Biotechnology and
Biological Sciences
Research Council

Evaluation of the effectiveness and impact of BBSRC's investments in Industrial Biotechnology

This document represents the views and conclusion of a panel of experts.

Contents

Executive Summary

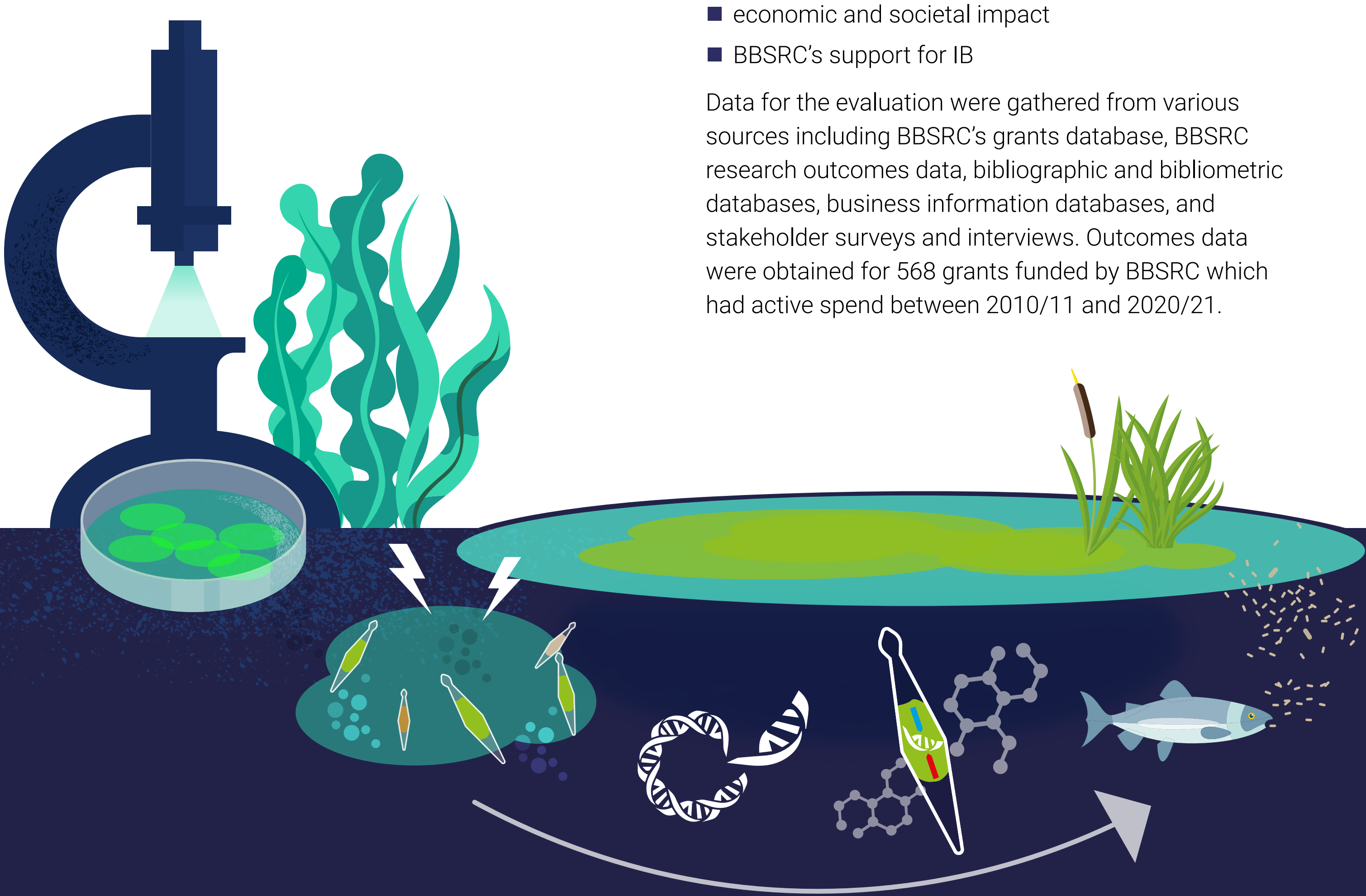
Bio-based solutions have the potential to transform everyday life by reducing our reliance on fossil fuels and their derivatives, as well as making a significant contribution to the UK economy. Industrial biotechnology (IB) is a set of cross-disciplinary approaches that use biological resources for the production and processing of materials and chemicals with the principal aim of reducing greenhouse gas emissions by replacing fossil chemical feedstocks or fossil chemical powered processes. The applications of IB are vast and span a wide range of industry sectors, including materials, chemicals, energy carriers, pharmaceuticals and biopharmaceuticals, waste processing and recycling but also extends to agriculture, food and construction sectors.

The Biotechnology and Biological Sciences Research Council (BBSRC) identified IB as a strategic priority in 2010. Between 2010/11 and 2021/22, BBSRC's total spend in IB research and innovation was £413 million (including £42.4m co-funding from the Engineering and Physical Sciences Research Council (EPSRC) and Innovate UK). Current annual BBSRC expenditure on the IB portfolio is approximately £29 million. IB continues to be a key area for investment within BBSRC and UKRI. BBSRC's IB investments sit within the wider UKRI strategic theme of 'Building a Green Future'[1], working towards the delivery of Net Zero. It was therefore timely to assess the portfolio's achievements and the overall effectiveness of BBSRC's investments in IB.

This report summarises the conclusions of an expert panel appointed to conduct an independent evaluation of BBSRC's investments in IB research and innovation. The evaluation encompasses four major themes:

- new knowledge and understanding
- knowledge exchange and supporting collaboration
- economic and societal impact
- BBSRC's support for IB

Data for the evaluation were gathered from various sources including BBSRC's grants database, BBSRC research outcomes data, bibliographic and bibliometric databases, business information databases, and stakeholder surveys and interviews. Outcomes data were obtained for 568 grants funded by BBSRC which had active spend between 2010/11 and 2020/21.



Key conclusions

1. BBSRC's investments in IB have supported high quality research that is internationally competitive.

BBSRC's IB investments have supported the generation of new knowledge across the breadth of the IB research area. The investments enabled the community to conduct high quality research and this was demonstrated within the portfolio's knowledge outputs, including the associated publication outputs. A comparison of the category normalised citation impact (cNCI[2]) for the BBSRC IB publication portfolio with that of other countries supported the view that the research was internationally competitive. For example, the cNCI of BBSRC supported publications within the Web of Science (WoS) Biotechnology & Applied Microbiology research area was higher than for other G7 countries. Overall, 16% of journal articles within the BBSRC IB publication portfolio ranked within the top 10% of related WoS publications in terms of citation impact.

2. BBSRC's investments in IB are building capability and capacity, producing future IB leaders within the UK and beyond.

When surveyed, IB grant holders gave examples of how the training received by their staff was considered beyond the scope of a 'typical' research grant, encompassing valuable commercial skills. The majority (84%) of postdoctoral researchers supported through IB investments remained research active following completion of the grant. The next destination data for staff working on IB grants were also very good when compared with BBSRC's overall portfolio. For example, a sizeable proportion (26%) were employed in the private sector as their next destination, which is higher than the general BBSRC research portfolio (14%). This suggests that IB investments have enabled early career researchers (ECRs) to gain a broad variety of lab and commercial skills valued by employers. The panel noted that effective postgraduate training is essential to fill the skills gaps required to address complex IB challenges. BBSRC has a critical role to play in contributing to increasing the UK's capacity to undertake basic and strategic research in IB through increasing the critical mass of trained staff in UK universities and institutes. Focused early career support, recognising the specialist training required to develop capability in IB, would help ensure that BBSRC continues to contribute future leaders in this area.

3. Targeted investments in the IB portfolio aimed at strengthening links between industry and academia are delivering significant impact and benefit.

Collaboration is essential for facilitating high quality cross- or multidisciplinary IB research and the delivery of economic and societal impact. The formation of strong collaborations with industry is a highlight of the IB portfolio and, in this context, the Networks in Industrial Biotechnology and Bioenergy (BBSRC NIBB) and the IB Catalyst have been major successes. When surveyed, 75% of grant holders reported that they had formed new collaborations or partnerships with non-academic stakeholders as part of their BBSRC funded IB work. Publication outputs also demonstrate the success in developing partnerships between academia and industry. For example, 7% of IB publications between 2017 and 2021 had an industry co-author, compared with 4% in BBSRC's overall research portfolio. Collaborative activities were equally valued by industry, with surveyed businesses identifying new academic-industry partnerships as a key outcome arising from working with BBSRC funded IB activities and researchers.

4. The BBSRC NIBB initiative was an innovative and effective approach, helping to grow a vibrant IB community across multiple sectors and leveraging significant industry co-investment.

BBSRC has provided effective support for IB research through a variety of different investment mechanisms. A stand-out success was the networks formed by the BBSRC NIBB initiative which catalysed strong research communities working on industrially-relevant problems. The BBSRC NIBB Phase I (2014 to 2019) leveraged nearly £98 million of additional funding from an initial BBSRC investment of £18 million, demonstrating its value to the wider IB community. A total of 277 different businesses were involved in projects during this time. The BBSRC NIBB facilitated and enhanced collaboration between academics and industry. For example, 11% of publications arising from the BBSRC NIBB had an industry co-author, compared to 7% from the whole IB portfolio and 4% of BBSRC's overall research portfolio. The membership of the networks within the BBSRC NIBB reflect the reach of this initiative, encompassing various scientific areas, across all career stages, with strong involvement from academia and the private sector, nationally and internationally. In addition to industry and academia, membership included the third sector, government departments, policy think tanks, social enterprises and scientific societies.

5. The IB portfolio provided a translational pathway that has significant potential for economic impact, with notable contributions to policy.

BBSRC's IB research portfolio had clear applications across multiple sectors and there was strong potential to deliver significant economic impact. Many researchers capitalised on the potential industrial application of their BBSRC funded work, for example, contributing to the development of new intellectual property (IP) and the establishment of spin-out companies. IB investments made a strong contribution to BBSRC's overall portfolio of IP and spin-outs. For example, the IB portfolio had contributed to 31% of all instances BBSRC attributable IP and 34% of all instances of BBSRC attributable spin-outs arising between 2017 and 2021, despite the IB investment representing only 11% of BBSRC research funding. Many of the IB-attributable spin-outs are successful companies that have brought products to market, created new employment opportunities across the UK and established a critical mass in the market / industry sector. Participation in BBSRC IB activities and research had also provided benefits for businesses. When surveyed, 33% of businesses reported that they had experienced an increase in overall turnover or expected to do so in the next two years, as a result of their interactions with BBSRC's IB portfolio. In addition, 67% of businesses surveyed reported that their organisation has invested more in IB related R&D following engagement with BBSRC. There was also good evidence of BBSRC's IB investments influencing the development of policy and, for example, BBSRC NIBB members have been instrumental in developing and influencing policy relating to IB.

6. International partnerships within the IB portfolio are helping the UK address global challenges such as Net Zero.

IB is a group of cross- or multidisciplinary technologies with diverse outputs beyond traditional academic impact and significant potential to meet key environmental and societal challenges (for example, fully biodegradable plastics, effective replacements for a range of fossil fuel-derived products). IB research and innovation is an international activity and there was good evidence that BBSRC's IB investments were enabling international collaboration. For example, 58% of publications produced by BBSRC's IB portfolio had an international co-author, involving researchers from 78 countries. Global Challenges Research Fund (GCRF) work undertaken within BBSRC's IB portfolio in countries such India and Thailand highlight how advances in IB are of benefit to nations in the Global South as well as the UK.

7. Barriers to accessing specialist infrastructure may be limiting the delivery of further impact in BBSRC's IB portfolio.

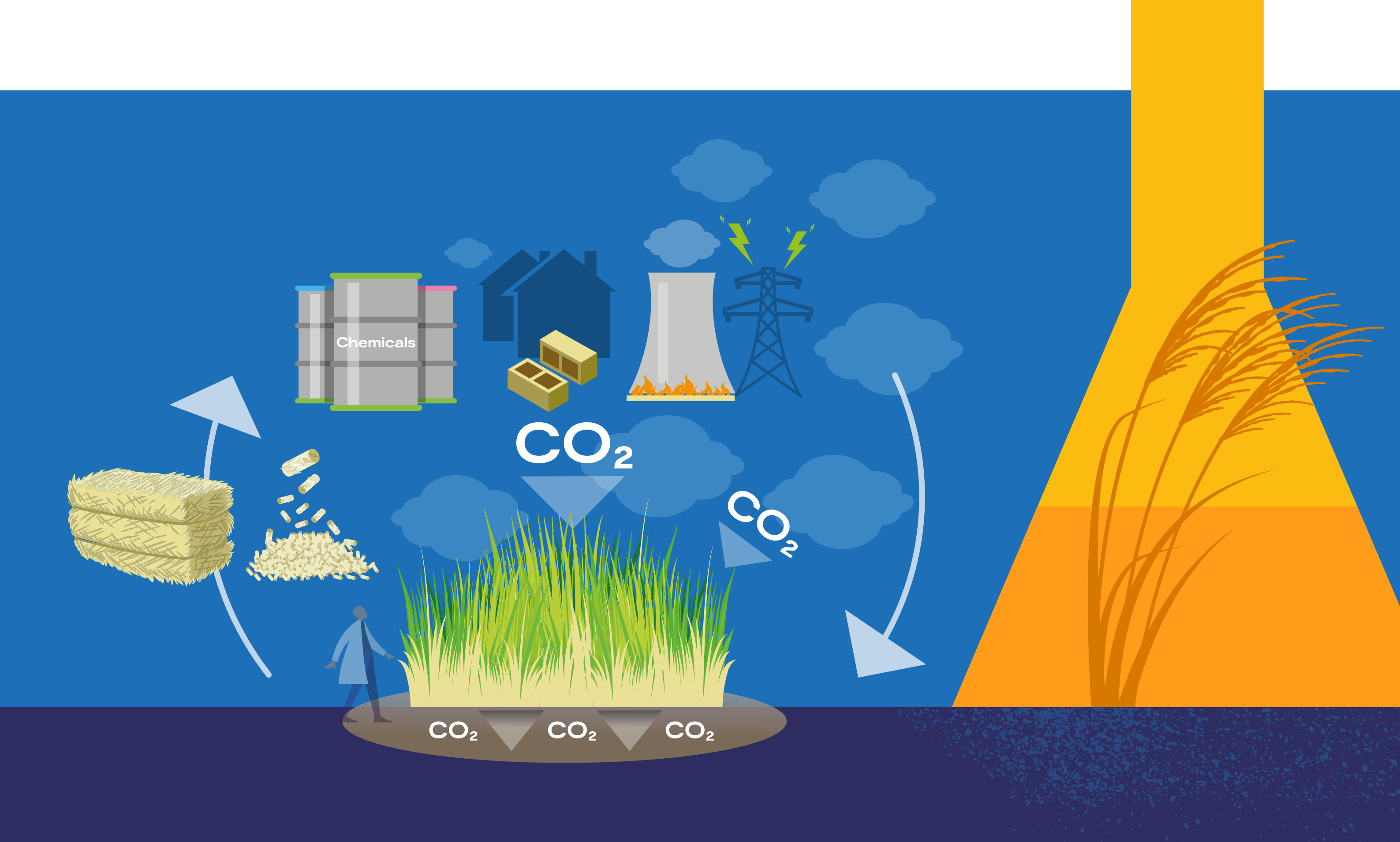
Insufficient scale-up opportunities within the UK were identified as a barrier to impact by the IB community. For example, 42% of BBSRC funded IB researchers surveyed stated that an inability to scale-up was a barrier to achieving impact from their work. The panel supported this view and considered the high costs of accessing some facilities, as well as the availability of appropriate infrastructure within the UK, to be impeding innovation and commercialisation. There are opportunities to undertake complementary work with other components of UKRI, principally with Innovate UK, to support IB researchers in overcoming such barriers and in augmenting translational funding for maximal impact. As a major funder of IB research in the UK, BBSRC has an important role to play in helping to address these barriers and in fostering an effective IB community.

8. There are opportunities for BBSRC to build on its effective support for IB to deliver increased economic and societal impact.

Although good progress is being made with the delivery of impact from BBSRC IB investments, currently the potential of the work to deliver economic and societal impact is not being fully realised. There is an opportunity to further align IB research with industrial and societal challenges to achieve increased innovation and impact. The panel highlighted the need for supportive long-term government polices to enable the full potential of IB to be achieved. There is a role for BBSRC, together with other parts of UKRI, to increase the overall level of awareness of policymakers on the potential of the IB sector to contribute further to the UK economy. A more coordinated approach to the UK policy landscape in IB would be beneficial and would help the UK secure its potential to be a world-leader in this area.

9. Sustained investment is needed to realise the full potential impact of IB

The panel welcomed BBSRC's support for IB research and innovation as a strategic priority since 2010 and the successes it has delivered. It will be essential for BBSRC and UKRI to continue to support this area as a priority in the future, delivering sustained and increased investment. The evidence captured for this evaluation demonstrates the value of dedicated initiatives in this area, and further investment through such mechanisms is likely still needed to realise the full potential of IB. The full scale of the impact IB could have on our day-to-day lives in the future is still being uncovered. UKRI (and BBSRC within it) have a critical role in supporting and championing researchers to work with businesses in exploiting the capability to develop less carbon intensive products and processes, whilst also reducing costs and opening up new, emerging and established markets. It is clear that this field has the potential to equip our society to live more sustainably and our economy to compete more effectively in the decades ahead. IB will be one of the strongest driving forces behind the world's low-carbon revolution.



