interviewees have suggested that, while a UK version of the programme might mirror the US approach by using bio-based as its foundation, other environmental aspects such as the carbon footprint of products might be an alternative framework for a UK version.

The stated objective of the BioPreferred Program is to increase the purchase and use of bio-based products, as well as to support economic development, create new markets for farm commodities, and take advantage of the positive environmental impacts associated with bio-based products. A major driver of the programme is the requirement for federal agencies to purchase bio-based products in the 139 categories identified by the USDA, including cleaners, carpet, lubricants, paints, etc. The US Federal Government spends approximately $445 billion USD on goods and services. The BioPreferred program leverages this procurement spend to create a consistent subsidy to support commercial growth of bio-based products. Each mandatory purchasing category specifies the minimum bio-based content that is required for products within the category. The programme also provides acquisition tools, a directory of BioPreferred products (BioPreferred Catalog), and training resources to assist in meeting bio-based purchasing requirements; all of these components are designed to support procurement managers in easily identifying bio-based products that support their needs.

The second key element of the programme is a voluntary product certification and labelling scheme. A business with a bio-based product that meets USDA criteria may apply for certification, allowing them to display the USDA Certified Bio-based Product label on the product, which communicates the verified amount of renewable biological ingredients (referred to as bio-based content) to consumers.

There are currently three groups of bio-based products under the BioPreferred Program:

1. Certified-only – bio-based products that do not fit into one of the 97 categories qualified for mandatory federal purchasing, but have gone through the BioPreferred Program's certification process, including third-party ASTM D6866 bio-based content testing and validation. **BS EN 16785-1:2015 Bio-based products - Bio-based content - Part 1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis** and **ISO 16620-2:2019 Plastics — Biobased content — Part 2: Determination of biobased carbon content** are a comparable standards that may be considered for a UK program modelled after the US BioPreferred program for certification.
2. Qualified-only – bio-based products that fall within a mandatory federal purchasing category but have not gone through the BioPreferred Program's certification process nor third-party bio-based content testing.
3. Qualified/Certified – products that belong in one of the 97 product categories qualified for mandatory federal purchasing **and** have gone through the BioPreferred Program's certification process, including third-party bio-based content testing and validation.

"The BioPreferred scheme used in the US has shown government commitment to bio-based products and no doubt driven innovation to make them for a big customer and open up the market. We should do the same here."

Only Certified-only and Qualified/Certified bio-based products can bear the USDA Certified Biobased Product Label, which also communicates the percentage volume of bio-based content of the product, on their packaging and marketing materials. The testing required for certification measures the percentage of natural biomass-derived materials versus petroleum-derived synthetic materials.

A UK programme modelled after the BioPreferred Program would play an important role in promoting awareness and broader adoption, and is therefore an option that IB stakeholders are keen to explore. The primary benefit of the USA programme is the mandatory purchase of BioPreferred products by Federal procurement departments. This creates rapid market demand, which supports commercial growth and creates a more predictable investment environment.

Interviewed IB stakeholders have suggested that development of a UK scheme might potentially be designed around other environmental metrics, such as either the carbon footprint or the carbon neutrality of a product. The possible approaches for a UK programme therefore align with the three options for labelling described in the "Communication tools" section of this report, which range from broad promotion of bio-based content, to mandatory communication of carbon footprints, to a more aggressive IB-specific initiative to attain and promote carbon neutrality of bio-based products.

Supportive level playing field recommendation 3 (SLPF3) – incentivization of organic recycling

Explore options such as soil carbon credits to increase financial yields on organic recycling and raise output quality, creating a better adapted ecosystem for compostable bioplastics

R

Incentives to steer municipal solid waste away from landfill or incineration could additionally be configured to promote organic recycling processes, including the circular end-of-life solutions needed to establish a compostable bioplastics market at greater scale. The current market value of compost is such that MRFs have progressively cut their composting times in order to maximize their volume throughput to reach a level of acceptable commercial return, in a trade-off that has had negative consequences for compostable bioplastics since their decomposition needs are no longer in line with standard composting practices. Here again, an opportunity is seen by stakeholders for intervention to create a more commercially attractive market for the production of compost and digestate. For example, there could be merit in exploring how to boost the value of these outputs through, for example, soil carbon credit schemes, with the aim of lifting commercial yields to the point at which it is more viable for waste companies to increase compost processing times. The benefit would be multiple, as it would create a more favourable context for compostable bioplastics, while potentially improving levels of compost quality and increasing the overall volumes of CO_2 retained in a short carbon cycle returning to the soil.

An initiative of this kind could be combined with a ringfencing of funds raised from Extended Producer Responsibility (EPR) for investment in the enhancement of the country's organic recycling infrastructure.

"Bioplastics need help to take off properly. They are more costly right now than petroleum ones and they need support, possibly in both manufacture and end of life to get them into the supply chains."