1. Introduction

1.1 UK and BBSRC policy drivers to support IB

1. IB is a set of cross-disciplinary approaches that use biological resources for the production and processing of materials and chemicals with the aim of reducing greenhouse gas emissions by replacing fossil chemical feedstocks or fossil chemical powered processes.
2. IB has been consistently funded as a BBSRC strategic priority since 2010, recognising the importance of research and innovation in this area. A key aim has been supporting research that works towards a reduction in dependency on petrochemicals and helping the UK become a low carbon economy, as well as supporting the manufacture of high value products such as biopharmaceuticals and vaccines. Now that some time has now elapsed, it was timely to review the effectiveness and impact of BBSRC's investments in IB.
3. IB offers huge potential for the UK in providing jobs and economic growth across a wide range of markets and industry sectors. IB can help mitigate climate change through the development of greener, cleaner manufacturing processes, as well as offering opportunities for waste utilisation and new products that benefit society which cannot be made any other way. Examples of IB at work include:
   - clean energy and transport fuels from waste and industrial by-products
   - bio-based plastics and chemicals manufacturing that preserves the environment
   - using microbes instead of chemical processes to create medicines and personal care products
   - strong, lightweight materials for the automotive and aerospace industries
   - using plants to manufacture vaccines to quickly tackle disease epidemics

   In addition, some new challenges are being addressed, such as biodegradable food packaging promising superior recyclability and compostability, meaning that sustainable production can be linked to better end of life performance, a key objective of the circular economy[3].
4. BBSRC's Strategic Delivery Plan[4] highlights the importance of IB as a significant research theme for the Council. The IB portfolio supports research and innovation underpinning many key objectives of the Delivery Plan including, for example:
   - Sustainable agriculture and food
   - Advanced manufacturing and clean growth
   - Transformative technologies
   - Enabling innovation and working with business
   - Translation, enterprise, and venture activities
5. BBSRC's investments in IB sit within the wider UKRI strategic theme of 'Building a Green Future'. This theme is aligned with UK government's Net Zero strategy: Build Back Greener[5], working towards the UK's target to reach Net Zero by 2050. BBSRC IB research also makes important contributions to other UKRI strategic themes including 'Securing better health, ageing and wellbeing for everyone' and 'Tacking infections'.

1.2 Introduction to the evaluation of BBSRC investments in IB

6. This report summarises the views and conclusions of a specialist evaluation panel ("the panel") who were appointed to conduct an independent review. The panel membership is provided in Appendix 1.1. The panel were asked to consider and synthesise the evidence provided and use their expert knowledge to address the evaluation objectives set out in Appendix 1.2 . The panel met in October 2022.

7. The methodology for the evaluation is provided in Appendix 1.3. Evidence for the evaluation was obtained from the following sources:
   - BBSRC grants database
   - research outcomes data (for example, collected via the Researchfish platform)[6]
   - bibliographic and bibliometric databases (namely WoS and the InCites platform provided by Clarivate Analytics)
   - surveys of all 13 NIBB Phase I directors, 18 businesses and 48 former grant holders
   - semi-structured interviews with four businesses and six grant holders[7]

8. Between 2010/11 and 2021/22, BBSRC's total spend in IB research and innovation was £413 million (including £42.4m co-funding from EPSRC and Innovate UK[8]). The research was supported through a variety of funding mechanisms including responsive mode[9], strategic institute investments[10] and fellowships[11], together with more tailored initiatives such as BBSRC NIBB[12]. Further information on IB funding mechanisms is provided in Appendix 1.4.

9. Outcomes analysis was conducted on 568 IB grants with start dates between 2010 and 2020. The Researchfish outcomes data for these awards was for data submitted up to March 2022.

10. The remainder of this report is presented in four main themes, reflecting the evidence provided:
    - new knowledge and understanding
    - knowledge exchange and supporting collaboration
    - economic and societal impact
    - BBSRC's support for IB

11. Supporting evidence for each of these areas is provided in the corresponding Appendices.

2. New knowledge and understanding

2.1 Summary

- BBSRC's IB portfolio has supported high quality research that is internationally competitive.
- The research is generating new knowledge with clear applications in multiple sectors such as agriculture, materials and chemical production, biopharmaceuticals, waste processing and recycling.
- A majority (77%) of grant holders were successful in delivering their project's research objectives.
- The quantity and quality of publications arising from the IB portfolio was very good (for example, the cNCI for publications within the WoS Biotechnology & Applied Microbiology research area was higher than for other G7 countries).
- Wider research outputs such as new datasets and databases were a strength of the portfolio and underpin translational IB work.
- The level of further funding obtained by grant holders was very good (for example, 58% of projects resulted in further funding; £185 million further funding was reported).
- The next destination data for staff working on IB grants was very good (for example, 26% of postdoctoral researchers were employed in the private sector following completion of the grant).

The supporting data for this Chapter are provided in Appendix 2.

2.2 Grant performance

12. Overall, grant performance within BBSRC's IB portfolio was very good. The majority (77%) of grant holders in the IB portfolio reported meeting their original project objectives (Appendix 2.1). The BBSRC NIBB was also considered highly successful and all 13 BBSRC NIBB network directors reported that the original objectives were met.

2.3 Research quality

13. The overall quality of research within the BBSRC IB portfolio was high. The research supported within the IB portfolio was internationally competitive for research in the area. This is most clearly evidenced by the quality of the publication outputs (Section 2.4) and the other knowledge outputs arising from the investment (Sections 2.5, 2.6, 2.7).

2.4 Publication outputs

14. The quantity and quality of publication outputs arising from BBSRC's IB portfolio was very good. For example, 84% of grants from the IB portfolio[13], with start dates between 2013 and 2017, resulted in the publication of one or more original research articles. In total, 2,371 research articles were published from the IB portfolio between 2017 and 2021 (Appendix 2.2).

15. The quality of the publication outputs for the whole IB portfolio and the BBSRC NIBB was demonstrated by a variety of bibliometric data, as well as through 'publication highlights' identified by the grant holders surveyed (Appendix 2.3 and 2.4). For example, 16% of BBSRC IB research articles were in the top 10% of related WoS publications, 40% were in the top 25%, and the cNCI for the portfolio was 1.45 (note: the world average is 1). For research articles arising from the BBSRC NIBB investment, 21% were in the top 10% of related WoS publications, 42% were in the top 25%, and the cNCI was 1.50. Examples of highly-cited[14] articles published between 2017 and 2021 are provided in Appendix 2.5.

16. BBSRC IB research compared well to other UK and international funders (Appendix 2.6). For example, the cNCI for BBSRC attributable publications within the WoS Biotechnology & Applied Microbiology research area was higher than for other G7 countries. BBSRC attributable publications within the Microbial Biotechnology WoS citation topic also compare well with other international funders.

17. The collaborative nature of the IB portfolio was demonstrated by the level of co-authorship on publications. For example, 7% of publications arising from the IB portfolio between 2017 and 2021 had an industry co-author, compared with

4% for BBSRC overall research portfolio. 11% of the BBSRC NIBB publications had an industry co-author.

2.5 Other research outputs

18. BBSRC's IB portfolio consisted of projects across a range of disciplines, encompassing the breadth of IB as a research area. The new knowledge generated from this portfolio had clear applications in multiple sectors such as agriculture, materials and chemical production, biopharmaceuticals, waste processing and recycling. This was demonstrated through the IB portfolio's publications as well as other knowledge outputs.

19. A wide variety of other research outputs were reported in Researchfish. For grants with start dates between 2013 and 2017:

    - 14% resulted in new datasets, databases and models, with 125 outputs reported. Examples include: 'Minimum information about a biosynthetic gene cluster'[15] and 'Data obtained from operation and calibration of Microbial Fuel Cells[16]
    - 24% resulted in the development of new tools or methods, with a total of 166 outputs reported. For example, two new tools were the 'Open Enzyme' and 'Open Reporter' collections which include useful enzymes and reporter genes for both basic and applied sciences relating to IB
    - 4% contributed to the creation of new software or technical products, with a total of 33 outputs reported. Examples include:
        - Enlighten2 – a software package for running molecular dynamics simulations of protein-ligand systems
        - KnetMiner – software to help wheat researchers in gene discovery and knowledge visualisation
        - MORF – a browser-based tool to store, share and analyse multiomics data
        - PartsGenie – a web application for the design of reusable synthetic biology parts

20. The panel considered that these research outputs were a major strength of BBSRC's IB portfolio, demonstrating how fundamental research can provide the knowledge base needed to underpin translational IB work. Many of these software and web-based applications are open access, improving the accessibility of IB advances supported by BBSRC. The case study below exemplifies this concept.

Advancing Plant Engineering Biology

"The NIBB (specifically PhycoNet and now AlgaeUK) have been vital for maintaining links between academics and industry in the UK/EU."

A Professor at the University of Edinburgh works on the fundamental biology behind engineering green algae and cyanobacteria for applications in plants and IB processes. BBSRC funding supported lab work to develop a 'Golden gate assembly toolkit' called CyanoGate, which is a molecular cloning suite for engineering cyanobacteria that accelerates the development of reliable synthetic biology tools for the cyanobacterial community. Proof of concept funding from PhycoNet enabled this Professor to first work with local SME Scotbio on engineering cyanobacteria to produce phycocyanin, a natural blue pigment used in food colouring and dyes. Further funding from PhycoNet's Phase II successor - AlgaeUK, has supported the development of improved thermal engineering properties of the cyanobacteria used in this process to be able to produce phycocyanin at industrial scale.

The links established due to participating in PhycoNet and AlgaeUK activities have led to continued funding from the Industrial Biotechnology Innovation Centre in Scotland, as well as further EU funding applications. Collaborative BBSRC grants with the United States National Science Foundation have enabled this Professor to internationally expand the plant side of his research, working with collaborators in the United States. The team at the lab is continuing to work with industry to investigate other uses for natural secondary products generated by his engineered cyanobacteria.

Professor in plant molecular physiology and synthetic biology, University of Edinburgh

2.6 Further funding

21. Further funding to continue or develop research can be an indicator of a project's success. The sources of further funding may also demonstrate that researchers are seeking to translate their research into practical application. Overall, the level of further funding obtained within the BBSRC IB portfolio was high and the panel considered this to be an excellent demonstration of researcher's success in obtaining continued support for their IB work. For example, 58% of IB projects resulted in further funding, with 607 unique instances of further funding reported in total.

22. Further funding was obtained from 145 different sources. The majority of the further funding was obtained from the public sector (70%). The remainder was funding from academia/university (12%), charities and non-profit (11%), private sector (6%) and learned societies (0.2%). In total, 54% of grant holders surveyed reported attracting additional funding for their IB work from the private sector.

23. The main sources of further funding were BBSRC (34%), EPSRC (7%), Innovate UK (7%), European Commission (7%), UKRI (3%), the Royal Society (3%), Wellcome Trust (2%) and the Medical Research Council (MRC) (2%). This highlights the importance of key funders (BBSRC, EPSRC, Innovate UK and MRC) within UKRI for furthering IB research and innovation.

24. In total, £185 million of further funding arising from the IB portfolio was reported[17], with at least £37 million obtained from non-UK funding sources. £7.6 million of further investment came from the private sector. The Phase I BBSRC NIBB were also successful in obtaining further funding, with approximately £40 million reported[18].

2.7 Staff next destinations, training and skills

25. For the 556 postdoctoral researchers where data were available, 84% were reported as remaining 'research active' in their next employment. A sizeable proportion (26%) were employed in the private sector as their next destination, which is higher than the general BBSRC research portfolio (14%). This suggests that IB investments had enabled postdoctoral researchers to gain a broad range of lab and commercial skills that were highly valued by employers. IB grants contributed to an increase in specialist IB related expertise, with grant holders reporting that staff gained additional skills beyond that of a 'standard' research grant.

26. The panel noted that effective postgraduate training is also critical to fill the skills gaps required to address complex IB challenges. BBSRC funding has enabled the training of ECRs to become specialised researchers in the field of IB, with IB studentships representing 9% of all studentship awards made by BBSRC between 2011 and 2020 (Appendix 2.8). Focused early career support, recognising the specialist training required to develop capability in IB, would help ensure that BBSRC continues to contribute future leaders in this area.

27. It was the panel's view that businesses often consider studentships to be a lower-risk method of investing in research and innovation with academia. BBSRC may wish to consider how it could seek co-investment from the private sector to support doctoral training entities in delivering high-quality cohort-based doctoral education which would further build capacity in IB.

28. BBSRC's investments in IB contributed skilled workers both within the UK and internationally. For example, 67% of postdoctoral researchers remained within the UK for their next role, while 33% moved outside of the UK. Of the individuals that left the UK, 17% moved to other European destinations, 4% moved to the United States and 3% to China.

29. Approximately 60% of grant holders surveyed had been independent researchers for over 20 years. There was a more equal spread of representation amongst years of experience in conducting IB research specifically, indicating possible movement into IB from other research areas (Appendix 2.9).

3. Knowledge exchange and supporting collaboration

3.1 Summary

- The overall level of collaboration and partnership within BBSRC's IB portfolio was excellent.
- The formation of collaborations with industry has been a major success of BBSRC's IB portfolio (for example, 75% of surveyed grant holders reported a new or improved collaboration partnership with non-academic stakeholders as a result of their research project).
- Targeted initiatives such as the BBSRC NIBB and IB Catalyst have strengthened links with industry, enabling IB researchers to further align their work to industrially-relevant problems.
- The networks formed by the BBSRC NIBB initiative were considered to be a stand-out success, catalysing strong industry-relevant research communities and leveraging significant additional investment (for example, £98 million was leveraged from £18 million of initial BBSRC investment).
- The level of national and international academic collaboration was very good (for example 58% of publications had at least one international co-author).

The supporting data for this Chapter are provided in Appendix 3.

3.2 Collaborations and partnerships

30. Collaboration and partnership are essential for delivering high-quality IB research and subsequent economic impact. The overall level of collaboration and partnership within the IB portfolio was strong and BBSRC support had enabled many new partnerships to be established and grow. A total of 749 collaborations were reported via Researchfish for IB grants starting between 2013 and 2017. There was a good balance of collaboration with other academics (49% of reported collaborations) and with the private sector (42%). Approximately £130 million of direct financial contributions was reported as being leveraged from these collaborations, with £55 million from private sector organisations[19].

3.3 Working collaboratively with industry

31. The overall level of collaboration with industry within the IB portfolio was very good. For example, 75% of grant holders surveyed reported forming new collaborations or partnerships with non-academic stakeholders as part of their BBSRC funded IB work, and industry co-authorship on publications was also high (Section 2.4).

32. A wide variety of businesses were involved in academia-industry collaboration within the IB portfolio, and this included large companies as well as SMEs. The top industry collaborators named as partners on grants between 2017 and 2021 were UCB Celltech (7 grants), GlaxoSmithkline (4 grants) and Syngenta Ltd, Pall Europe, Astra Zeneca UK Ltd (all with 3 grants). The top industry collaborators reported through Researchfish were GlaxoSmithkline (10 grants) Unilever (8 grants) and Fujifilm (4 grants).

33. Academics that had engaged with the private sector reported that their research was steered more towards industry relevant problems and consequently the development of products and solutions that would excite investors. Grant holders surveyed reported that industry brought complementary knowledge, enabled scaling up and helped to identify demand versus supply chain issues. Industry partnerships also supported academics through the process for protecting IP, provided the ability to test materials in an applied setting and gain access to industrial users. Grant holders also acknowledged that collaborations and partnerships had enabled them to broaden their research programmes (for example, through direct and in-kind funding contributions), helped them develop a better understanding of materials and their commercial potential, and provided the basis for further investment in technology development.

34. A survey of 18 businesses indicated that the top three reasons for wishing to engage with BBSRC were:

- developing new technology, products, or services (83%)
- finding new partners, collaborators, suppliers, or customers (72%)
- accessing funding opportunities (61%)

35. The top 3 business outcomes / expected outcomes reported by businesses were:

- establishing new collaborations with academic partners (94%)

- introductions to new organisations (89%)
- identifying new opportunities for funding (78%)

36. In total, 56% of businesses surveyed suggested that BBSRC could do more to increase face-to-face networking events and facilitate introductions between potential partners.

3.4 Networks in Industrial Biotechnology and Bioenergy

37. The Phase 1 BBSRC NIBB comprised a total of 6,422 members[20] across 13 networks. Member affiliation included academia and industry, as well as presence from charities, government departments, NGOs, policy think tanks, social enterprises and scientific societies (Appendix 3.1). Industry engagement with the BBSRC NIBB was very good, with a total of 277 different businesses involved in projects during the lifespan of the initiative. For example, 68% of projects funded by the BBSRC NIBB initiative involved at least one industry partner. These projects leveraged 39% of funding (cash or in-kind) from industry, alongside the funding provided by BBSRC.

38. BBSRC NIBB directors and members were instrumental in realising the potential outputs from their networks. The BBSRC NIBB leveraged £98 million additional support from £18 million of initial BBSRC investment, with funding gained from a mixture of public and private funders. Over £92 million of this leveraged funding supported new research grants, £4.6 million supported ECRs and students by deployment of schemes such as vacation scholarships, training awards and short-duration fellowships.

39. A success of the BBSRC NIBB was the ability to encourage, activate, support and enable cross-sectoral working as demonstrated through some of the proof of-concept grants (for example, pilot production of engineered nucleases with applications in molecular biology and diagnostic devices, and optimisation of influenza vaccine manufacturing through inhibition of autophagy). Many different types of partners were involved from food scientists, plant scientists and chemical engineers, to IB technology providers and personal care companies. Based on the scale of membership, industrial engagement and leveraged funding, the panel considered the BBSRC NIBB to be a beacon of success within BBSRC's IB portfolio, catalysing strong industry relevant research communities across multiple sectors, capable of delivering significant impact.

40. The BBSRC NIBB initiative had a good level of international engagement. Network growth and interconnectivity between academia and industry drew in international members from across the world. For example, 16% of members were from outside of the UK, with 553 members being based in Europe and 492 based elsewhere. The PhycoNet Network was a good example of this. It built from scratch a UK-wide community of around 750 algal researchers, SMEs and other stakeholders. The network organised missions to the United States, China and New Zealand in which UK academics and SME directors established new networks with counterparts in these countries through a series of workshops and visits.

41. All BBSRC NIBB network directors described lasting impacts from establishing and facilitating specific communities in their respective areas of IB. Collaborations continue to form and strengthen beyond the initial lifetime of the networks, enabling continued working towards common research goals. Several networks, such as the Anaerobic Digestion Network (ADNet) and Chemicals from C1 Gas network (C1Net), are evolving to become part of the BBSRC NIBB Phase II. BioProNet has also developed into a secondary phase and is now self-funded by predominantly industry contributions, demonstrating the success of this network in particular and its value to the

IB community. Further evidence of the success of this type of initiative is also evidenced by the development of similar initiatives within UKRI and in other countries.

3.5 International collaboration

42. The UK has a strong IB science base and the level of international collaborators on BBSRC's IB portfolio reflects the international nature of IB research and innovation. For example, collaborators from 46 different countries were reported via Researchfish for collaborations and partnerships arising between 2017 and 2021.

43. Strong international engagement is also supported by publication data. For example, 58% of publications arising from BBSRC IB grants had an international co-author and 49% of BBSRC NIBB publications had an international co-author. In total, 78 countries were listed as co-author locations within the IB research article portfolio. The top ten countries for international co-authors by number of research articles published were United States, Germany, France, China, Netherlands, Spain, Australia, Denmark, Switzerland, and Sweden (Appendix 3.2).