Supportive level playing field recommendation 4 (SLPF4) – optimization of IB feedstock access

Design assertive interventions to boost feedstock access for innovative IB technologies

Assured access to feedstock in sufficient volumes is a key factor for stakeholder confidence, and for the overall viability and attractiveness of the UK as a location for future investment in IB-based production. The importance of this is described in the "Circular resource" section of this report, together with the need for tools and standards to maximize resource visibility within functioning circular systems. In addition to the recommendations in that section, several other areas of opportunities were identified for direct regulatory interventions to better enable IB technology developers to access important feedstock resources, which otherwise remain uncaptured or locked into more established supply chains.

4a. Divert MSW away from other legacy routes (SPLF4a)

Municipal solid waste (MSW) is an essential component of the overall IB feedstock mix and one which exemplifies the desirable circular principle of transforming otherwise low-value resource through innovative technologies into high-value materials and products, from advanced fuels to fine chemicals. However, this resource can be hard to tap into due to local waste disposal companies having long-running contracts for the waste to be sent to landfill or incinerated instead. From an IB perspective, these incumbent supply chains are an obstacle to surety of long-term access to a key material supply.

Stakeholders felt that suitable solutions could include a government commitment to a date for the introduction of an incineration tax, through which waste would be taxed in the same way that waste sent to landfill is. Similarly, a halt to new investment in energy-from-waste (EfW) facilities, coupled with an explicit deprioritization of that route in the waste hierarchy, were identified as likely measures for containing and progressively reducing a system that is felt to have no rationale within a circular economy. A UKWIN report[44] has stated that the UK's 42 incinerators released a combined total of nearly 11 million tonnes of CO_2 in 2017. A proportion of this could be displaced by the progressive reweighting of MSW pathways in favour of the re-use of waste in low or zero-carbon processes and technologies.

4b. Incentivize the supply of MSW as an IB feedstock (SPLF4b)

Incineration and landfill are today built into the business models of waste management companies, for whom they offer a degree of bankable certainty over a long enough future horizon. For innovative technologies, particularly when at an early stage of commercial maturity, disrupting these entrenched supply patterns is a recognized challenge, with waste management companies heavily invested in current operations and potentially risk averse when it comes to new technologies. It is therefore recommended that consideration be given to future incentivization mechanisms targeted at MRF (Materials recycling facilities) which make it commercially attractive enough for them to treat the circulation of waste into IB value chains as a market, rather than an afterthought. While municipal waste is available today, there is a sense that 'you have to know where to look for it' - and that a system of market-creating incentive would lower the hurdle for IB technology developers to access supply.

Such as system would benefit from being designed to promote the preparation, segregation and supply of MSW to standards that align better with IB customer needs for turning that waste into a feedstock suitable for use in their various processes. It could additionally be expected that waste management companies co-develop the technologies to valorize MSW into building block chemicals, such as ethanol.

4c. Incentivize the use of recycled carbon for fuels production through the RTFO (SPLF4c)

The Renewable Transport Fuel Obligation (RTFO) Order is the UK's mechanism for reducing greenhouse gas emissions from fuel supplied for use inroad vehicles and non-road mobile machinery, by encouraging the supply of renewable fuels. The main obligation requires fuel suppliers to supply a certain share of renewable fuels. Obligated suppliers may meet their obligation by redeeming Renewable Transport Fuel Certificates (RTFCs) – which are gained by supplying sustainable renewable fuels - or by paying a fixed sum for each litre of fuel for which they wish to 'buy-out' of their obligation.

Outside of the main obligation, The RTFO incentivizes development fuels. These are a sub-target of advanced fuels, including notably aviation fuels, which are technically complex to produce but which fit the UK's long-term strategic needs and therefore warrant greater support. A sub-mandate exits for these fuels, which are double rewarded under the scheme for their use of sustainable wastes or residues as feedstock. Converting MSW into sustainable aviation fuel is an example of this type of pathway, which turns dirty, nasty feedstocks into high value, desirable fuels which offer an essential decarbonization route for the important but otherwise much harder to decarbonize aviation sector.

At present, the double credit system applies only to the portion of such fuels made from renewable feedstock sources. It therefore excludes the category of recycled carbon fuels, which uses surplus waste of other origin, such as waste plastic and the non-renewable portions of co-mingled black bag waste, which might otherwise end up in landfill. This means, for example, that a company producing fuels using a combination of renewable

[44] https://ukwin.org.uk/files/pdf/UKWIN-2018-Incineration-Climate-Change-Report.pdf

sources and recycled carbon is eligible for the incentive only on the percentage of the fuel that is of renewable origin. Since the aim of the development fuels strategy is to draw investment into the UK, there is likely merit in providing support to recycled carbon fuels as well.

The recycled carbon fuels category extends to processes that utilize carbon captured from industrial waste flue gases, and which would similarly benefit from eligibility for these incentives. Until these are introduced, it is likely that a number of production projects and investments will remain on hold.

4d. Incentivize carbon capture and utilization (CCU) via emissions trading system (ETS) (SPLF4d)

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The EU Emissions Trading System (EU ETS) is a cornerstone of the EU's policy to combat climate change and its key tool for reducing greenhouse gas emissions cost-effectively. A cap is set on the total amount of certain greenhouse gases that can be emitted by installations covered by the system. Within the cap, companies receive or buy emission allowances, which they can trade with one another as needed. They can also buy limited amounts of international credits from emission-saving projects around the world. Following the UK's departure from the EU, proposals under consideration include introduction of the UK's own emissions trading system, or a carbon tax, or for development of both in a conjoined strategy.