44. International partnerships within the IB portfolio are helping the UK address global challenges such as Net Zero. For example, BBSRC's IB portfolio includes work undertaken as part of GCRF, which highlights how advances in IB are addressing global challenges and benefiting nations in the Global South as well as the UK. GCRF work in India has supported the development of biodigesters that break down waste biomass through anaerobic digestion to generate biogas (Section 3.6), whereas work in Thailand has supported the establishment of biopharmaceutical and animal vaccine production capacity in Thailand (Section 4.6).

3.6 Case studies of collaborative partnerships arising from BBSRC's investments in IB research

Extraction of sugar from waste

Fiberight was founded in 2009. After a couple of pivots in company direction, their focus now is on the recovery of high value products from everyday household waste. Advanced Microwave Technologies (AMT) was founded in 2008 and specialise in continuous flow microwave technology for various sector applications, including fermentation pre-treatment, microwave assisted reactions and microwave enhanced extraction.

Both Fiberight and AMT have been involved in various BBSRC funded projects with academics to support their development work. Fiberight received funding in 2016 and 2017 from the IB Catalyst scheme, to work with academics on improving the production of sugars from waste. Between 2014 and 2018 they participated in several NIBB, namely FoodWasteNet, LB Net and P2P. AMT were also active members of both FoodWasteNet and HCVfP NIBB projects. It was at NIBB networking events that the foundations of future working between Fiberight and AMT were formed. Both companies then worked together as part of a consortium led by the University of Leeds, on a BBSRC Newton-Bhabha project aiming to translate existing IB technology on extraction of sugar from waste in India. As well as supporting translation of research in a developing country, a patent application on the methodology supporting this work at a full-scale extraction plant level was approved.

Following on from their participation in BBSRC funded projects, Fiberight has since gained EU Horizon 2020 funding to showcase their work at industrial demonstration scale. AMT have entered a commercial equipment rental agreement with Fiberight to aid them in the scale-up of their waste recovery technology on this project and others in the future. Both companies continue to work with academic partners and ECRs, providing them with valuable exposure to industry and aiding in upskilling of the IB community.

Head of R&D, Fiberight

Invasive weed provides solution to clean energy

Across many developing countries, there is a lack of suitable fuel for energy needs, particularly in rural areas. An international team of UK, Indian, and Ugandan scientists and industry partners, through a GCRF project, have developed biodigesters that break down waste biomass through anaerobic digestion to generate biogas. Led by the University of Leeds, the project is delivering demonstration units in rural areas of India and Uganda that are now being used by local communities for cooking.

Water hyacinth was used because it invades waterways, damaging the ecosystem and preventing communities from using the water for fishing or other activities. The removal and clean-up of rivers is associated with high operational costs, environmental concerns and spread of diseases. The project focuses on the utilisation of invasive aquatic macrophytes such as water hyacinth in combination with nutrient rich waste and immobilised microbial systems to maximise the production of biogas, clean water and recovery of these nutrients in low income communities, by developing innovative biotechnology solutions that promote resource efficiency and long-term sustainable services.

Defiant Renewables is an industry partner to the project and playing a key role in developing the technology in terms of designing bioreactors and highly active bacterial consortium to effectively produce large quantities of biogas from water hyacinth. Supplied with different mixes of biomass, four demonstration digesters have been built for the use of local communities. Locals have been engaged in the process, educated, and trained in this work, helping to build their knowledge of anaerobic digestion for producing biogas. The team are now developing the technology further and exploring its potential for use in other countries.

Associate Professor, University of Leeds.

Aligning IB research with industry

A structural biologist based at the University of Exeter has specialised in enzymology and biocatalysis for over 20 years, with IB being a key theme of their work throughout this time. They have received numerous grants from BBSRC to support their IB work, working extensively with industry partners on many of these. BBSRC's joint industrial grant mechanisms have allowed her to align the application of her research with the needs of industry. Highlights include a successful IB Catalyst grant which led to a large Innovate UK grant working with Unilever and an ERA-CoBiotech grant called HotSolute, working with Evonik on producing compounds capable of stabilising cell reactions in IB processes.

As well as research staff working on these projects, joint BBSRC and industry supported studentships have allowed trainees in their lab to gain crucial IB experience beyond a traditional PhD award. A previous studentship with Chirotech (now owned by Dr Reddy's pharmaceuticals) working on production of the enzyme aminoacylase from Thermococcus was taken from a TRL of 1 to 2 in the lab to fully deployed large scale production used by Dr Reddy's. In more recent times, students have worked with Unilever on developing novel enzymes for health care products and have been named on patents filed by the company for these.

Professor of Biological Chemistry, University of Exeter

4. Economic and societal impact

4.1 Summary

- BBSRC's investments in IB are delivering economic and societal impact, with many researchers seeking to maximise the industrial application of their work.
- There is notable progression of IB technologies by academic researchers and business within the IB portfolio (for example, 42% of researchers had worked on developing technologies or products).
- The IB portfolio has made an excellent contribution to the development of new IP and establishment of spin-out companies (for example, the IB portfolio had contributed to 31% of all instances of BBSRC attributable IP and 34% of all instances of BBSRC attributable spin-outs arising between 2017 and 2021).
- Business engagement with BBSRC IB activities and researchers contributed to increased levels of business investment in R&D (for example, 67% of businesses surveyed reported this outcome).
- There were notable contributions to policy evident in the portfolio (for example, 12 of the 13 NIBB reported that their network had influenced policy relating to IB).

The supporting data for this Chapter are provided in Appendix 4.

4.2 Progression of IB technology

45. The success of innovation across BBSRC's IB portfolio was evidenced by the progression of IB technologies by researchers and business. Technology Readiness Levels (TRLs) are used to classify the developmental stage of technology or products, from basic principles to deployment in the real world. Grant holders were asked to report the TRL level of their technology or product development prior to, and immediately following the end of funding from BBSRC. In total, 42% of grant holders surveyed had worked on developing technologies or products as part of their BBSRC funded research. The most common TRLs reported by this group prior to the BBSRC support were 1 to 2; following BBSRC support the most reported TRLs were 3 to 4 (Appendix 4.1).

46. Businesses working with BBSRC academics were also asked to report the TRLs of their technology or product development prior to, and immediately following the end of funding from BBSRC. In total, 56% (10 out of 18) businesses surveyed had worked with a BBSRC funded partner to bring technology or products closer to market. The TRLs reported by this group prior to interacting with BBSRC were TRLs 1 to 2 (50% of businesses) and TRLs 3 to 4 (50% of businesses). Following support from BBSRC the most reported was TRL 5 to 6 (90% of businesses) (Appendix 4.1).

47. Several researchers and businesses reported achieving full commercialisation (see case studies in Section 4.8). The panel considered this to be an excellent achievement.

4.3 IP and spin-outs

48. Investment and support provided by university technology transfer teams have an important role to help realise the successful commercialisation of research. These dedicated in-house teams can help researchers understand whether there is commercial potential for the research. They can test assumptions around a proposed business model to further inform market discovery. Universities can support researchers in exploring licensing opportunities or seeking public or private funding, and support protection and exploitation of the university's IP, generated through its research, helping to maximise the economic, commercial and societal impact of that research.

49. BBSRC's investments in IB had contributed to an excellent level of IP generation and covered a good variety of potential applications. For example, 14% of grants in the IB portfolio with start dates between 2013 and 2017 had contributed to new IP. In total, 83 distinct instances of IP were reported as arising from the IB portfolio between 2017 and 2021. This represents 31% of all instances of BBSRC attributable IP reported over this period, despite the IB investment only representing 11% of BBSRC research funding. In addition, 22% of businesses surveyed reported that their

organisation had applied for licencing of IP as a result of their participation in BBSRC led initiatives.

50. BBSRC's IB investments had made very positive contributions to the establishment of spin-out companies. For example, 9% of grants with start dates between 2013 and 2017 reported a spin-out arising from their grant. In total, IB investment had contributed to the establishment of 44 spin-out companies with incorporation years between 2010 and 2021 (Appendix 4.2). Twenty-nine spin-outs were reported as arising from the IB portfolio between 2017 and 2021, which represents 34% of all BBSRC attributable spin-outs reported over this period.

51. Thirty of these spin-outs formed by BBSRC funded IB researchers were still active at the time of the evaluation (2022), three were dormant and the remainder had been dissolved. Several of these companies employ a considerable number of staff (see examples below), indicating evidence of growth within the organisation. Many are now successful companies that have brought products to market, created new employment opportunities across the UK and established a critical mass in the market and industries.

52. The panel identified several examples of successful spin-outs arising from BBSRC's IB portfolio:

- Oxford Biotrans[21] (see case study in section 4.7)
- Colorifix – developing a new method to dye textiles using microbes to produce, deposit and fix pigments to fabric. The company has raised £26.4 million in investment and has over 70 employees[22,23,24,25,26]
- Cellularevolution – refining continuous cell culturing techniques, employable in various industries. The company has raised £2.8 million in investment funding and has 15 employees[27,28]
- Deep Branch – using clean and renewable carbon and energy sources to create ingredients for a more sustainable food system. Their first product is Proton™, a single cell protein developed for the animal feed industry. The company has raised £9 million in funding and have over 30 employees[29,30,31,32]
- LabGenius – the first biopharmaceutical company developing next generation protein therapeutics using a machine learning-driven evolution engine (EVA™). Their protein engineering platform integrates several technologies from the fields of machine learning, synthetic biology and robotics. The company has raised £23.8 million to date and has over 50 employees[33,34,35]

4.4 Commercial impact

53. BBSRC's IB portfolio contained noteworthy examples of grant holders achieving commercial impact from their research (see case studies in Section 4.7). Together with the data on IP and spin-outs, this demonstrates that researchers working within BBSRC's IB portfolio were mindful of the commercial applications of their research.

54. Survey responses from businesses provide a positive view on the achievement of commercial outcomes from BBSRC IB investments (Appendix 4.5). For example, 33% (6 out of 18) of existing businesses surveyed had already experienced an increase in turnover, or expected to do so in the next two years, as a result of their interactions with BBSRC's IB portfolio. Businesses were not asked to provide their turnover figures, so the economic value of the impact achieved cannot be identified. Additionally, 31% of businesses surveyed had already experienced hiring of additional staff, or expected to do so in the next two years.

55. Businesses acknowledged that BBSRC initiatives were helpful in overcoming potential barriers to the application of IB research. The majority (78%) rated initiatives as helpful or very helpful in overcoming the challenges of finding suitable partners for collaboration, 72% rated initiatives as helpful or very helpful in allowing them to access technical expertise and skills and 61% said they were helpful or very helpful in allowing them to overcome the costs and risks of initial technology development (Appendix 4.3).

56. BBSRC support has allowed businesses working with academics to further exploit IB solutions and in turn, businesses are investing more in IB related R&D. Twelve out of 18 (67%) of businesses surveyed reported that their organisation has invested more in IB related R&D following engaging with BBSRC (Appendix 4.6).

4.5 Influence on policy and practice

57. The use of research findings to inform policy and practice is an important route to creating the conditions for impact from IB investments. In total, 14% of IB grants with start dates between 2013 and 2017 reported an influence on policy or practice. Between 2017 and 2021, 107 distinct instances of policy influence were reported as arising from the IB portfolio. Of the policy influences reported, 45% were described as having national reach and 23% had an international reach. Examples of policy influence included membership of guideline committee (25%), participation in advisory committee (21%), participation in national consultation (11%) and providing evidence to government reviews (10%).

58. An analysis of BBSRC IB publications using citations within policy documents indicated that 2.4% of research articles had been cited in a policy paper or other official policy document. Over half of policy documents (53%) citing BBSRC IB research were published by governmental organisations. Areas of policy which were citing BBSRC IB research included decarbonisation pathways for industry, addressing plastic pollution, and bio-based value chains for chemicals, plastics and pharmaceuticals.

59. The BBSRC NIBB initiative had made notable contributions to policy, with 12 of the 13 NIBB directors reporting how their network had influenced policy relating to IB. For example, the BBSRC NIBB initiative was able to leverage influence through the expertise of the membership and involvement with key stakeholders in the Bioindustry Association. Four BBSRC NIBB had contributed to the publication of 'Developing a Strategy for Industrial Biotechnology and Bioenergy in the UK'[36] in October 2017. The report provided short and long-term recommendations to support IB and help UK global competitiveness. The directors and network managers of two BBSRC NIBB (Network in Biocatalyst Discovery, Development and Scale-Up [BioCatNet] and Crossing Biological Membranes network [CBMNet]) have worked with the Industrial Biotechnology Leadership Forum (IBLF) to set out a vision for the future of IB in the UK. The IBLF took the evidence-based recommendations from the earlier 2017 aforementioned report and went on to publish 'Growing the UK Industrial Technology Base: A National Industrial Biotechnology Strategy to 2030'[37]. This also highlighted the opportunity to increase the overall level of awareness of policymakers to affect a more strategic approach for the IB sector to fully realise potential impacts.

4.6 Societal impact

60. Researchers provided examples of how their work contributed to areas of global public and societal interest. For example:

- a collaborative project between UK and Thai researchers that addressed the need for other South East Asian countries to produce their own, affordable, effective animal vaccines and lifesaving biopharmaceuticals by developing capacity and capability for large scale recombinant protein production[38]
- primary coffee production generates large amounts of liquid waste, which can pollute local water supplies around coffee growing sites. A low-cost microbial fuel cell has been developed that breaks down contaminants in wastewater from coffee production and generates cheap renewable energy
- there are no approved vaccines for Zika and Dengue fever, due to the risk of inducing more severe disease by a similar virus type. IB has developed a 'cloaking' technique to hide the part

of the vaccine proteins responsible for this effect

61. The examples of IB research contributing to wider societal impact were more limited compared with the contribution to commercial impact. The panel noted that greater societal impact would likely arise from BBSRC's IB investments over time.

62. Outreach events were highlighted by grant holders, such as their work in inspiring future careers in IB and uptake of IB solutions in society. However, the panel would have expected to see more evidence of public engagement to stimulate 'grassroots' appreciation for IB, which it considered to be important in understanding the unique role of this enabling technology in addressing global sustainability challenges. Certain networks in the BBSRC NIBB initiative invested in specific outreach initiatives that were considered successful. For example, ADNet supported the 'Circular Bioeconomy Roadshow' promoting the applications of anaerobic digestion and biogas at Glastonbury festival[39].

4.7 Case studies of economic and societal impact arising from BBSRC's IB research

63. The following section provides case studies of the economic and societal impact arising from BBSRC's IB portfolio. In addition to the case studies presented below, several successful IB projects were highlighted in BBSRC's Impact Showcase[40,41] and seven impact case studies attributable to BBSRC's IB investments were submitted to the 2021 Research Excellence Framework[42] exercise:

- improving efficiency for alcohol producers: from raw materials to final product[43]
- commercialisation of synthetic biology research delivers sustainable economic growth and job creation in South West England[44]
- Horizon Proteins: Circular economy innovation from whisky by-product to fish feedstock[45]
- innovation friendly regulation: implementing proportionate and adaptive governance for innovation in technology in the UK (PAGIT)[46]
- novel biorefining strategies for reprocessing agricultural waste, bioethanol production from sea water and the recycling of textiles[47]
- cultivation and genetic manipulation of cyanobacteria boosts production of natural blue food colouring, and investment at the SME ScotBio[48]
- driving the industrial biotechnology revolution: cheaper and more sustainable chemical manufacturing through enzyme discovery, engineering and scale-up[49]

Holiferm[50]

Formed in 2018, Holiferm is a spin-out company focused on the production of surfactants, a key ingredient in household and personal care products. Holiferm is facilitating the transition of the $42 billion surfactant market away from harmful, fossil fuel-based chemicals to biobased alternatives, resulting in biodegradable products that are also low in ecotoxicity. These products have applications in personal care, home care, industrial cleaning and agricultural settings. The technology was first demonstrated in the lab of a Reader in Chemical Engineering at the University of Manchester, with research being driven by then PhD student, who is now CEO of the organisation.

A number of small grants from various BBSRC NIBB provided targeted support at critical time points in the development of Holiferm's technology, supporting work with industry partners and allowing the company to grow. In September 2021, a £5.8m investment from United States based company, Rhapsody Venture Partners, was the latest capital investment secured by Holiferm. Holiferm won the Innovation Award at the Chemicals Northwest Awards 2022 for their patented gravity separation fermentation technology. As of early 2023, Holiferm employed 32 staff and they are set to launch their second and third fermentation derived biosurfactants to market in 2024. These are rhamnolipid and Mannosylerythritol lipids. They are currently being readied for pilot scale production before they go into a full manufacturing process at their Liverpool plant.

Reader in Chemical Engineering, The University of Manchester

From PhD student to Managing Director

"BBSRC support has been absolutely crucial to μFraction8's development at all stages of our growth."

The co-founder and Managing Director of μFraction8, a successful microfluidics company spun-out of Heriot-Watt University in 2017, developed propriety technology during their BBSRC funded CASE PhD studentship at the University of Edinburgh, sponsored by Scottish Water. Following this, they were supported by a BBSRC funded RSE enterprise fellowship to begin commercialisation of the research. This fellowship was instrumental in the formation of μFraction8, providing crucial business training needed to set up the company.

Originally developed to monitor water quality, μFraction8's microfluidic technology has been demonstrated to be more effective than traditional filtration methods on a variety of cell types used in IB processes. Being involved in various BBSRC NIBB introduced the researcher to collaborators with whom they could test these new applications of μFraction8's technology. Proof of concept funding from both BioProNet and PhycoNet funded work with researchers at Aston University and Swansea University to work on clarification of cells involved in chronic inflammation and micro-algae used for production of animal feed, respectively. Multiple larger grants followed to support scale-up of the technology, including work on an IB Catalyst grant, funding from the Eureka programme and an award from the Higgs Edge scheme for Scottish entrepreneurs.

μFraction8's core patent has now been granted in the UK, United States, Europe, Japan and Australia, and is pending in further territories. In 2019 a subsidiary company was set up in Poland to work with European Partners, having received fast-track funding from the European Innovation Council Accelerator to achieve this. A team of 6 are currently employed in the UK, with 10 staff working in the Poland branch.

CEO, μFraction8

Oxford Biotrans

Oxford Biotrans is a spin-out company focused on the development and commercialisation of enzymatic process technologies, formed by research at the University of Oxford. Their first product was a natural grapefruit flavouring called Nootkatone, which is now available to buy commercially. Nootkatone is a highly valued flavouring in the food and drink industry, with natural supplies from grapefruits themselves unable to meet global demand. Synthetic approaches to production rely on undesirable methods using heavy metals and peroxide, hence the need for large scale natural and more environmentally friendly approaches to production. Around 20 years of funding support from BBSRC and EPSRC allowed a Professor and colleagues to first create and patent the enzymes needed to create Nootkatone more sustainably.