Under the current scheme, companies are able to earn credits for Carbon capture and storage (CCS) which locks CO_2 into carefully selected underground locations and prevents it from entering the atmosphere. However, this incentive does not apply in the same way to Carbon capture and utilization (CCU), whereby one company's waste gas is used by another company's production process. This is due to the logic that the CO_2 is not permanently contained and will eventually return into the atmosphere.

For IB technology, these gases are an important latent resource opportunity: they can be recycled using biological systems that are a platform for innovative products from fuels to plastics, fine chemicals and animal feed proteins. Potential adjustments to the current regulatory system have been suggested in order to recognize the indirect carbon savings that these CCU processes can deliver, in cases where the IB-based material produced through CCU displaces the use of more carbon intensive alternatives. This would be the case, for example, where a feed protein produced by this route is significantly less carbon intensive than the soy or fishmeal alternatives which it replaces. The opportunity is therefore to design regulation that recognizes these indirect savings, which are measurable in terms of overall CO_2 displacement, but require the measurement boundary to extend beyond the manufacturing process.

Potentially a credit or saving on emissions tariffs could be made available for waste gas generators who make gas available for recycling. The credit would be established by calculating the indirect CO_2 saving achieved through the recycling of the gas. It would give IB companies a further element to their value proposition, by being able to offer a carbon offset mechanism to companies who supply them with gas.

Opportunities to effectively and efficiently quantify displaced or avoided emissions resulting from carbon recycling technologies should be explored and leveraged. This may be via comparisons that are calculated via existing Life Cycle Assessment (LCA) standards or via updated standards developed specifically for the purpose of calculating the carbon savings from avoided emissions. Either would be required to support such a credit mechanism. At present, the most definitive guidance on the subject is provided via the World Resources Institute working paper titled, **Estimating And Reporting The Comparative Emissions Impacts Of Products**[45]

"It always comes down to feedstock availability. So, there needs to be some decent logistics for making suitable quality municipal solid waste, which is probably assorted solid waste already, available in large quantities."

[45] https://ghgprotocol.org/sites/default/files/standards/18_WP_Comparative-Emissions_final.pdf

Supportive level playing field recommendation 5 (SLPF5) – interventions to accelerate IB uptake

Regulatory mandates, incentives and targets to boost market for IB-enabled technologies

5a. Implement legislative measures to accelerate the use of compostable bioplastics (SPLF5a)

Compostable plastics present the best near-term opportunity for bioplastics to gain a critical mass of market adoption, which will drive further investment into the sector. **It is recommended that targeted regulatory measures are taken to accelerate the replacement of petroleum-derived plastics across the range of applications to which these bio-based alternatives are potentially better adapted.** These are primarily for flexible packaging/products that are likely to be contaminated with food. Through its use in these applications, compostable plastic material can facilitate the recycling of food waste, since the packaging/product and food can be disposed of together effectively through organic recycling collections.

Such a mechanism might involve an outright ban of fossil-derived plastics in specified applications, or instead mandating only plastics containing above a specified percentage of bio-based content.

Although not a definitive list, single-use applications for likely early inclusion in the scope are:

- Food bin liners
- Plastic shopping bags
- Plastic tableware
- Coffee pods
- Food meal trays
- Fruit and vegetable stickers

Depending on the chosen mechanism, regulations would in these cases specify only materials which conform to **BS EN 13432**, or with a specified bio-based content measured according to the standard **BS ISO 16620-2:2019, Plastics. Biobased content. Determination of biobased carbon content**.

As an illustration of the power of such initiatives, the Italian Government has, over the past ten years, adopted policies to support displacement of carbon-derived plastic bags by bio-based bags and liners. These have resulted in significant positive environmental and economic impacts, including notably the doubling of the revenue of the Italian bioplastics sector in seven years, matched by the similar growth of the number of companies and people employed by the sector.

It is anticipated that the recommended measures would boost UK market demand for compostable bioplastics from a current level approaching 15,000 tonnes/year to over 100,000 tonnes per year.

5b. Develop measures to support a transition to bio-based drop-ins for high-volume polymer manufacture (SPLF5b)

While compostable plastics represent an opportunity for bioplastics to establish an early market footprint from which to expand, an IB strategy for the plastics sector must also consider how to displace fossil-derived feedstocks from existing high-volume polymer production, by supplanting these with bio-based drop-ins on the existing manufacturing assets of the UK's major polymer manufacturers. For example, these can potentially be used for bio-polyethylene (bio-PE), bio-propylene (bio-PP), bio-polyethylene terephthalate (bio-PET). However, the current financials and raw material costs present volume polymer producers with little incentive to switch away from existing fossil-based technologies.

Policies are therefore needed to support drop-in bioplastics that make them more attractive than their petrochemical counterparts. A carbon tax would be one effective measure. Alternatively, a plastics tax on all plastics with below a specified percentage of bio-based content is an assertive option to consider.