Follow-on funding from BBSRC, along with a business interaction voucher from the Metals in Biology BBSRC NIBB enabled the technique to become industrially viable. Oxford Biotrans gained an initial £600,000 in seed funding, followed by £2.5m private investment in 2015 and a further £2.1m in 2017. To unlock these benefits, it was vital to have a scalable fermentation process to produce the enzymes. As a young, virtual company, Oxford Biotrans sought to collaborate with an open access research organisation (Centre for Process Innovation [CPI]) to perform the process development. However, maintaining IP ownership position was of paramount importance and key to protecting the interests of the company's investors. For a spin-out company with minimal manufacturing assets, the road to commercialisation often presents significant challenges. Using the CPI allowed Oxford Biotrans to take their economically and environmentally superior process from innovation to commercial manufacture faster, and with a significantly reduced level of risk.

Professor of Chemistry, University of Oxford

Vanillin from plastic waste

Plastic waste is a severe environmental problem, with plastic bottles being the second most common type of plastic pollution found in the oceans worldwide. Current recycling efforts are not enough to combat this, with traditional plastics losing about 95% of their value as a material after single use. A BBSRC funded discovery fellow at the University of Edinburgh aims to combat this by 'upcycling' plastic bottle waste into more a desirable product. Previous work has already demonstrated the ability of genetically engineered enzymes to break down polyethylene terephthalate, the principal material used in manufacturing plastic bottles, into its basic units terephthalic acid. Building on this, the researcher developed a method for converting terephthalic acid into vanillin using engineered E. Coli. Vanillin is widely used in the food and cosmetics industries and is an important bulk chemical used to make pharmaceuticals, cleaning products and herbicides. Global demand for vanilla flavouring far exceeds the supply chain from natural beans, with the majority of vanillin currently synthesised from chemicals derived from fossil fuels. Replacing this supply chain with the bioprocessing method developed by this researcher could not only tackle plastic pollution but also eliminate the need for fossil fuel usage in meeting the global demand for Vanillin.

Researcher in Biological Sciences, University of Edinburgh

Sustainable plastic production[51]

Modern bioplastics have the capability to replace oil-based plastics in both short-life disposable products and long-life durable products, thus contributing to a more sustainable plastic industry and reducing the environmental impact of plastics in the long term. A Professor at the University of Warwick was funded by an Integrated Biorefining Research and Technology Club grant to undertake research which resulted in the identification of a bacterial enzyme capable of breaking down lignin, a structural material found in plants and a natural by-product of the paper pulp industry. This was the first step towards production of bioplastics from lignin and led to a collaboration with Biome Bioplastics, one of the UK's leading bioplastic developers. Further support from the BBSRC NIBB and the IB Catalyst enabled more collaboration to advance the project, this time with the University of Leeds and the CPI. Biome Bioplastics are now focused on demonstrating that lignin products can be produced on a commercial scale for bioplastics production. This Professor is supported by a BBSRC ERA-CoBioTech funding to continue this work.

Professor of Biological Chemistry, University of Warwick

5. BBSRC's support for IB

5.1 Summary

- BBSRC has played a critical role in providing leadership for IB research, fostering a vibrant IB community and helping to address barriers to delivering innovation and impact.
- BBSRC's investments in IB have enabled researchers to effectively advance their research programmes (for example, 62% of grant holders rated BBSRC's funding mechanisms as either effective or very effective).
- The coverage of BBSRC's IB portfolio is good, spanning a wide range of industry sectors including materials, chemicals, energy, pharmaceuticals and biopharmaceuticals, waste processing and recycling, agriculture, food and construction sectors.
- There are opportunities for BBSRC to build on its effective support for IB, working with other constituent components of UKRI to help ensure long-term effective routes and funding opportunities for the translation of IB research.
- IB has huge potential to ensure the UK is equipped to meet global sustainability challenges such as Net Zero; further alignment of BBSRC's IB portfolio with industrial and societal challenges will help support this.
- There is a need for a more co-ordinated approach to the UK policy landscape for IB. In this context, there is a role for BBSRC, together with other parts of UKRI, to increase the overall level of awareness among policymakers of the potential of the IB sector to contribute further to the UK economy.

The supporting data for this Chapter are provided in Appendix 5.

5.2 Effectiveness of BBSRC's IB portfolio

64. BBSRC has supported IB research through a variety of investment mechanisms including responsive mode and managed initiative funding (Appendix 5.1). The majority (67%) of researchers surveyed had received a mixture of

© Scottish Association for Marine Science both responsive mode[52] and managed initiative support. A minority (10%) had been supported only through responsive mode, whereas 23% had only been supported through managed initiatives.

65. The majority of former grant holders (62%) stated that BBSRC's funding mechanisms for supporting IB research were effective of very effective. The panel welcomed the diversity of funding mechanisms within the BBSRC IB portfolio, highlighting the value of targeted initiatives such as the BBSRC NIBB and IB Catalyst in enabling greater impact from the research. The panel noted the value of specialist expertise in assessing IB research, given that IB research objectives are not always directly comparable to other subjects or disciplines. In this context, the responsive mode funding mechanism may create additional challenges for IB researchers seeking to secure funding to advance their research programmes.

66. The panel considered the balance and coverage of BBSRC's IB portfolio to be good (Appendices 5.2 and 5.3). BBSRC's IB portfolio spans a wide range of industry sectors including materials, chemicals, energy, pharmaceuticals and biopharmaceuticals, waste processing and recycling, agriculture, food and the construction sectors and it is making and effective contribution to the wider IB research and innovation landscape.

5.3 Supporting continued interactions with industry and industry-led challenges

67. A healthy IB research community with strong connections between academia and industry is critical for ensuring the delivery of excellent science and the subsequent delivery of wider benefit and impact. BBSRC's IB funding mechanisms have supported extensive networking opportunities and targeted engagement of industry partners, which were considered to be very beneficial. The panel noted the important role of BBSRC's research industry clubs, the BBSRC NIBB, industry challenge-led workshops and calls in key areas relating to IB (for example CO_2 capture and biomass valorisation) in facilitating continued interactions with industry and ensuring that BBSRC IB research was addressing research questions relevant to industry.

68. The panel considered that continued investment in the networks would enable a vibrant IB research and innovation community to thrive. Building on this extensive engagement with researchers and industry, BBSRC could strengthen its networking both within the UK and internationally with relevant stakeholders including, for example, policy makers in related government departments such as Defra and end users. An increase in stakeholder interactions has the potential to further expand pathways to impact for BBSRC's IB portfolio.

5.4 Supporting capacity building

69. The panel considered skills and capacity building to be a vital component for the successful translation of IB research. In this context, there are opportunities to promote interdisciplinary research for PhD students, postdoctoral researchers, and ECR fellows as a good route to maximise capacity building for IB. The panel noted that large companies have an interest in maintaining a healthy research base. The panel considered that BBSRC could seek co-investment from the private sector to support doctoral training entities in delivering high-quality cohort-based doctoral education in IB, which would further build capacity. In relation to skills, 25% of grant holders surveyed cited their lack of commercial expertise as a barrier to achieving impact. The panel suggested that this could be addressed through enhanced training in key skills which IB researchers are keen to develop such as IP, commercial awareness and business management.

5.5 Barriers limiting opportunities for translation

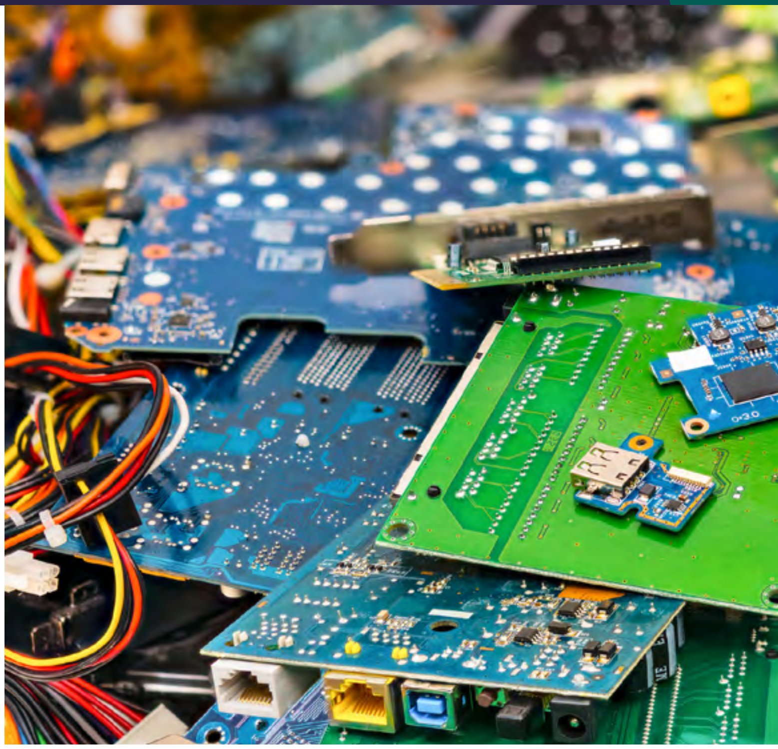
70. Good progress is being made with the delivery of impact from BBSRC IB investments, including the development and commercialisation of innovative new products. However, there are barriers that are limiting opportunities for the research to realise its full potential (Appendix 4.4). When surveyed, grant holders identified a variety of barriers to impact including (i) being unable to access infrastructure to upscale lab-based bioprocesses to a commercial industrial scale , (ii) a lack of opportunities for commercialisation (for example, funding opportunities, having an appropriate partner), and (iii) a lack of commercial/business expertise.

71. De-risking the commercialisation of bio-based products and processes by trialling new technologies is critical to encouraging the successful translation of BBSRC IB research. For example, researchers require access to specialist infrastructure to progress the development of IB technologies and scale up IB products to a commercially viable scale. However, the high costs of accessing some facilities, as well as the availability of appropriate infrastructure is impeding innovation and commercialisation. It was the panel's view that facilities such as the Centre for Process Innovation (CPI)[53] which is part of the UK's High Value Manufacturing Catapult[54] could potentially help address such barriers, for example, if the academic research base had greater access to these and other scale-up facilities.

72. IB is a group of cross- or multidisciplinary technologies with diverse outputs beyond traditional academic impact and strong potential to meet key environmental, health and societal challenges. BBSRC's IB portfolio has enabled researchers to expand current networks of industry partners and develop new networks in different sectors, and this has been critical to successful delivery of collaborative research leading to new products or processes.

73. There are opportunities to improve the exploitation of IP arising from IB investments, for example, accelerating contract negotiations around IP ownership between academia and industry (particularly for smaller value contracts). These could be very slow, even considering the availability of toolkits and model agreements which are intended to facilitate negotiations and speed-up the time required to secure agreement (for example, the Lambert Toolkit[55]). The panel noted that this was a significant limitation in the commercialisation process, which may be linked to insufficient business expertise in universities and other research organisations (Appendix 4.4). When surveyed, businesses working with IB researchers indicated that they would value more agile grants with more favourable IP terms for the business partner and 'follow-on' grants which could focus on generation of IP.

74. Technology transfer teams in universities and other research organisations also have an



important role in enabling the development of IP and supporting commercialisation. It was the panel's view that there was an inconsistent approach to the level of support provided to researchers by technology teams across the UK, which may limit the delivery of impact from BBSRC IB research.

75. The panel considered the potential use of pre-competitive funding to accelerate translational research within the IB portfolio. A model given was CMAC, an internationally leading research centre, that has a unique configuration of academic research, applied and precompetitive programs and translation to industry models[56]. Pre-accelerator programmes such as BBSRC's ICURe[57] (and Leanlaunch[58], the United States equivalent), were seen as excellent programmes for exploring the commercial application and potential of UK IB research. The National Centre for Biofilms[59], an Innovation Knowledge Centre, was also identified as a successful mechanism with co-funding from BBSRC and Innovate UK.

76. The IB Catalyst scheme was also considered a successful mechanism for supporting translational research. The IB Catalyst supported research and development into the processing and production of materials, chemicals (including pharmaceutical precursors and biopharmaceuticals) and bioenergy. In addition, it supported the development and commercialisation of innovative IB processes

to manufacture a wide range of existing and new products through collaborative and non-collaborative research grants. The panel considered the closure of the IB Catalyst scheme[60], which was a joint enterprise between BBSRC, EPSRC and Innovate UK, to have created a gap in support.

77. BBSRC supports innovation programmes that ensure businesses can thrive in their collaborations with the UK's world-leading research base. The panel noted that the gap between TRL of academic discoveries and that required for industrial implementation to be too wide to be covered by a single grant. A pipeline of funding opportunities is likely to be necessary to enable the commercialisation of discoveries from BBSRC's IB research. When surveyed, grant holders identified the need for continued support for academic research, as well as follow-on funding to facilitate further development of new products and processes with industry partners. It was also noted that Innovate UK funding does not necessarily dovetail with earlier stage academic research funding provided by BBSRC. Businesses also expressed a need for more options for tapered increases in financial contributions to help facilitate emerging technologies from proof of concept to full scale-up (for example in relation to the Knowledge Transfer Partnership contribution levels).

78. There is scope for UKRI to develop an augmented pipeline of translational funding to provide long-term sustained investment that is required to maximise the impact from IB research. In this context, there are opportunities for BBSRC to undertake complementary work with other constituent components of UKRI, principally with Innovate UK, to build on existing successes. Enabling closer working between the academic research base and processing and manufacturing hubs in the UK (such as CPI and other similar facilities) would also be beneficial.

5.6 IB in the UK's bio-based economy

79. The UK has core strengths in potential high growth areas such as manufacturing high value chemicals and recombinant biologics. Public and private sector support have combined to build emerging markets and there are major opportunities to exploit UK expertise in synthetic biology to create new medicines, green chemicals and fuels. Global markets addressed by IB, including drop-ins and replacements, often promise higher compound annual growth rate (CAGR): bio-surfactants 5.1% CAGR, 2017 to 2022; bio-plastics 28%, 2017 to 2033[61].

80. IB is supporting some UK market segments that are pioneering. For example, IB is already embedded in food manufacturing through the use of enzymes and fermentation for production. The UK has strengths in high growth and emerging IB markets, exploiting the academic expertise in genomic, systems and synthetic biology in partnership with SMEs and multinational companies. The magnitude of the opportunity available to the IB-enabled end-users is clear, with more than $34 billion of addressable established product markets in the UK, and estimates of the global IB revenues reaching $450 billion by the middle of the next decade[62]. There is however a lack of penetration in new markets.

81. The panel highlighted the need for supportive long-term government policies (including, for example, standards and regulation) to enable the full potential of IB to be realised. A more co-ordinated approach to the UK policy landscape for IB would be beneficial, signalling to those emerging markets the opportunity to exploit UK expertise. It would also encourage future investments to nurture academic-industry partnerships, enhance access to pilot facilities for SMEs and foster rapid commercialisation, ensuring that the UK could secure its place as a world-leader in IB. Without a national IB strategy and sustained long-term investment, it is likely that the UK will remain behind countries such as the United States. There is a role for BBSRC, together with other parts of UKRI, to increase the overall level of awareness of policymakers on the potential of the IB sector to contribute further to the UK economy.

5.7 Conclusions

82. It is clear that BBSRC recognises the value of IB as a research discipline and its provision of a co-ordinated package of support mechanisms to the IB research community is very welcome. The IB communities catalysed by BBSRC via initiatives

such as the BBSRC NIBB are highly valued. It is by bringing together established groups, new academic groups, established companies, up and coming start-ups, and policy makers that the interdisciplinary expertise needed to solve complex environmental and societal challenges is galvanised. Continued support of these IB communities will help to maximise translation and the level of impact generated from BBSRC's investment.

83. BBSRC's support for IB has enabled the translation of basic discoveries into new products and processes, producing substantial commercial outcomes and impacts beyond the lab. The opportunities for collaboration with industry via a variety of BBSRC investment mechanisms have been key to this success.

84. UKRI has a role in demonstrating continued leadership in IB which is important for these emerging technologies. There is also a need to foster wider appreciation for IB with the general public, highlighting the contribution of the up-take of IB technologies towards a building a new, 'greener' future.

85. The panel welcomed BBSRC's support for IB research and innovation as a strategic priority since 2010 and the successes it has delivered. It will be essential for BBSRC and UKRI to continue to support this area as a priority in the future, delivering sustained and increased investment. The evidence captured for this evaluation demonstrates the value of dedicated initiatives in this area, and further investment through such mechanisms is likely still needed to realise the full potential of IB. There also are clear links between IB and other research areas, including Engineering Biology whose technologies form a sub-set of IB tools used by the community, and it will be important for the IB community to take full advantage of relevant UKRI funding opportunities available here.

86. The full scale of the impact IB could have on our day-to-day lives in the future is still being uncovered. UKRI (and BBSRC within it) have a critical role in supporting and championing researchers to work with businesses in exploiting the capability to develop less carbon intensive products and processes, whilst also reducing costs and opening up new, emerging and established markets. It is clear that this field has the potential to equip our society to live more sustainably and our economy to compete more effectively in the decades ahead. IB will be one of the strongest driving forces behind the world's low-carbon revolution.

Appendix 1

1.1 Membership of the evaluation panel

Professor Peter Fryer (Chair)	University of Birmingham
Dr Alison Mohr	Independent Research Consultant
Professor Claire Eyers	University of Liverpool
Dr Jonathan Scurlock	National Farmers' Union
Dr Linda Randall	Pharmaron UK
Dr Matthew Bycroft	Dr Reddy's Laboratories
Professor Matthew Davidson	University of Bath
Professor Siddharth Patwardhan	University of Sheffield

A representative from the Bio-Based and Biodegradable Industries Association[63] which represents companies involved in the production of bio-based and biodegradable products was due to sit on the evaluation panel, however due to unforeseen circumstances they were unable to attend.

1.2 Evaluation objectives

The aim of the evaluation was to conduct an independent assessment of the effectiveness and impact of BBSRC's investments in IB. Specifically, the objectives of the evaluation were to:

- assess the quality and international standing of the IB research supported through a range of investment mechanisms
- assess the outputs, outcomes and achievements of BBSRC's major investments in IB research and training
- assess the economic, societal and policy impacts of BBSRC supported IB research and training
- examine interactions with industry within the IB portfolio and their effectiveness in stimulating research and innovation
- consider how BBSRC's investments in IB have met the expectations of users, stakeholders and policy makers
- examine the role of BBSRC in building capacity and capability and in fostering strong communities
- examine the strategic balance and coverage of BBSRC's support for IB research and training
- examine the strengths and weaknesses within the IB portfolio supported through a range of investment mechanisms

1.3 Methodology

The results and evidence in the paper presented to the panel were drawn from the following sources:

- **BBSRC grants database:** relevant data were obtained from the BBSRC grants database (ReSOURCe). Spend data for financial years 2010/11 until 2021/22 was determined to be an appropriate timeframe for the evaluation. The sum of BBSRC's spend in IB over this time was approximately £413 million
- **research outcomes data:** all BBSRC grant holders are required to report information on the outputs, outcomes and impacts arising from their funding annually via the Researchfish system. For the evaluation,

outcomes analysis was conducted on grants with start dates between 2010 and 2020, the latest Researchfish submission window for these was March 2022. This equated to 568 grants in total; 13 NIBB Phase I grants were analysed separately from this main cohort. Additional information for NIBB outcomes was obtained from an extranet reporting system for NIBB Directors

- **bibliographic and bibliometrics databases:** additional data on publications arising from the BBSRC IB portfolio were obtained from Clarivate Analytics WoS, InCites software packages and a policy database. Citation data were captured in May 2022
- **grant holder survey:** a survey was conducted to capture evidence from the academic community who had received BBSRC support for IB research. A sample of 150 grant holders was selected to ensure a balance of coverage across the BBSRC IB portfolio. In total, 48 responses were received (32% response rate) between November 2021 and January 2022. The survey is available on request
- **business survey**[64]: a survey was conducted to capture evidence from the industrial community who had participated in BBSRC supported IB research activities. A sample of 100 businesses was selected to ensure a balance of coverage across the BBSRC IB portfolio and for which contact details were available. In total, 18 responses were received (18% response rate) between November 2021 and January 2022. The survey is available on request
- **BBSRC NIBB Directors survey:** all BBSRC NIBB Phase I directors were surveyed to collect additional evidence on outcomes and impacts arising from their networks. A total of 13 responses (100% response rate) were received between October 2021 and November 2021. The survey is available on request
- **semi-structured interviews:** 10 interviews were conducted between January and February 2022, with six academics and four businesses selected for these based on their survey responses. The intent was to develop a richer understanding of how BBSRC has supported their work, understand the wider research and innovation landscape context, and to develop impact case study examples, some of which incorporate lessons learned
- **additional economic data on spin-outs:** names of spin-out companies attributed to BBSRC funding are initially captured in Researchfish submissions. Additional data on employee number, location, net assets and incorporation dates were obtained from Companies House and Endole in July 2022

Two distinct approaches are used to analyse the outputs and outcomes data:

- **outcomes-focused analyses:** such analyses are based on outcomes that have arisen between 2017 and 2020. The data includes outputs from 568 grants with active spend between 2010/11 and 2020/21, totalling approximately £384 million
- **grant-focused analyses:** such analyses are based on 310 grants with start dates between 2013 and 2017. This approach is intended to provide sufficient time for the grants to realise and report outputs and outcomes, noting that there can be a significant lag time between the research activity and the realisation of outputs and outcomes

It should be noted that when the NIBB initiative is referenced in this report, it refers to Phase I only. BBSRC (with support from EPSRC) invested £11 million to fund six unique collaborative NIBBs through Phase II from 2019 to 2024, however as these projects are still active and due to the length of time it takes for impact to occur, this report only includes data and outcomes from NIBB Phase I.

The panel considered the bioenergy sector to be underrepresented in the evidence collected for the evaluation. Due to the extensiveness of UKRI IB-related initiatives, specific bioenergy initiatives such as Supergen, funded through EPSRC, were not included as part of the evaluation.

In this report, the words 'grant' and 'project' are used interchangeably.

1.4 BBSRC's investments in IB

Between 2010/11 and 2021/22, BBSRC's total spend in IB research and innovation was £413 million. Table 1.1 provides information on the main funding mechanisms used to support BBSRC's IB portfolio during this time.

Table 1.1 Main funding mechanisms used to support BBSRC's IB portfolio

Funding Mechanism	Total spend	Lifespan	Brief description
Responsive mode	£129.6m	Throughout	BBSRC's standard research grant application stream, open for applications at any time. Various schemes have operated under responsive mode; notably for IB, LINK and IPA supported partnerships with industry.
Strategic institute investments	£49.1m	Throughout	Strategic funding awarded to the BBSRC strategically supported institutes.
Fellowships	£8.9m	Throughout	Various types of fellowship awards have been operated by BBSRC/UKRI. Fellowship grants are to support early- and mid-career scientists transitioning to an independent research career.
Bioprocessing Research Industry Club (BRIC)[65]	£13.8m	2006–2011	Research club launched in partnership with EPSRC and industry. Jointly managed by BBSRC and the HealthTech & Medicines KTN. Eighteen company members contributed to funding and steering of the club.
Integrated Biorefining Research and Technology Club (IBTI)[66]	£5.9m	2008–2016	Research and technology club launched in partnership with EPSRC and the Biosciences Knowledge Transfer Network (KTN). Nine company members contributed to funding research and directed activities of the club.
Networks in Biotechnology and Bioenergy (NIBB)	£21.2m	2014–2019	Network funding across BBSRC's IB remit to establish communities and pump-prime a pipeline of translation focused research projects. Thirteen Networks[67] were funded within BBSRC NIBB Phase I.
IB Catalyst	£39.8m	2014–2016	Joint venture with Innovate UK and EPSRC, set up to accelerate the commercialisation of IB derived products and processes.
ERA-IB[68] **and ERA-IB-2**[69]	£5.8m	2006–2011 2011–2016	Funded via the European Commission's Framework Programme. Joint initiatives to foster the exchange of IB knowledge across borders.
ERA CoBioTech[70]	£3.4m	2016–2022	Joint research initiative funded via Horizon 2020, bundling three predecessor ERA-Networks in IB.
Newton fund[71]	£5.2m	2014 onwards	UK governmental funding to build research and innovation partnerships with middle-income countries in Africa, Asia and Latin America.
Global Challenges Research Fund[72]	£7.9m	2016 onwards	UK governmental funding to support UK and international researchers tackling key issues affecting developing countries.

Appendix 2

2.1 Grant performance

Data on grant performance are shown in Table 2.1.

The data are drawn from the 'Key Findings' section of Researchfish where grant holders are asked to make a self-assessment by answering the question "Have you met your original objectives?"

Information was available for 310 grants in the IB portfolio. In total, 77% of grant holders with completed IB-related grants reported that their project had met its objectives.

Table 2.1 Project performance data from Researchfish for IB grants (start dates 2013 - 2017)

	Proportion of grant holders (%)			
	Yes	Partially	No	Too early to say
Completed grants (n = 310)[1]	77	17	0.3	5

1 Data are for IB-related grants with start dates between 2013 and 2017 that were complete at the time of the most recent Researchfish Submission Period (February 2022).

For the one grant that had not met its original objectives, the reason stated was that the project was high risk at the outset and while it had made progress it had not yet achieved its end goal.

For the 55 grants where objectives had only been partially met, the reasons for this included[73]:

- access to archives, data or participants (2%; 0.3% of all grants)
- changing landscape of research programme (33%; 6% of all grants)
- difficulties with collaborative partners (9%; 2% of all grants)
- experimental, methodological or technical issues (82%; 15% of all grants)
- other resourcing issues (7%; 1% of all grants)
- staffing matters (16%; 3% of all grants)
- unrealistic initial objectives (13%; 2% of all grants)

All 13 BBSRC NIBB Phase I grants had achieved their original objectives (as reported by network directors).

2.2 Publication outputs

Researchers are able to report a variety of publication types within Researchfish including original research articles, review articles, books, book chapters and conference proceedings.

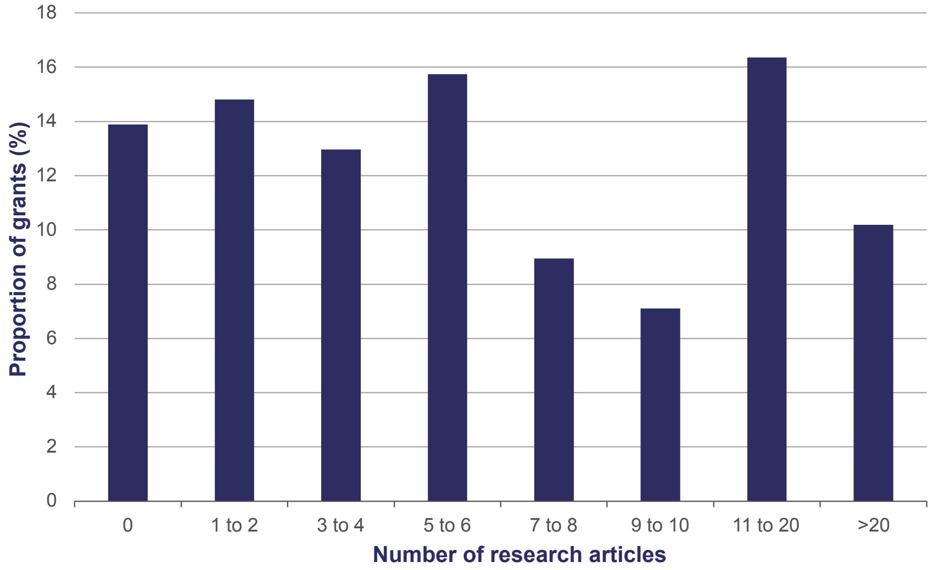
87% of grants from the general IB portfolio with start dates between 2013 and 2017 resulted in a publication output (of any type).

84% of grants from the general IB portfolio with start dates between 2013 and 2017 resulted in the publication of one or more research articles.

The number of research articles reported for grants within the general IB portfolio with start dates between 2013 and 2017 is shown in Figure 2.1. The mean number of research articles per grant was 12, the median was 5.

Between 2017 and 2021, a total of 2371 research articles were reported as arising from the IB portfolio. Figure 2.2 shows a breakdown of research articles by publication year.

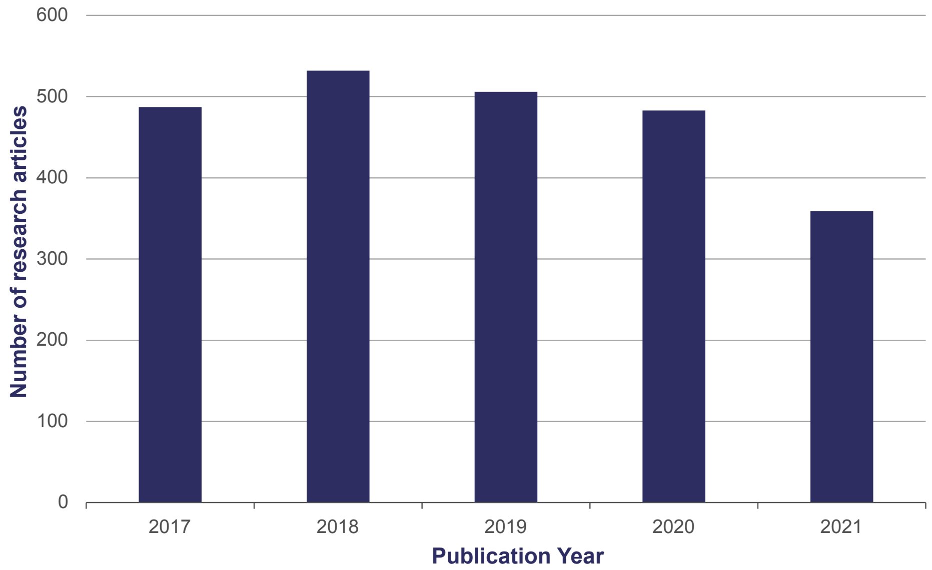
Figure 2.1 Number of original research articles published per IB grant



Data Table

	Number of research articles							
	0	1 to 2	3 to 4	5 to 6	7 to 8	9 to 10	11 to 20	>20
Proportion of grants (%)	13.9	14.8	13.0	15.7	9.0	7.1	16.4	10.2

Figure 2.2 BBSRC IB research articles reported by publication year

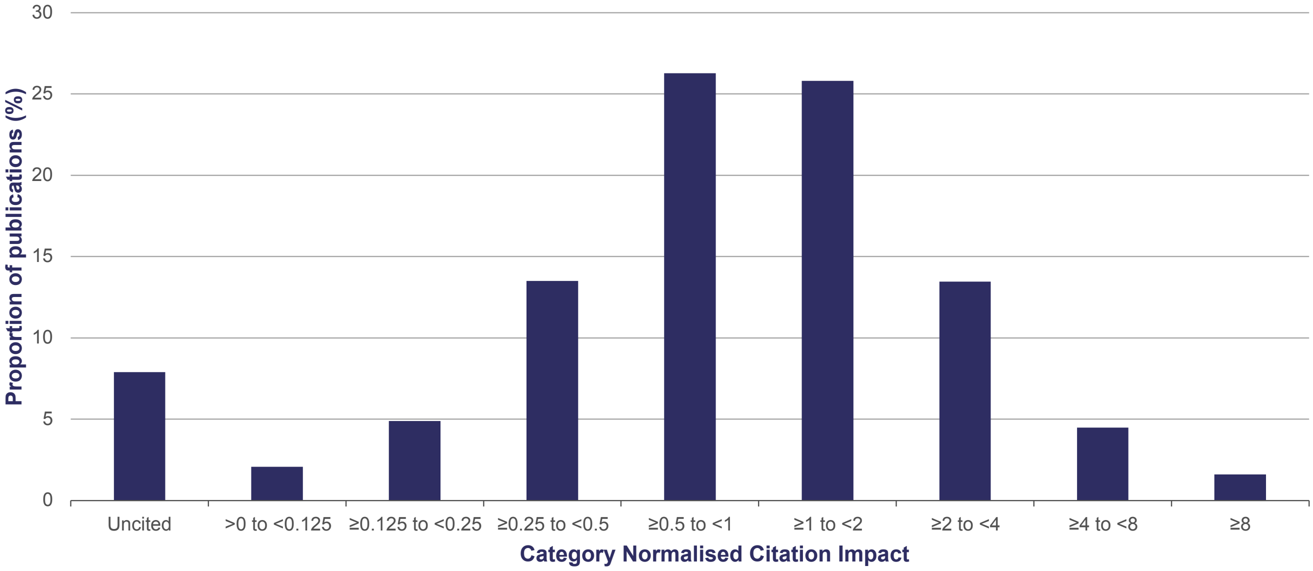


Data Table

	Publication Year				
	2017	2018	2019	2020	2021
Number of research articles	487	532	506	483	359

2.3 Citation impact analysis of IB publication outputs

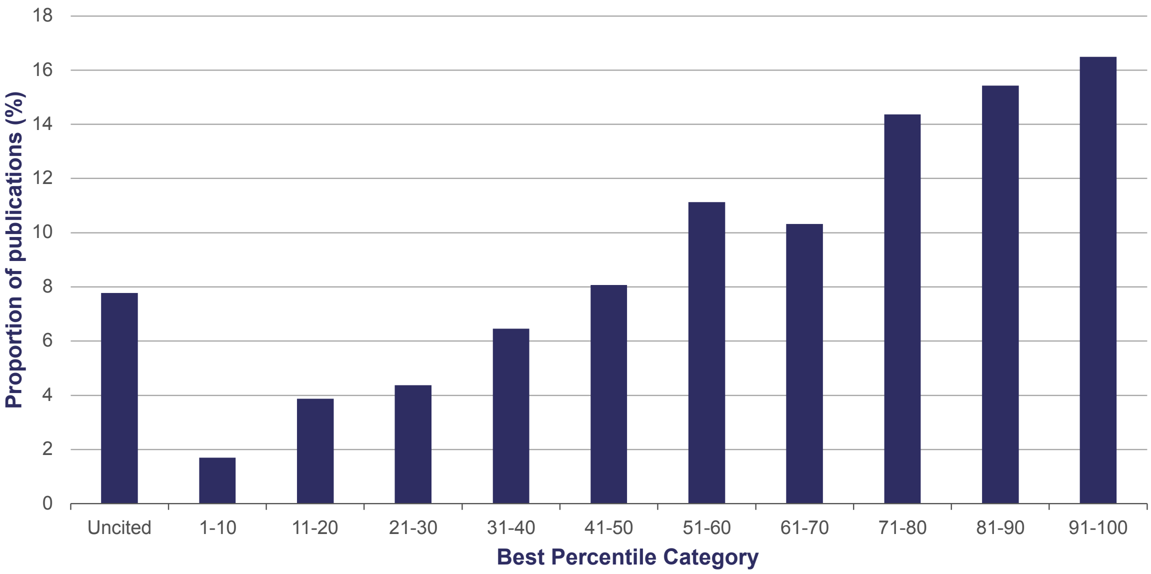
Figure 2.3 Category Normalised Citation Impact for IB portfolio research articles (2017-2021)



Data Table

	Category Normalised Citation Impact								
	Uncited	>0 to <0.125	≥0.125 to <0.25	≥0.25 to <0.5	≥0.5 to <1	≥1 to <2	≥2 to <4	≥4 to <8	≥8
Proportion of publications (%)	7.9	2.1	4.9	13.5	26.3	25.8	13.5	4.5	1.6

Figure 2.4 Best Percentile Analysis for IB portfolio research articles (2017-2021)



Note: the 90 to 100 category represents papers that are in the top 10% of publications etc.

Data Table

	Best Percentile Category										
	Uncited	1 to 10	11 to 20	21 to 30	31 to 40	41 to 50	51 to 60	61 to 70	71 to 80	81 to 90	91 to 100
Proportion of publications (%)	7.8	1.7	3.9	4.4	6.5	8.1	11.1	10.3	14.4	15.4	16.5

2.4 Most impactful publications

Researchers who responded to the grant holders survey were asked to provide their single most impactful publication in IB that had resulted from BBSRC funding. Below is a list of those 39 papers including the cNCI, number of citations, year published and digital object identifier (DOI). Panel members were invited to note the research quality of IB publications.