5c. Use existing volumetric tools and incentive mechanisms to boost uptake of biofuels (SPLF5c)

Move to E10 petrol in 2021 as a stepping-stone to progressively higher bioethanol blend levels

Unleaded petrol in the UK currently contains up to 5% bioethanol, a grade known as E5, whereas E10 petrol which contains up to 10% bioethanol is not currently available. The main barrier to its introduction is said to have been at the fuel retailer level, where a perceived "first mover" risk has prevented fuel retailers from unilaterally introducing the new grade, and with competition law cited as hindering the alternative of a co-ordinated industry-led roll-out. This combination of factors means it is unlikely that E10 will be introduced without government intervention at retail level (current obligations to supply renewable fuels apply to suppliers rather than retailers/forecourts).

The DfT has recently launched a consultation on the introduction of E10, with the proposal being to introduce it as the 95 octane 'Premium' grade from 2021. This move offers the prospect of much needed new momentum for the bioethanol sector, with envisaged recommissioning of mothballed capacity, creation of further headroom for investment in new production, as well as an increased commercial outlet for local agricultural crops and residues.

The UK currently has bioethanol production capacity of around 1 billion litres per year, with two large biorefineries based in Humberside and Teesside and one smaller facility in Norfolk. To date, this capacity has regularly been underutilized. Currently, of the larger plants, one is operating at around half capacity, with the other mothballed due to poor market conditions. The introduction of E10 would therefore create the conditions needed for the revitalization and expansion of this sector.

The strategic value of such a move is also in terms of the increased domestic production of valuable by-products from ethanol that are an important platform for development of the UK's IB capability for value-added chemicals manufacture.

As an opportunity and mechanism for reducing CO_2 emissions, a move to E10 sits squarely in the category of 'low-hanging fruit'. The DfT's consultation[46] on introducing E10 notes that, if combined with an envisaged increase to overall biofuel supply targets, the move could cut overall transport CO_2 emissions by the equivalent of taking around 350,000 cars off the road. Those targets are on average 9.75% by volume in 2020, rising further to at least 12.4% by volume in 2032. However, these are minimum targets and are expected to increase.

With such a range of potential benefits from the introduction of E10, the question inevitably arises of whether 10% is an ambitious enough level, or whether, for example, significantly higher blend levels than E10 might be introduced or time tabled. The practicality of E10 is that it is a recognized fuel blend that does not require adjustments to the majority of vehicles. It is also already accounted for in the relevant standard (**BS EN 228:2012+A1:2017 Automotive fuels. Unleaded petrol. Requirements and test methods**), which references two levels of ethanol blending (up to 5% and up to 10%). Creating more space for additional biofuels supply, by stretching blending limits to E20, is nevertheless a feasible enough objective to explore. While it has been stated that vehicles coming onto the market since 2011 are able to handle fuels with up to 20% ethanol, it will be necessary to investigate potential technical barriers to use of fuels with higher levels of ethanol, in terms of their compatibility with both vehicles and fuel supply infrastructure. Introducing E20, and potentially higher levels to follow, would need to be supported by standardization to account for these higher blend rates and their referencing within the existing **BS EN 228** standard for unleaded petrol.

While blend levels and the RTFO are currently the UK's main volumetric tools for developing low carbon fuels, it is worth noting that they do not especially favour domestic producers or guarantee their competitiveness – as evidenced by the majority of ethanol blended in E5 today being imported. Other factors such as tariffs, planning permission and environmental building regulation, notwithstanding the high capital costs of installing facilities, are also at play and therefore all need configuring within a coordinated approach to boost the UK sector's competitiveness. Strong domestic convictions around environmental manufacturing standards risk displacing a carbon footprint to elsewhere, unless these factor in a carbon border adjustment for imported products.

Move to B10 diesel and incentivize use of higher blend levels for suitable applications

The standard **BS EN 590:2013+A1:2017 Automotive fuels. Diesel. Requirements and test methods** describes the physical properties that all automotive diesel fuel must meet if it is to be sold in the UK. It currently allows for B7 diesel which is based on the blending of up to 7% Fatty Acid Methyl Ester (FAME) biodiesel with conventional petrochemical diesel. **BS EN 590 overlaps with BS 2869:2017 Fuel oils for agricultural, domestic and industrial engines and boilers,** which is a set of British Standards that mirrors the same 7% blend limit across a wide range of off-road applications. The fuel types covered within the scope of BS 2869 are referred to as off-road diesel or red diesel.

As with petrol, a future strategy for diesel should look to optimize blend levels to the highest rates with which vehicles and equipment are compatible. A general increase from B7 to B10 – i.e. through a 3% lift of the blend limit - was suggested by stakeholders as a realistic and achievable early move.

Significantly higher FAME blend levels than 10% can be supplied – such as B20, B30 or even B100- however, vehicles (normally buses or HGVs) need to be approved for these fuels by the manufacturer. Similar compatibility exists on a case-by-case basis by OEM and equipment type across tractors and other agricultural equipment, as well as in other categories such as inland waterway vessels. While a universal move to much higher blend levels would need to be a progressive and gradual process based on cross-OEM alignment, there are therefore nearer-term opportunities to transition to higher blend levels where vehicles and equipment are compatible. IB stakeholders recommended exploring the opportunity for an incentive mechanism for users of fuels with these higher levels of biodiesel content.