Table 2.2 Sample of publications for the whole IB portfolio

Article Title	Publication Year	Total Cites	cNCI	DOI
Biosynthesis of Poly(3HB-co-3HP) with Variable Monomer Composition in Recombinant Cupriavidus necator H16	2021	2	0.54	10.1021/acssynbio.1c00283
Self-assembly of Quillaja saponin mixtures with different conventional synthetic surfactants	2022	2	0.30	10.1016/j.colsurfa.2021.127854
Enabling large-scale production of algal oil in continuous output mode	2021	0	0	10.1016/j.isci.2021.102743
C-type cytochrome-initiated reduction of bacterial lytic polysaccharide monooxygenases	2021	1	0	10.1042/BCJ20210376
Enzymically attaching oligosaccharide-linked 'cargoes' to cellulose and other commercial polysaccharides via stable covalent bonds	2020	4	0.50	10.1016/j.ijbiomac.2020.09.039
A Thermally Reformable Protein Polymer	2020	5	0.46	10.1016/j.chempr.2020.09.020
Enzymatic C-H activation of aromatic compounds through CO_2 fixation	2020	20	1.74	10.1038/s41589-020-0603-0
Low carbon strategies for sustainable bio-alkane gas production and renewable energy	2020	35	3.22	10.1039/d0ee00095g

Article Title	Publication Year	Total Cites	cNCI	DOI
Loss of TaIRX9b gene function in wheat decreases chain length and amount of arabinoxylan in grain but increases cross-linking	2020	5	0.89	10.1111/pbi.13393
Pressurised disc refining of wheat straw as a pre-treatment approach for agricultural residues: A preliminary assessment of energy consumption and fibre composition	2020	6	0.38	10.1016/j.biortech.2020.122976
An in vivo platform to select and evolve aggregation-resistant proteins	2020	13	1.16	10.1038/s41467-020-15667-1
Understanding the role of SilE in the production of metal nanoparticles by *Morganella psychrotolerans* using MicroScale Thermophoresis	2020	3	0.34	10.1016/j.nbt.2019.09.002
Identification of a major QTL and associated molecular marker for high arabinoxylan fibre in white wheat flour	2020	6	1.17	10.1371/journal.pone.0227826
A proteome-integrated, carbon source dependent genetic regulatory network in *Saccharomyces cerevisiae*	2020	2	0.23	10.1039/c9mo00136k
A Natural Diels-Alder Biocatalyst Enables Efficient [4+2] Cycloaddition Under Harsh Reaction Conditions	2019	2	0.11	10.1002/cctc.201901285
CyanoGate: A Modular Cloning Suite for Engineering Cyanobacteria Based on the Plant MoClo Syntax	2019	63	6.85	10.1104/pp.18.01401
Impact of a Heat Shock Protein Impurity on the Immunogenicity of Biotherapeutic Monoclonal Antibodies	2019	8	0.67	10.1007/s11095-019-2586-7
Birth of a Photosynthetic Chassis: A MoClo Toolkit Enabling Synthetic Biology in the Microalga *Chlamydomonas reinhardtii*	2018	97	6.86	10.1021/acssynbio.8b00251
Self-sustaining closed-loop multienzyme-mediated conversion of amines into alcohols in continuous reactions	2018	78	2.98	10.1038/s41929-018-0082-9

Article Title	Publication Year	Total Cites	cNCI	DOI
Light-Driven H-2 Evolution and C=C or C=O Bond Hydrogenation by *Shewanella oneidensis:* A Versatile Strategy for Photocatalysis by Nonphotosynthetic Microorganisms	2017	46	1.42	10.1021/acscatal.7b02736
Drug-tunable multidimensional synthetic gene control using inducible degron-tagged dCas9 effectors	2017	34	2.03	10.1038/s41467-017-01222-y
Use of a protein engineering strategy to overcome limitations in the production of Difficult to Express recombinant proteins	2017	11	0.69	10.1002/bit.26358
Improving the 'tool box' for robust industrial enzymes	2017	21	0.44	10.1007/s10295-017-1920-5
Challenges in microbial ecology: building predictive understanding of community function and dynamics	2016	332	5.47	10.1038/ismej.2016.45
Deimmunization for gene therapy: host matching of synthetic zinc finger constructs enables long-term mutant Huntingtin repression in mice	2016	35	1.39	10.1186/s13024-016-0128-x
The mechanism of phi C31 integrase directionality: experimental analysis and computational modelling	2016	15	0.60	10.1093/nar/gkw616
Heterologous Production of Fungal Maleidrides Reveals the Cryptic Cyclization Involved in their Biosynthesis	2016	38	1.36	10.1002/anie.201511882
Direct and Absolute Quantification of over 1800 Yeast Proteins via Selected Reaction Monitoring	2016	51	2.80	10.1074/mcp.M115.054288
Alginate-Encapsulation for the Improved Hypothermic Preservation of Human Adipose-Derived Stem Cells	2016	44	1.70	10.5966/sctm.2015-0131
High-Throughput Thermal Stability Analysis of a Monoclonal Antibody by Attenuated Total Reflection FT-IR Spectroscopic Imaging	2014	41	1.85	10.1021/ac502529q

Article Title	Publication Year	Total Cites	cNCI	DOI
Functional screening of willow alleles in Arabidopsis combined with QTL mapping in willow (*Salix*) identifies *SxMAX4* as a coppicing response gene	2014	9	0.37	10.1111/pbi.12154
Transcription of Click-Linked DNA in Human Cells	2014	57	1.51	10.1002/anie.201308691
Proteomic analysis of *Bacillus subtilis* strains engineered for improved production of heterologous proteins	2013	31	0.91	10.1002/pmic.201300183
BslA is a self-assembling bacterial hydrophobin that coats the *Bacillus subtilis* biofilm	2013	178	5.67	10.1073/pnas.1306390110
The Copper Active Site of CBM33 Polysaccharide Oxygenases	2013	136	3.31	10.1021/ja402106e
Cytochrome P450-catalyzed L-tryptophan nitration in thaxtomin phytotoxin biosynthesis	2012	135	3.51	10.1038/nchembio.1048
Membrane Proteins Solubilized Intact in Lipid Containing Nanoparticles Bounded by Styrene Maleic Acid Copolymer	2009	337	7.23	10.1021/ja810046q
Identification of the extracellular matrix (ECM) binding motifs of tissue inhibitor of metalloproteinases (TIMP)-3 and effective transfer to TIMP-1	2007	57	1.00	10.1074/jbc.M610490200
High-throughput classification of yeast mutants for functional genomics using metabolic footprinting	2003	405	7.93	10.1038/nbt823

2.5 Top 10 cited articles arising from IB portfolio

The top cited articles arising from the IB portfolio and NIBB initiative published between 2017 and 2021 are shown in Table 2.3 and 2.4 respectively

Table 2.3 Top 10 cited articles arising from IB portfolio published between 2017 and 2021

Article Title	Publication Year	Total Cites	DOI
antiSMASH 4.0-improvements in chemistry prediction and gene cluster boundary identification	2017	741	10.1093/nar/gkx319
Molecular remission of infant B-ALL after infusion of universal TALEN gene-edited CAR T cells	2017	488	10.1126/scitranslmed.aaj2013
Insights into Land Plant Evolution Garnered from the Marchantia polymorpha Genome	2017	464	10.1016/j.cell.2017.09.030
One thousand plant transcriptomes and the phylogenomics of green plants	2019	379	10.1038/s41586-019-1693-2
Characterization and engineering of a plastic-degrading aromatic polyesterase	2018	275	10.1073/pnas.1718804115
Lost, but Found with Nile Red: A Novel Method for Detecting and Quantifying Small Microplastics (1 mm to 20 µm) in Environmental Samples	2017	263	10.1021/acs.est.7b04512
Design of a synthetic yeast genome	2017	259	10.1126/science.aaf4557
Complex pectin metabolism by gut bacteria reveals novel catalytic functions	2017	250	10.1038/nature21725
Fatty acids in arbuscular mycorrhizal fungi are synthesized by the host plant	2017	247	10.1126/science.aan0081
Comparative genomics reveals high biological diversity and specific adaptations in the industrially and medically important fungal genus Aspergillus	2017	224	10.1186/s13059-017-1151-0

Table 2.4 Top 10 cited articles arising from NIBB initiative published between 2017 and 2021

Article Title	Publication Year	Total Cites	DOI
Protein-Sol: a web tool for predicting protein solubility from sequence	2017	127	10.1093/bioinformatics/btx345
Long-term stability and reusability of molecularly imprinted polymers	2017	102	10.1039/c6py01853j
Valorisation of agricultural waste with an adsorption/nanofiltration hybrid process: from materials to sustainable process design	2017	94	10.1039/c7gc00912g
Robust Covalently Cross-linked Polybenzimidazole/Graphene Oxide Membranes for High-Flux Organic Solvent Nanofiltration	2018	93	10.1021/acsami.8b03591
Membrane-Grafted Asymmetric Organocatalyst for an Integrated Synthesis-Separation Platform	2018	77	10.1021/acscatal.8b01706
Formicamycins, antibacterial polyketides produced by Streptomyces formicae isolated from African Tetraponera plant-ants	2017	58	10.1039/c6sc04265a
Bacterial sensors define intracellular free energies for correct enzyme metalation	2019	55	10.1038/s41589-018-0211-4
Bio-Inspired Robust Membranes Nanoengineered from Interpenetrating Polymer Networks of Polybenzimidazole/Polydopamine	2019	55	10.1021/acsnano.8b04123
Mobius Assembly: A versatile Golden-Gate framework towards universal DNA assembly	2018	50	10.1371/journal.pone.0189892
Bottom-Up Elucidation of Glycosidic Bond Stereochemistry	2017	46	10.1021/acs.analchem.6b04998

2.6 BBSRC IB portfolio compared against the UK and international funders

To provide additional context on the BBSRC IB publication portfolio, equivalent citation data were obtained for IB publications supported by other UK and international funders. The analysis examined two different research area classifications, which were considered to be the closest relevant categories for BBSRC's IB portfolio: 'Biotechnology and Applied Microbiology' WoS research area and 'Microbial Biotechnology' InCites citation topic.

Table 2.5 shows bibliometric indicators for the BBSRC IB portfolio compared with other major UK and international funders (Biotechnology and Applied Microbiology WoS research area).

Table 2.6 shows bibliometric indicators for the BBSRC IB portfolio compared with the UK and other G7 Countries (Biotechnology and Applied Microbiology WoS research area).

Table 2.7 shows bibliometric indicators for the BBSRC IB portfolio compared with other major UK and international funders (Microbial Biotechnology InCites citation topic).

Table 2.8 shows bibliometric indicators for the BBSRC IB portfolio compared with the UK and other G7 Countries (Microbial Biotechnology InCites citation topic).

Table 2.5 Comparison of BBSRC IB portfolio bibliometric indicators with other UK and international funders (2017-2021; Biotechnology & Applied Microbiology)

Funder	Biotechnology & Applied Microbiology WoS research area				
	Number of articles	cNCI	% documents in top 10%	% International Collaborations	% Industry Collaborations
UK funders					
BBSRC	1364	1.8	21.2	55.0	5.3
MRC	798	2.1	24.7	59.4	5.0
EPSRC	737	1.2	14.4	42.3	8.0
Wellcome Trust	688	2.6	29.2	61.5	4.4
NERC	209	1.3	17.7	58.4	2.9
International funders					
National Natural Science Foundation of China	26216	1.2	16.3	17.5	0.6
National Institutes of Health (USA)	7769	1.9	22.5	33.1	3.4
Ministry of Education, Culture, Sports, Science and Technology (Japan)	3218	0.8	6.1	25.0	3.5
German Research Foundation	1630	1.5	14.3	45.0	3.9
European Research Council	791	2.3	27.9	59.0	4.1

Table 2.6 Comparison of BBSRC IB portfolio bibliometric indicators with the UK and other G7 countries (2017-2021; Biotechnology & Applied Microbiology)

Funding country	Biotechnology & Applied Microbiology WoS research area				
	Number of articles	cNCI	% documents in top 10%	% International Collaborations	% Industry Collaborations
BBSRC	1364	1.8	21.2	55.0	5.3
United States	37437	1.4	14.7	43.1	4.0
Germany	10290	1.3	12.7	55.1	5.8
UK	9674	1.4	16.1	65.1	6.2
Japan	8636	0.8	6.6	32.6	5.2
Italy	6756	1.2	13.0	49.1	2.5
France	5787	1.2	12.7	63.2	5.2
Canada	5384	1.4	14.5	55.6	3.3

Table 2.7 Comparison of BBSRC IB portfolio bibliometric indicators with other UK and international funders (2017-2021; Microbial Biotechnology)

Funder	Microbial Biotechnology InCites citation topic				
	Number of articles	cNCI	% documents in top 10%	% International Collaborations	% Industry Collaborations
UK funders					
BBSRC	197	1.9	23.4	51.8	8.1
EPSRC	106	1.6	21.7	48.1	11.3
Wellcome Trust	34	1.1	17.7	61.8	5.9
MRC	31	1.4	25.8	61.3	9.7
NERC	5	1.3	20.0	60.0	0.0
International funders					
National Natural Science Foundation of China	2861	1.1	11.8	0.5	0.5
National Institutes of Health - USA	527	1.4	14.6	2.9	2.9
Ministry of Education, Culture, Sports, Science and Technology, Japan	410	0.7	4.4	7.1	7.1
German Research Foundation	293	1.4	14.3	4.1	4.1
European Research Council	123	1.9	29.3	4.9	4.9

Table 2.8 Comparison of BBSRC IB portfolio bibliometric indicators with the UK and other G7 countries (2017-2021l; Microbial Biotechnology)

Funding country	Microbial Biotechnology InCites citation topic				
	Number of articles	cNCI	% documents in top 10%	% International Collaborations	% Industry Collaborations
BBSRC	197	1.9	23.4	51.8	8.1
United States	2268	1.2	11.5	51.7	3.4
Germany	1272	1.3	15.0	53.8	5.8
Japan	992	0.7	5.0	23.2	6.1
UK	846	1.4	17.9	70.1	8.3
Italy	543	1.3	12.5	51.4	2.8
France	443	1.3	14.5	67.7	3.8
Canada	351	1.1	10.8	10.8	3.7

2.7 Most frequently used journals for publication of articles for the IB portfolio

Table 2.9 Journals used for publication of articles for the IB portfolio

Journal Title	Number of publications
Nature Communications	163
Scientific Reports	156
PNAS	119
ACS Catalysis	97
Nucleic Acids Research	86
ACS Synthetic Biology	86
Angewandte Chemie - International Edition	85
Journal of the American Chemical Society	78
Chemical Science	77
Chemical Communications	71
Biotechnology For Biofuels	70
Frontiers in Microbiology	60
PLOS one	52
Journal of Biological Chemistry	52
ChemBioChem	50

2.8 Studentships awarded

Table 2.10 shows the number of studentships awarded by BBSRC per academic year (September/October yearly start) that have been classified as IB[74]. Studentships are typically four years in duration i.e. awards that commenced in 2019 are predicted to complete in 2023.

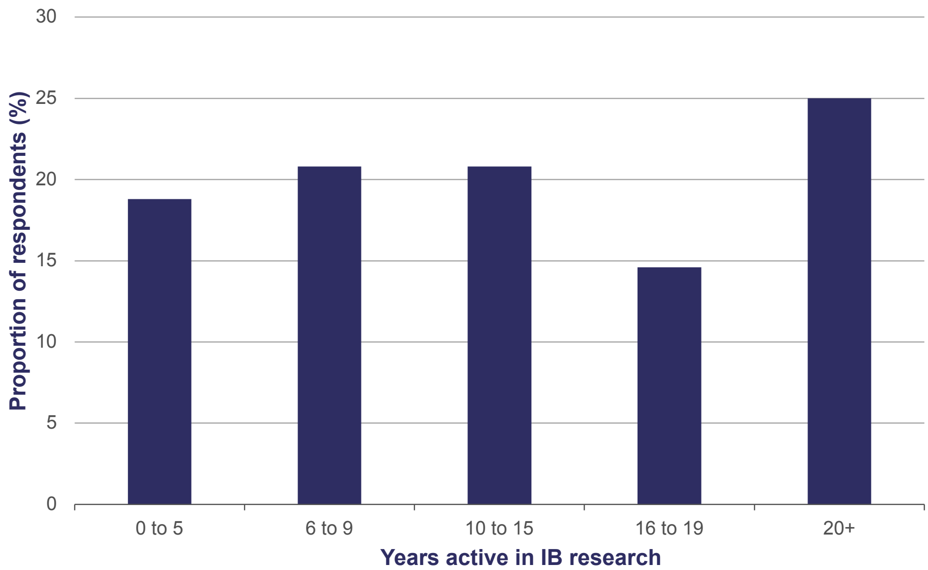
Table 2.10 IB classified and total BBSRC studentships awarded per academic start year

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Number of IB studentships	34	46	64	37	39	43	66	41	61	55
Total BBSRC Studentships	621	545	551	511	570	529	604	488	568	557

2.9 Researchers working in IB

Figure 2.5 shows the number of years grant holders have been working in the IB research area, based upon survey responses.

Figure 2.5 Number of years grant holders have been conducting IB research



Data table

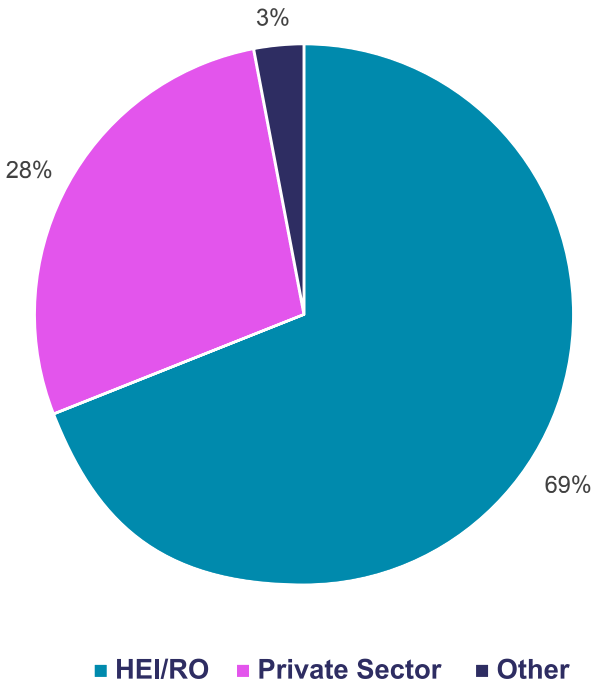
	Years active in IB research				
	0 to 5	6 to 9	10 to 15	16 to 19	20+
Proportion of respondents (%)	18.8	20.8	20.8	14.6	25.0

Appendix 3

3.1 BBSRC NIBB Phase I membership

Figure 3.1 shows the breakdown of affiliations of members for NIBB Phase I across 13 funded networks. The 'Other' category included charities, government departments, NGOs, policy think tanks, social enterprises and scientific societies.