Stakeholders also commented that the 7% biodiesel limit specified in **BS EN 590** refers only to (FAME) content. It does not include hydrogenated vegetable oil (HVO) which is a renewable diesel that is flexible in its feedstock requirements and allows for the use of a wide range of low-quality waste and residue materials in the production of drop-in products. Since it may be used at high blend levels, it was noted as a route to fast track an increase in the renewable content in diesel.

[46] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/876383/introducing-e10-petrol-consultation.pdf

5d. Develop targets and incentives to drive market penetration for the UKBiochem10 (SPLF5d)

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As described earlier, the UKBiochem10 are ten bio-based chemicals that were identified through extensive consultation with industry as being those on which the UK could focus resources for maximum impact.

Developing a strategy to leverage the UKBiochem10 is therefore a key element of the roadmap for industrial biotechnology, since they play to UK strength and are potentially commercially viable. Investing in these areas will lead to direct short-term advantage, whilst also promoting the infrastructure and networks to allow other early stage chemicals to develop successfully.

In order to scale these up to commercial products, the development of manufacturing standards is recommended (see recommendation in the "*Informed science-led approach*" section of this report). These standards would provide a framework for focusing resources on exploiting value from these specific chemicals, as well as setting the reference for future regulation to drive their market penetration. For example, it was suggested that mandated usage targets could be set, or Incentives made available to industry users who transition away from fossil-derived materials in favour of these bio-based drop-in alternatives, in order to speed up market uptake and the development of viable commercial models.

5e. Set thresholds of bio-based content or carbon intensity as a basis for mandating use (SPLF5e)

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Bold and ambitious regulatory measures are needed to force the pace of change, as without this the transformation to bio-based and lower-carbon technologies will inevitably be a far slower one, which will negatively impact UK's net zero aspirations and UK prospects to attract and grow IB companies, who may choose other jurisdictions whose policy landscape favours IB development and implementation.

The European ban on phosphates in laundry and dishwasher detergents is an often-cited example of how industry has the agility to switch to new technologies and products at relative speed when under pressure. Prior to the introduction of phosphate-free products, household detergents contributed almost half of the phosphate load in water. Although phosphates are non-toxic, they cause eutrophication – excessive nutrients - and they are therefore deleterious to the environment by causing algal blooms to flourish, resulting in reduced oxygen levels in waterways which impact fish and other aquatic life. A proposal to ban the use of phosphates and to limit the content of other phosphorous containing compounds in consumer laundry detergents was made in 2011 and was effective mid-2013. Similar restrictions applied to dishwasher detergents for consumers as of January 2017. A range of alternative products such as zeolites, citric acid, sodium (bi)carbonate and EDTA and other biodegradable chemicals have replaced phosphates, in a way that evidences industry's adaptability.

From an IB perspective, there would be merit in exploring similar interventions across a wide range of materials and products, in order to fast track the conversion from fossil-derived to bio-based and low-carbon technologies, and to bring forward the environmental benefits. In addition to the comprehensive option of a Carbon Tax that is outlined in this report, stakeholders saw the opportunity for measures that target individual products on a case-by-case basis. Thresholds could be established for a percentage of bio-based content in a product, referencing **BS EN 16785-1:2015 Bio-based products. Bio-based content. Determination of the bio-based content using the radiocarbon analysis and elemental analysis**. Alternatively, a metric of product's carbon footprint might be used. The established thresholds would then serve as the reference for either mandating usage (e.g. only products with above the specified percentage of bio-based content may be used) or for a tax applied on products below the threshold.

Product areas mentioned for priority consideration included plastics, lubricants, hydraulic fluids and surfactants; however, such a mechanism could potentially be applied to most products in time.

"And by specifying minimum bio-based content, that's how you drive feedstocks. That's how you drive everything else because there is a role for government in market development."

Supportive level playing field recommendation 6 (SPLF6) – Plastic Packaging Tax

Amend the design of the planned plastic packaging tax to avoid an unnecessary disadvantage for compostable bioplastics

The Plastic Packaging Tax, expected to take effect in April 2022, will apply to plastic packaging produced in, or imported into the UK that does not contain at least 30% recycled plastic. The policy considers plastic packaging as packaging that is predominantly plastic by weight and is intended to provide a clear economic incentive for businesses to use recycled material in the production of plastic packaging.

The initiative derives from the Resources and Waste Strategy which set out the UK Government's ambitions for higher recycling rates, increased resource efficiency and a more circular economy. According to the current plans, manufacturers and importers of plastic packaging with less than 30% recycled content are to be subject to a tax of £200 per tonne (above a threshold of 10 tonnes). This would mean that plastics which are not recyclable, but are designed to be compostable, will be taxed.

IB stakeholders have expressed concerns that the new tax will unfairly and unnecessarily disadvantage compostable plastics made with bio-based materials, despite their having a profile that aligns with the broader policy goals of reducing plastic waste, lowering GHG emissions, and increased circularity.

The simple solution is to create an exemption to the tax that is specific to bio-based content. This would specify a 30% bio-based threshold as being equivalent to 30% recycled. Such an adjustment would serve the intentions of the tax, while avoiding placing a further obstacle in the path of the bioplastics sector.

This issue has been pointed out by several industry stakeholders in the summary of consultations released by the HM Treasury[47] and HM Revenue & Customs[48], with respondents focusing on including bio-based, biodegradable and compostable plastic within the Plastic Packaging Tax.

"Bioplastics will never take off properly if they are not given the right consideration when developing regulations. They can't be treated exactly the same way as regular plastics".

[47] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/819465/Summary_of_responses_to_the_plastic_packaging_tax_consultation_digital.pdf

[48] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/871559/Plastic_Packaging_Tax_-_Consultation.pdf

Supportive level playing field recommendation 7 (SPLF7) – mass balance methods

Standardize mass balance methods to protect credibility while using their transformative potential for large-scale fossil material substitution via IB routes

The mass balance system is a chain of custody option where sustainability characteristics remain assigned to batches of material on a 'book-keeping' basis, while the physical material can be mixed. Effectively it means that manufacturers can introduce an amount of renewable content into their production and apportion that amount across their products for the purposes of making claims of renewable content, including to products which individually may contain no renewable carbon.

It is a pragmatic mechanism that is widely acknowledged as having a role to play in accelerating the transition of industry towards the large-scale phasing out of fossil raw materials, by offering an economically feasible route to introduce renewable feedstock into high-volume manufacturing.

As acceptance of the system has grown, however, so too has the need for a globally recognized mass balance standard to define the method – particularly since the way the system is now applied can differ significantly. For this reason, the International Organization for Standardization (ISO) is currently working on a new standard to establish a method that is both credible and transformative.

While mass balance can be of benefit to IB, it also poses a real risk to product and brand credibility at consumer level: there is the prospect that 'renewable' marketing claims could understandably be perceived as misleading. It will therefore be important that these standardized methods integrate analysis that can determine chemical and physical traceability, so that claims are only made for products where it is reasonable, and that exclude potentially questionable transfer of renewable credits.

Supportive level playing field recommendation 8 (SPLF8) –pilot and demonstration facilities

Establish and fund open-access demonstration scale plant(s) to de-risk technology, and increase funding to support existing open-access pilot facilities and extend their coverage

Young IB companies often face a period of uncertainty after successful small-scale lab research, but before scale-up and commercialization – during which many stall. This stage often requires capital investment into expensive industrial biorefinery and/or bioprocessing equipment, and still entails risks as to whether research successes can be replicated reproducibly at production scale. These costs and uncertainties are significant barriers that can discourage investment and impede IB's development.

Companies that can access pilot and demonstration scale IB facilities and capabilities have the advantage of reproducing proof of concept studies at scale, thus helping to de-risk their technology and give investors the confidence needed for significant amounts of capital to be raised. These facilities create an environment where more young enterprises and innovations can flourish, since they enable companies to fail and fail fast, and to rapidly iterate without catastrophic losses. Beyond just supporting existing entrepreneurs, this type of environment draws them and their investors in. This serves to create clusters around the facilities, especially if they are also close to academic institutions, providing critical mass and peer-to-peer support, potentially including incubators and IB accelerators.

One approach that targets this critical make-or-break stage of development is to establish open access pilot and demonstration plants. These act to bridge the gap by enabling a more stepwise path, where companies can produce at increasingly larger scales, but not so large that failures become disincentivizing. Creating a path from research discoveries to pilots to production at larger demonstration sites prior to full-scale commercialization offers an optimal environment for both investors and entrepreneurs. It is anticipated that providing open access without capital investment will significantly lower barriers to entry in the IB arena, in a way that mirrors how software-as-a-service has enabled the rapid growth of technology-enabled services developed by small, entrepreneurial firms.

Although the UK has good lab and small-scale pilot facilities, in the form of the BioPilots UK alliance, there is a need for further funding to support the use of these capabilities. Additionally, there is a real need to establish the type of demonstration plant facilities described above that go beyond large pilot scale. This is particularly important for companies who are developing fuels or the biorefinery concept.

It was suggested that existing industrial sites should be assessed for repurposing as demonstration plants, and with an eye for opportunities to co-locate alongside end users and/or feedstock suppliers. The suitability of a location would also be assessed in terms of the scope to develop innovation clusters of existing IB companies, and to leverage adjacent industries, universities, and local talent capital.

Furthermore, investment is needed to ensure that the country's pilot facilities cover more of the wide range of technologies under investigation with commercial potential. This includes setting up dedicated facilities for agriculture, which are equipped to carry out in-field trials of new materials or new crop types, and which can, for instance, provide suitable test facilities for the trialling of new soil improvers.

The UK will greatly increase the likelihood of IB flourishing commercially and contributing to its net zero target by creating this environment. Supportive policies, tax incentives, and direct investment that enable the government, private investors, joint ventures, co-developers and public-private partnerships to invest in maintaining current pilot facilities and developing much needed demonstration sites would further ensure that this becomes a shared investment in UK research and production infrastructure.