Figure 3.1 Breakdown of BBSRC NIBB Phase I membership by affiliation



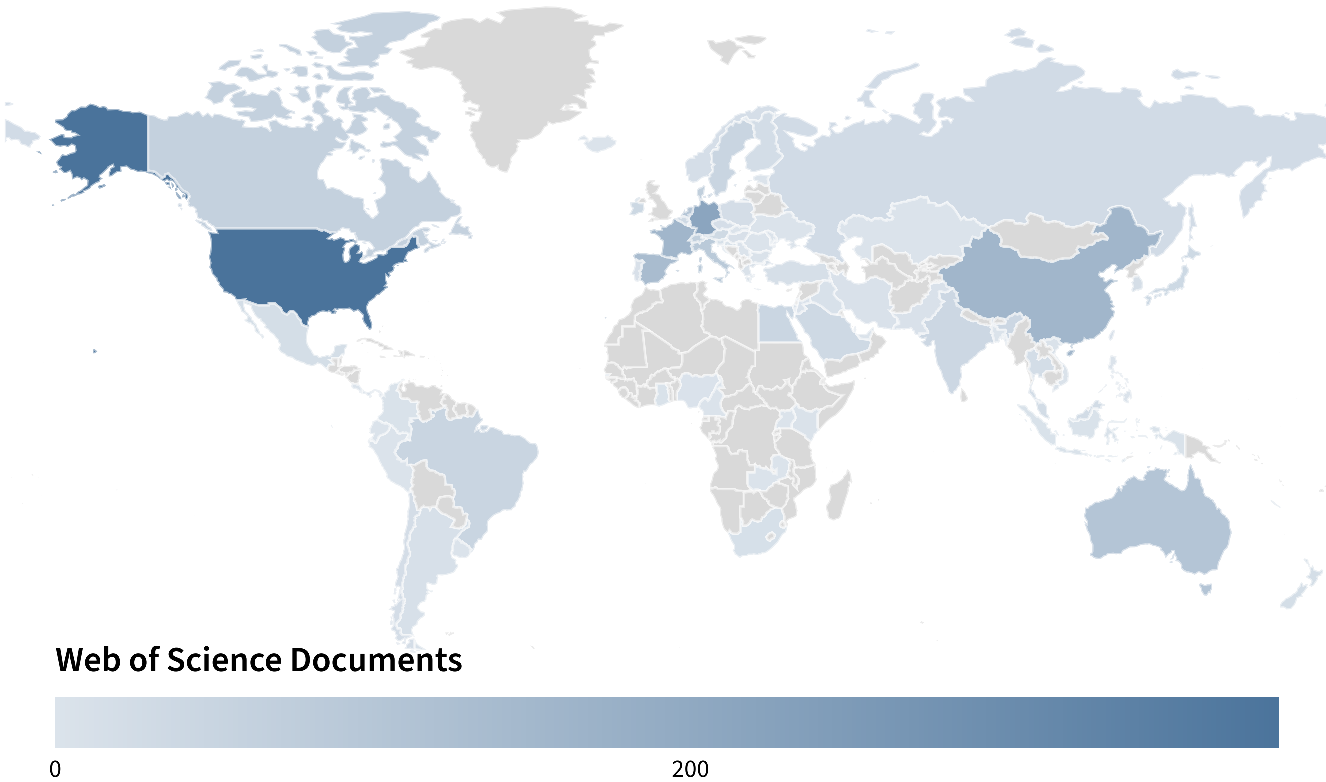
Data Table

NIBB Phase I membership	Proportion of members (%)
HEI/RO	69
Private Sector	28
Other	3

3.2 International collaboration

Information on international co-authorship was obtained from Web of Science. Figure 3.2 shows the global distribution of research articles by location of international co-authors for the IB portfolio.

Figure 3.2 Location of international co-authors (2017 to 2021)

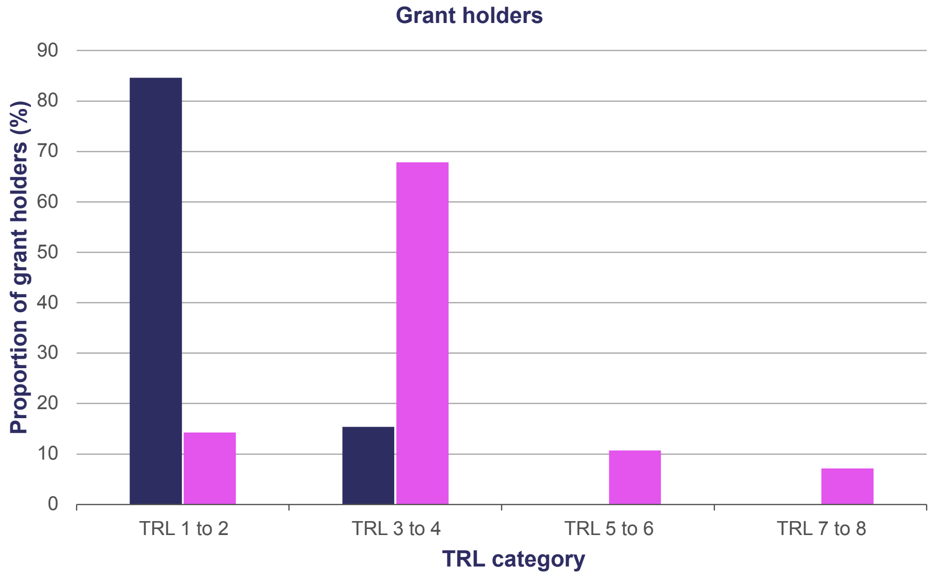


Appendix 4

4.1 Intellectual property and progression of IB technology

Figure 4.1 shows data on the individual TRLs reported prior to, and following, interaction with BBSRC. The grantholder data refer to the 42% of surveyed grantholders who indicated that they had worked on developing technologies and products as part of their BBRC funded research. The business stakeholder data refer to the 56% of surveyed businesses who had worked with a BBSRC funded partner to bring technology or products closer to market.

Figure 4.1 Reported Technology Readiness Level (TRL) movement as a result of BBSRC IB work



Data table

Respondent type	Proportion of respondents (%)							
	TRL prior to interaction with BBSRC				TRL following interaction with BBSRC			
	TRL 1 to 2	TRL 3 to 4	TRL 5 to 6	TRL 7 to 8	TRL 1 to 2	TRL 3 to 4	TRL 5 to 6	TRL 7 to 8
Grant holder	85	15	0	0	14	68	11	7
Business stakeholder	50	50	0	0	0	10	90	0

4.2 Spin-outs

A total of 44 spin-out companies with incorporation years between 2010 and 2021 were reported as arising from the IB portfolio. Table 4.1 shows summary data for these organisations[75].

Table 4.1 Spin-out companies reported as arising from IB portfolio

Company name	Incorporation Date	Current status	Company synopsis	Location
3D Bio-tissues Ltd	November 2018	Active	3D bio-printing of transplantable corneal replicates for the treatment of corneal stromal disorders.	Newcastle Upon Tyne
Agroceutical Ltd	February 2012	Active	Natural production of Galanthamine – an active pharmaceutical ingredient in the treatment of Alzheimer's disease. Successor to previously dissolved business Alzeim Ltd.	Hereford
Alphacells Biotechnologies Ltd	February 2019	Active	Development of novel cryopreservation technologies for banking of human cells intended for medical use.	Sutton
Alternox Scientific Ltd	February 2020	Active	Development of novel proprietary inhibitors of the enzyme alternative oxidase (AOX) to be used in fungicides, for food crop and human anti-fungal treatments.	East Sussex
Amprologix Ltd	June 2018	Active	Development and upscaling of a microbial production system for Epidermicins – a class of antimicrobial biologics that have the potential to treat antibiotic resistant bacterial diseases.	Plymouth

Company name	Incorporation Date	Current status	Company synopsis	Location
Antimicrobial Discovery Solutions Ltd	June 2015	Active	Antimicrobial resistance focused business, providing consulting advice, reagents and assays to the AMR community.	Warwick
AR Citekbio Ltd	October 2018	Active	Sustainable solutions for the manufacturing of xylitol - a natural sweetener with wide ranging applications as a sugar substitute, from agricultural waste.	Aberystwyth
ArcVax Ltd	November 2016	Dissolved: January 2021	Using Protein Glycan Coupling Technology to produce low cost glycoconjugate vaccines from E. coli cells, for use in veterinary settings.	London
Arkvax Ltd	October 2020	Active	Successor to ArcVax Ltd (see above).	Cambridge
Astrea Power Ltd	April 2015	Dissolved: February 2022	Production of high-purity hydrogen for fuel cell vehicles, energy systems and industrial applications via a patented electrolysis method.	Glasgow
Atelerix Ltd	June 2017	Active	Transformative technology for the storage and transport of viable organic cells at room temperature, overcoming barriers and limitations presented by the current need for cryo-shipping.	North Shields
Beneficial Bio Ltd	July 2019	Active	A network of social enterprises run by biologists with the goal of helping labs around the world secure reagents quickly and economically, focusing on open-source registries.	Cambridge
Bio-Shape Ltd	November 2015	Active	Cutting edge synthetic and analytical tools available for bioindustry needs, to analyse large and complex biomolecules with a focus on biopharmaceuticals.	Cheshire
C3 Biotechnologies Ltd	June 2015	Active	Licensing company for technology that enables production of bio-propane.	Lancaster
Cambridge Glycoscience Ltd	February 2017	Active	Development and marketing of carbohydrates from plant cell walls for the food industry.	Cambridge

Company name	Incorporation Date	Current status	Company synopsis	Location
Cellularevolution Ltd	December 2018	Active	Refined continuous cell culturing techniques, employable in various industries.	Sunderland
Colorifix Ltd	March 2016	Active	Development of a new method to dye textiles using microbes to produce, deposit and fix pigments to fabric.	Norwich
Cromerix Ltd	April 2021	Active	Rapid phenotypic identification of bacteria and antibiotic susceptibility using propriety nonlinear acoustic technique.	Loughborough
Cytecom Ltd	March 2018	Active	Fast and economic detection of microorganisms in a range of samples, for example wastewater, food etc.	Coventry
Decima Biomed Ltd	June 2015	Dissolved: November 2016	Development of a novel, simple and scalable technique for the separation/ purification of human stem cells, irrespective of their tissue of origin.	Edinburgh
Deep Branch Biotechnology Ltd	July 2021	Active	Carbon dioxide recycling via microorganisms to convert CO_2 into high-quality protein substrate for livestock and agricultural feed.	London
Erebagen Ltd	March 2020	Active	Engineering of soil bacteria to produce new bioactive natural products with hit-rates 20x-better than synthetic chemicals currently being used in industrial screens.	Coventry
Green Bioactives Ltd	January 2019	Active	Utilising plants and cultured plant cells to produce biomolecules and cell extracts for the cosmetic, pharmaceutical, food and agricultural markets.	Edinburgh
Gyreox Ltd	May 2019	Active	Creating novel medicines addressing complex intra-cellular targets in a wide range of diseases, via a proprietary platform technology based on a combination of chemistry and synthetic biology deploying a set of rationally engineered enzymes.	Oxford

Company name	Incorporation Date	Current status	Company synopsis	Location
Hothouse Bioengineering Ltd	June 2020	Dormant	DNA-encoded chemical libraries for drug discovery.	Norwich
Humane Technologies Ltd	January 2018	Active	Design and development of life sciences research equipment.	Coventry
Iceni Glycoscience Ltd (formerly Iceni Diagnostics Ltd)	March 2014	Active	Development of carbohydrate-based therapeutics and point-of-care diagnostics for infectious diseases.	Norwich
Imperagen Ltd	November 2021	Active	Development of fast enzyme engineering platforms.	Manchester
Labgenius Ltd	August 2012	Active	Development of an autonomous AI-driven evolution engine for discovering high-value protein components.	London
Leaf Systems International Ltd	December 2014	Active	Production of proteins, metabolites and complex natural products for research and bio-medical applications using plants.	Norwich
Manchester Biofactory Ltd	June 2019	Dissolved: April 2021	Rapid discovery and engineering of high value proteins and enzymes for the biotechnology industry via a directed evolution platform.	Manchester
Nuspec Bioscience Ltd	July 2019	Dormant	Establishment of a public database for genomic data surrounding oilseed rape crop.	York
Nuspec Oil Ltd	November 2019	Active	Processing of novel rapeseed (and other) oils for industrial applications.	York
Ogi Bio Ltd	February 2020	Active	Development of a microbioreactor, to automate microbe culture (bacteria, yeast or algae) thus replacing manual flask culturing.	Edinburgh
Oxford Biotrans Ltd	August 2013	Active	Development and commercialisation of enzymatic process technologies to produce high-value chemical compounds used for flavouring and fragrances.	Thame

Company name	Incorporation Date	Current status	Company synopsis	Location
Persephone Bio Ltd	July 2014	Active	Production of bioactive compounds for the cosmetics and skin therapeutics sector from tomatoes.	Norwich
Phase Biolabs Ltd	May 2020	Active	Development of carbon capture and utilisation (CCU) technology for industrial scale carbon dioxide recycling.	Nottingham
Phenotypeca Ltd	November 2020	Active	Provision of novel production strains of yeast for biologicals manufacture, optimised for specific biotechnology processes.	Nottingham
Puridify Ltd	March 2013	Active	Development of a nanofiber-based platform purification technology for biopharmaceutical production.	Stevenage
Ripptide Pharma Ltd	September 2015	Dissolved: September 2017	Development of a chemoenzymatic process for the efficient production of macrocycles and cyclic peptides, addressing novel areas of chemical space for drug discovery and development.	Edinburgh
Roxijen Ltd	November 2020	Active	Commercialisation of novel analytical instrumentation for bioprocess monitoring and formulation of biologics.	St Albans
Sooba Medical Ltd	May 2020	Dormant	Engineering solutions to develop and improve medical devices, focusing on urological products such as stents and catheters.	Southampton
Young Owl Microfluidics Ltd	December 2021	Active	Commercialisation of novel microfluidic cell culture devices.	London
Zentraxa Ltd	March 2017	Active	Design, production and testing of complex novel peptides for wider industry, utilising a proprietary peptide biosynthesis platform.	Bristol

4.3 Working collaboratively with industry

Businesses were surveyed regarding how helpful BBSRC initiatives were in overcoming potential barriers to the application of IB research. Response data for each barrier is summarised in Table 4.2.

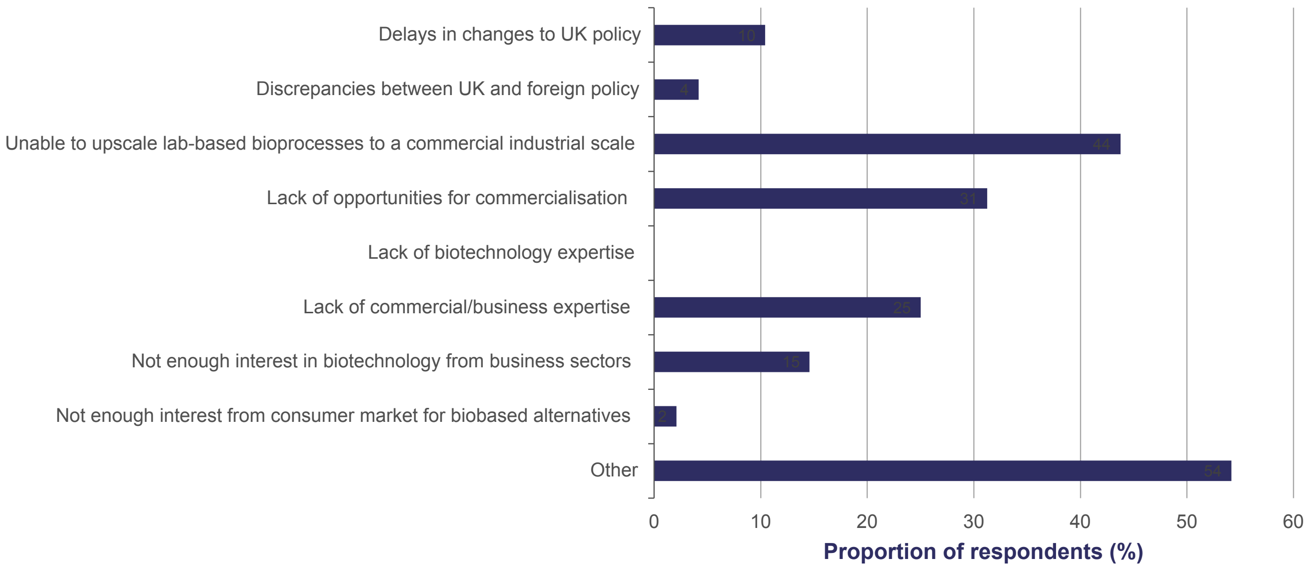
Table 4.2 How helpful businesses found BBSRC initiatives in overcoming the barriers to the application of IB research [n=18].

Barriers	Proportion of businesses (%)				
	Not at all helpful	Somewhat helpful	Helpful	Very helpful	N/A
Cost and risks of advancing IB TRLs	11	22	33	22	11
Costs and risks of initial technology development	6	22	33	28	11
Finding suitable partners for collaboration	6	17	22	17	17
Availability of technical expertise and skills	0	17	44	28	11
Understanding the market for IB and sector opportunities	11	33	22	17	17
Accessing latest developments in IB	11	22	39	11	17

4.4 Barriers to researchers achieving impact as part of BBSRC's IB portfolio

Researchers were also asked on the barriers to achieving societal and economic impact as part of their BBSRC funded IB work. Response data for this is summarised in Figure 4.2.

Figure 4.2 Current barriers to researchers achieving societal and economic impact in IB



Data table

Barrier to achieving societal and economic impact	Proportion of grant holders (%)
Delays in changes to UK policy	10
Discrepancies between UK and foreign policy	4
Unable to upscale lab-based bioprocesses to a commercial industrial scale	44
Lack of opportunities for commercialisation	31
Lack of biotechnology expertise	0
Lack of commercial/business expertise	25
Not enough interest in biotechnology from business sectors	15
Not enough interest from consumer market for biobased alternatives	2
Other	54

Themes covered in the ‘other’ category include:

- lack of time and mental capacity on top of heavy academic workload
- university structure being non-conducive to achieving this kind of impact
- slow pace of research, particularly during early-mid career stages
- lack of appropriate follow-on funding specific to this area
- not enough consumer demand.