"We need an open access demonstration facility in the UK - this would be the best way forward. To be able to show on a large scale that these things work, before people actually then commit hundreds of millions into creating the facilities that might be needed to make them. But this is clearly a valley of death point at the moment."

Supportive level playing field recommendation 9 (SPLF9) - collaborative R&D funding

Reinstate a dedicated IB funding structure, similar to the former IB catalyst, that links funding to assets already in place along the TRL range for collaborative R&D projects

As IB is yet to become 'business as usual' and be embedded within numerous sectors, there is still a need for dedicated funding across the TRLs to bring research projects closer to commercialization.

This type of support was previously embodied in the Industrial Biotechnology Catalyst, which funded collaborative R&D projects from early stage translational to experimental development, and was jointly supported by BBSRC, EPSRC and Innovate UK. The Industrial Biotechnology Catalyst was launched at the same time as the BBSRC funded Networks in Industrial Biotechnology and Bioenergy (NIBBs), which were designed to foster community building and collaborations: these were to be established and tested with proof of concept funding for the academic community, and with business interaction vouchers specifically for industry-academic projects. Due to the continuity of the funding, the Industrial Biotechnology Catalyst was highly successful in developing a pipeline of collaborative projects that progressed IB capability. The scheme had strong demand, in particular at the point when it was curtailed just 2 years and 4 rounds in to an anticipated initial 5-year lifecycle - and just as the supported projects were beginning to show strong signs of commercial potential through significant industry uptake.

The whole IB community has lobbied for the return of a similar funding structure, with enough funds to support the progressing of IB technologies closer to demonstration and ultimately commercialization.

"The IB Catalyst was always a big one: when that disappeared, it was a real shame. You're not going to foster the richness of the pipeline unless you actually support it through all technology readiness levels."

Supportive level playing field recommendation 10 (SPLF10) – IB accelerator network

Establish an IB accelerator or accelerator network for education, mentoring and investor access - with emphasis on mutual de-risking

The start-ups and spinouts that characterize much of industrial biotechnology today face numerous early-stage challenges in securing the quality of investment needed for their success and longevity:

- Technical risk to investors can be a barrier, for example where outlay on testing is needed
- Many of the technologies being developed do not have precedents that investors recognize
- Exciting technologies in themselves are not enough without a plausible route to market
- IB takes longer to get through to a return than investment cycles investors are used to
- Hurried early stage funding can result in clunky capitalization tables that hinder progress
- The wrong type of investors can finally lead to atrophy through lost IP and debt burden

An IB-specific accelerator, or accelerator network, would provide a combination of education, mentoring, and networking. Its focus would be on de-risking for investors by supporting start-ups with:

- Development of business models and value propositions: the frequent refrain that technology 'will be licensed' is not enough, as investors are instead receptive to well-researched business cases that show where value will be generated and have buy-in from value chain stakeholders
- Developing team structures: management is as or more important than technology within the venture evaluation framework; founders and teams need to align with investor expectations

De-risking the process for IB entrepreneurs will also require support, with guidance through their early funding that aims to minimize avoidable risk and maximize the prospect of longevity from day one. This requires avoidance of untidy capital structures and pairing with well-matched early investors who have the vision and commitment to maintain a position in the company through successive funding rounds.

A key function of the accelerator will evidently be to surround start-ups and spinouts with investors and corporates who buy into the process and to the idea of creating and being part of vibrant IB clusters. The accelerator community could further benefit from being connected to pilot and demonstration-scale IB facilities, which offer a powerful infrastructure for further de-risking across all stakeholders.

The combination of accelerator networks with pilot and demonstration facilities creates a strong pairing. For a more perfect triangle, however, it would additionally be worth exploring the creation of a public private partnership, for optimal collaborative deployment of private and public funding.

"You want investors who can go in early but have deep pockets. And I think they're out there, and they're probably looking for a home as well. But they don't have a home, in my opinion. And, you know, a framework, a process and a vehicle through an accelerator that can enable that would be very interesting."

Supportive level playing field recommendation 11 (SPLF11) – aviation fuels clearing house

Establish the proposed UK clearing house to provide the national capability needed to support SAF producers through testing for the approval of new ASTM fuels pathways

ASTM provides the main standards rule-book for aviation fuels, through **ASTM D4054- 19 Standard Practice for Evaluation of New Aviation Turbine Fuels and Fuel Additives**. There are currently eight different sustainable aviation fuel production pathways that have been approved under this route, of which two have been approved this year. Four more pathways are in the process of being approved.

Any new aviation fuel must undergo significant fit-for-purpose testing, with increasing cost and fuel volumes through a four-tier process. This is highly onerous and a barrier to many companies developing chemical processes for sustainable aviation fuels, and therefore to the opportunity to scale and commercialize new low carbon fuel production pathways. Overcoming this obstacle and de-risking market entry for new fuels will require specialist support and dedicated funding for jet fuel testing. The rationale for such targeted support is strengthened by the fact that, in the USA, the Federal Aviation Administration (FAA) funds producers through the first two test tiers in order to expedite market entry.

In order to address this challenge, KTN has worked with industry experts to create and submit a business case and operational framework for a UK Clearing House that will provide the national capability needed to support producers through the early stages of fuel testing. The UK Clearing House will work in close association with its USA equivalent and with the FAA. It will represent an essential one-stop-shop for access to test facilities, equipment and guidance through the steps of the standardization process.

The funding of a UK Clearing House is a strategically important element of the overall IB roadmap. It will play a key role in enabling the UK to consolidate an early leading position in the sustainable aviation fuels market and to attract further investment. Its strategic value is therefore also as an early move towards the UK's own greater fuel resilience and a reduced reliance on the jet fuel imports, which currently make up 70% of UK volumes. With liquid fuels set to remain essential for international aviation over the long haul and an integral component of the sector's long-term decarbonization strategy, the environmental and economic case for prioritising support for this fuels sector is a compelling one.

Next steps

Priorities for implementation of the recommendations of this report to ensure greatest impact are:

- CT1 – IB lexicon - Development of a standardized lexicon of industrial biotechnology to establish a common language and terminology for use across the sector and outside the IB community.

The fragmented nature of IB with its variety of specific languages hinders communication and understanding of IB and the potential benefits to be gained from exploiting the various technologies. This lexicon will provide the foundation for the private and public sector to accelerate the realization of these benefits initially by providing a platform for many of the other recommendations in this report e.g. characterization and bioresource inventory

- CT2 communication strategy - Formulate a communication strategy to raise the public profile of IB and enlist advocacy and funding, with targeted messaging by audience type

Raising awareness of IB as a valuable asset in reducing CO2 emissions is critical and a coherent strategy for achieving this is required. Immediately there should be a launch of this report across the IB sector, industry generally and government in particular. The lexicon will provide the platform for developing consistent and connected messages. Innovate UK and the IBLF should lead on this activity.

- CT3 – material characterization - Develop standards for the characterization of feedstocks and microbial host systems based on properties and process suitability, to build system predictability across the IB life cycle

Characterising feedstocks is essential to realize the benefits of a more circular economy. The absence of reliable descriptions of new feedstocks and microbial host systems poses too many uncertainties for potential users and is a serious barrier to their adoption. Providing standardized material characterizations will address this issue.

- ISLA1 - genome editing - Shape consensus and determine potential approach for removing gene-editing from the scope of future UK GM regulation, in order to create new headroom for innovation and investment; develop a PAS covering genome-editing techniques as a best-practice support

An evolving regime for the deployment of gene editing techniques would benefit from standards that capture best practice. Standards would accelerate R&D and effective collaboration by capturing and sharing best practice.

- ISLA2 - adaptive standards - Implement collaborative workstreams to agree and develop adaptive standards and guidelines that lighten evidence burdens and build momentum for IB opportunities

The considerable range of potential actions in this area require the establishment of collaborative workstreams together with task and finish groups to develop action plans and to provide an advisory steer for adaptive standards and approval processes.

Appendix: organizations interviewed

1. Aberystwyth University
2. AB Sugar
3. Aquapak Polymers
4. BBIA (Bio-based and Biodegradable Industries Association)
5. BBSRC (Biotechnology & Biological Sciences Research Council)
6. BDC (Biorenewables Development Centre)
7. BEIS
8. BioCity
9. BioComposites Centre
10. Bio-Key
11. Biome Bioplastics
12. Biovale
13. British Airways
14. Calysta
15. Clare Saunders Ltd
16. Corteva Agriscience
17. CPI (Centre for Process Innovation)
18. Croda
19. Deep Branch
20. Dent Associates
21. DfT
22. Earlham Institute
23. EBLC (Engineering Biology Leadership Council)
24. Environment Agency
25. Fera Science
26. Fiberight
27. Floreon
28. Fujifilm Diosynth Biotechnologies
29. Futamura
30. Green Fuels
31. IBioIC (Industrial Biotechnology Innovation Centre)
32. INEOS
33. Innogen Institute
34. Innovate UK
35. KTN
36. Lucite
37. Nouryon
38. Novamont
39. NNFCC (National Non-Food Crops Centre)
40. Oxford Biotrans
41. Shell
42. Shott Trinova
43. Solenis
44. Synbicite
45. UK Petroleum Industry Association
46. Unilever
47. University of York
48. World Council on Industrial Biotechnology
49. WRAP (Waste & Resources Action Programme)
50. Zero Waste Scotland

About BSI

BSI is the business improvement company that enables organizations to turn standards of best practice into habits of excellence. For over a century BSI has championed what good looks like and driven best practice in organizations around the world. Working with 84,000 clients across 195 countries, it is a truly international business with skills and experience across a number of sectors including aerospace, automotive, built environment, food, and healthcare. Through its expertise in Standards Development and Knowledge Solutions, Assurance, Regulatory Services and Consulting Services, BSI improves business performance to help clients grow sustainably, manage risk and ultimately be more resilient and trusted.

Innovate UK is the UK's innovation agency. Innovate UK is part of UK Research and Innovation, a non-departmental public body funded by a grant-in-aid from the UK government.

The Industrial Biotechnology Leadership Forum (IBLF) connects stakeholders across the industrial biotech community. The IBLF worked with other collaborative networks, and industry stakeholders, to develop the National Industrial Biotechnology Strategy to 2030.

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