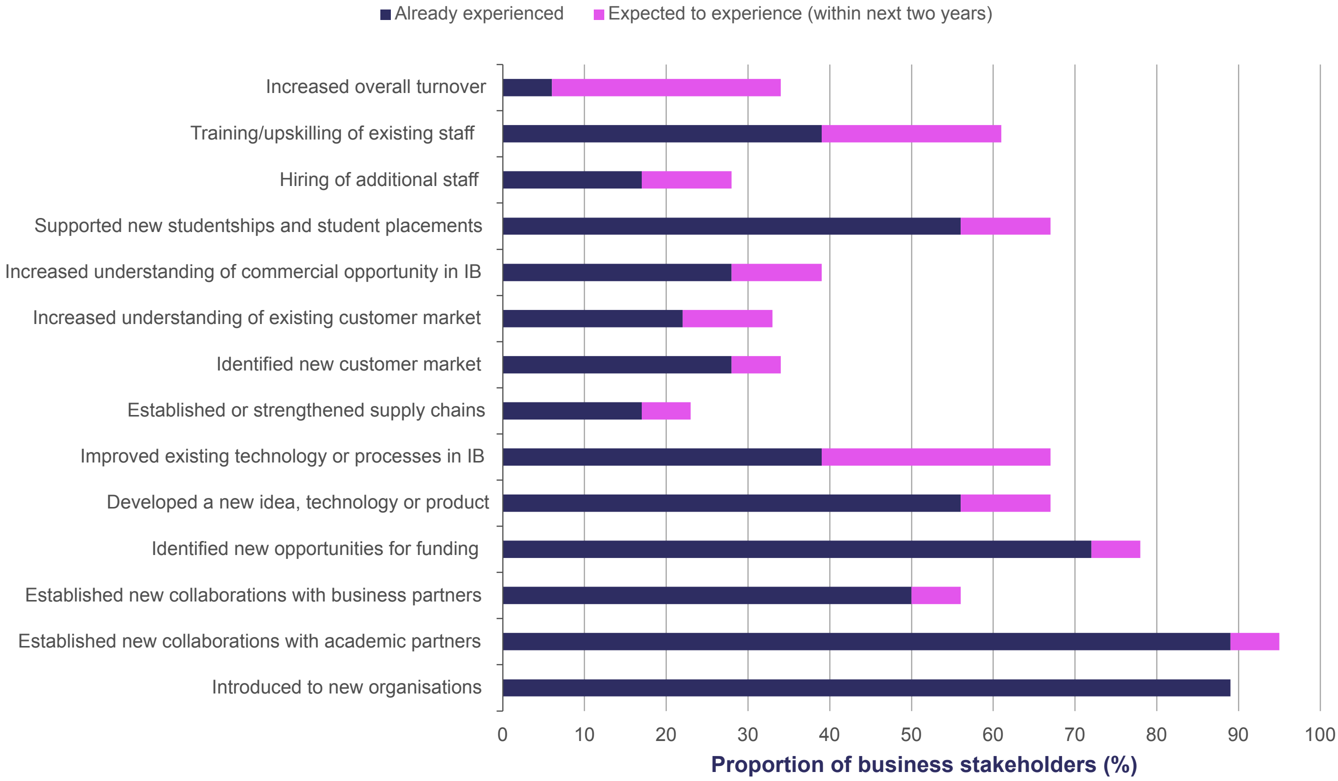
4.5 Business outcomes

Businesses were also surveyed on whether their organisation had already experienced or expected to experience more general business outcomes due to interactions with BBSRC led IB schemes. Figure 4.3 summarises the response data for this question.

The top 3 business outcomes reported (combining already experienced/expected to experience):

- established new collaborations with academic partners 94%
- introduced to new organisations 89%
- identified new opportunities for funding 78%

Figure 4.3 Business outcomes already experienced or expected to experience



Data table

Business outcome	Proportion of business stakeholders (%)	
	Already experienced	Expected to experience (within next two years)
Increased overall turnover	6	28
Training/upskilling of existing staff	39	22
Hiring of additional staff	17	11
Supported new studentships and student placements	56	11
Increased understanding of commercial opportunity in IB	28	11
Increased understanding of existing customer market	22	11
Identified new customer market	28	6
Established or strengthened supply chains	17	6
Improved existing technology or processes in IB	39	28
Developed a new idea, technology or product	56	11
Identified new opportunities for funding	72	6
Established new collaborations with business partners	50	6
Established new collaborations with academic partners	89	6
Introduced to new organisations	89	0

4.6 Business investment in R&D

Twelve of the 18 businesses surveyed reported that their organisation has invested more in IB related R&D following engagement with BBSRC and BBSRC funded researchers. The lower bound figure for this R&D investment was £3.6 million and the upper bound figure was £5.6 million, although it could have been more as the investment figure over £1 million is not known exactly. A breakdown of R&D investment level by company size is available in Figure 4.4.

Figure 4.4 Breakdown of R&D investment level by company size

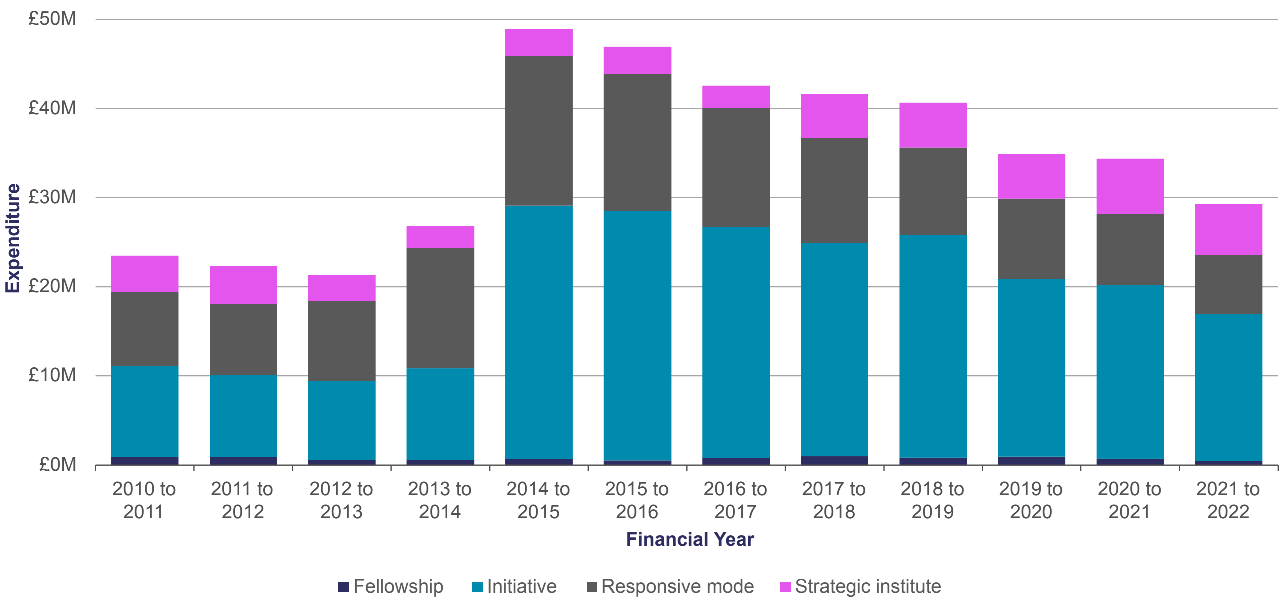
Data table

R&D investment level	Number of business respondents		
	Micro	Small	Large
Under £1k	0	0	0
£1k to £20k	1	2	0
£21k to £50k	2	0	2
£51k to £100k	0	0	1
£101k to £150k	0	0	0
£151k to £200k	0	0	1
£201k to £500k	2	0	0
£501k to £1m	1	1	0
More than £1m	0	1	1
N/A	0	2	1

Appendix 5

5.1 BBSRC investment in IB

Figure 5.1 BBSRC expenditure in IB 2010/11 to 2021/22



Expenditure figures contain both the 2013 and 2018 call for BBSRC Networks in Industrial Biotechnology (BBSRC NIBB).

Average annual expenditure for the 2013 NIBB is approximately £3m. Average annual expenditure for the 2018 NIBB is approximately £1.5m.

The main investments included within the initiative expenditure are: Synthetic Biology Research Centres (£54.4m); Industrial Biotechnology Catalyst (£39.8m); Networks in Industrial Biotechnology and Bioenergy (£21.2m); Bioenergy Initiative (£14.7m); Bioprocessing Research Industry Club (£13.5m); UK Biofilms Programme Biofilms Innovation Centre (£9.1m); Integrated Biorefining Research and Technology Club (£5.9m); ERA Industrial Biotechnology (£5.8m); Super Follow-on Fund (£5.2m); Newton Fund Open Call (£4.9m); Sustainable Bioenergy and Biofuels (£4.1m); ERA-NET Industrial Biotechnology (£4.0m); GCRF Industrial Biotechnology and Bioenergy in the Developing World (£3.6m); Research Council GCRF (£3.6m)

Data Table

	BBSRC Industrial Biotechnology Research Expenditure (between financial years 2010 to 2011 and 2021 to 2022)											
	2010 to 2011	2011 to 2012	2012 to 2013	2013 to 2014	2014 to 2015	2015 to 2016	2016 to 2017	2017 to 2018	2018 to 2019	2019 to 2020	2020 to 2021	2021 to 2022
Strategic institute	£4.1m	£4.3m	£2.9m	£2.4m	£3.0m	£3.0m	£2.5m	£4.9m	£5.1m	£5.0m	£6.2m	£5.7m
Responsive mode	£8.3m	£8.0m	£9.0m	£13.5m	£16.8m	£15.4m	£13.4m	£11.8m	£9.8m	£9.0m	£8.0m	£6.6m
Initiative	£10.2m	£9.2m	£8.8m	£10.3m	£28.4m	£28.0m	£25.9m	£23.9m	£25.0m	£19.9m	£19.5m	£16.5m
Fellowship	£0.9m	£0.9m	£0.6m	£0.6m	£0.7m	£0.5m	£0.8m	£1.0m	£0.8m	£1.0m	£0.7m	£0.4m
Total	£23.5m	£22.4m	£21.3m	£26.8m	£48.9m	£46.9m	£42.6m	£41.6m	£40.7m	£34.9m	£34.4m	£29.3m

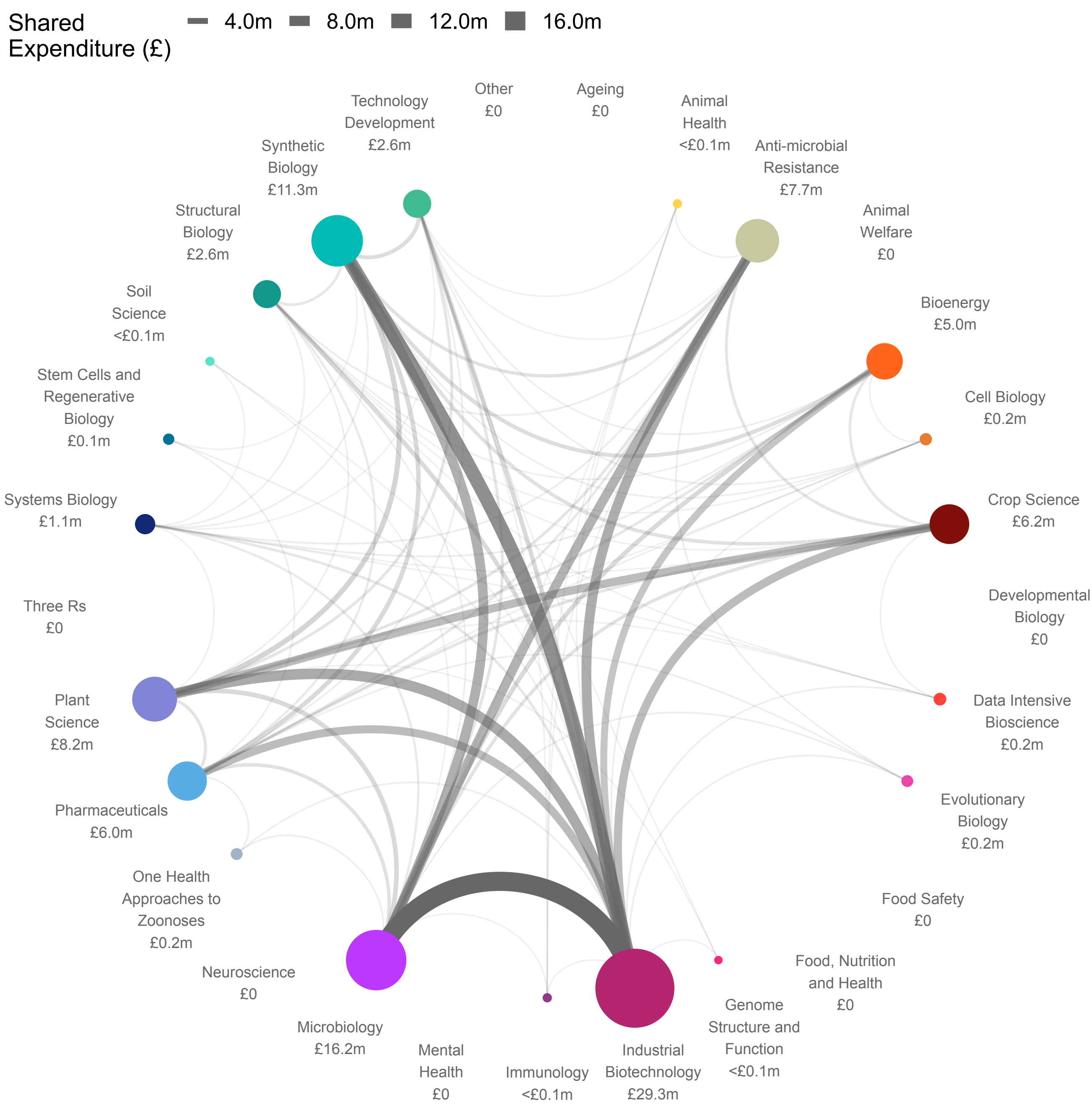
5.2 BBSRC IB research portfolio analysis (grant data)

Figure 5.2 shows a research topic co-occurrence network for BBSRC IB awards with expenditure in the 2021/22 financial year, as is intended to provide an overview of the coverage of the grant portfolio.

Awards are classified against the BBSRC research topic taxonomy.

Nodes show the total expenditure for each research topic. Edges (links between nodes) show the expenditure of awards classified in both topics.

Figure 5.2 Research topic co-occurrence network of BBSRC IB research portfolio (2021 to 2022 expenditure)



The VOSviewer tool was used to examine the science areas covered in the IB grant portfolio in more detail. This tool offers text mining functionality that can be used to construct and visualise term maps of key terms from the scientific text.

Figure 5.3 shows the term map of the BBSRC IB portfolio from project descriptions (Title, Technical Summary, and Objectives).

Term maps provide a visual representation of a collection of texts.

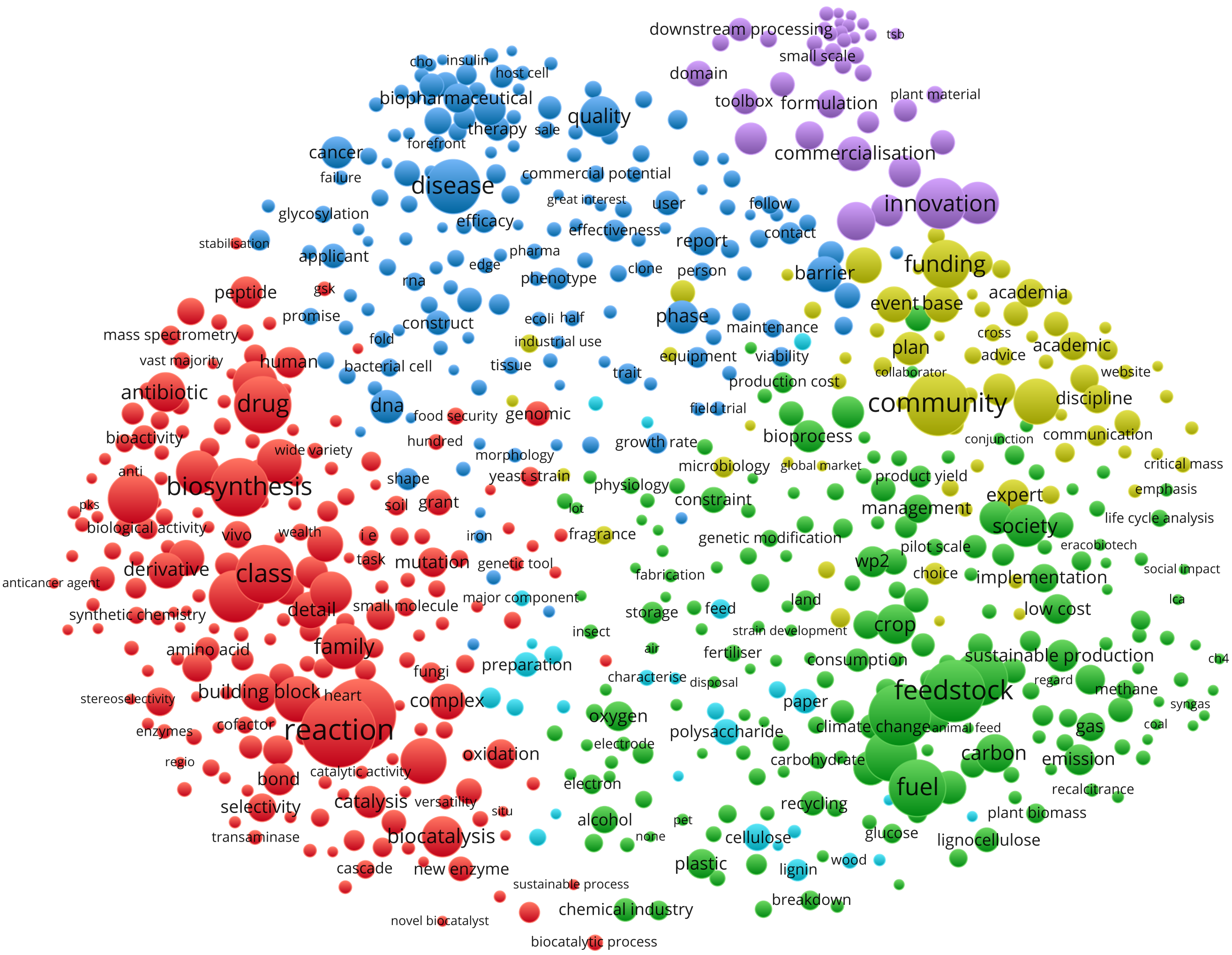
Terms extracted from the text are represented by bubbles. The size of a bubble indicates the number of awards in which the term occurs.

The proximity of two terms (approximately) indicates their relatedness. In general, the smaller the distance between two terms the more frequently the terms co-occur.

Term co-occurrences allow clusters of related terms to be identified, these are shown in different colours.

The horizontal and vertical axes have no special meaning.

Figure 5.3 Term map of IB research portfolio (grant data)



5.3 BBSRC IB research portfolio analysis (publication data)

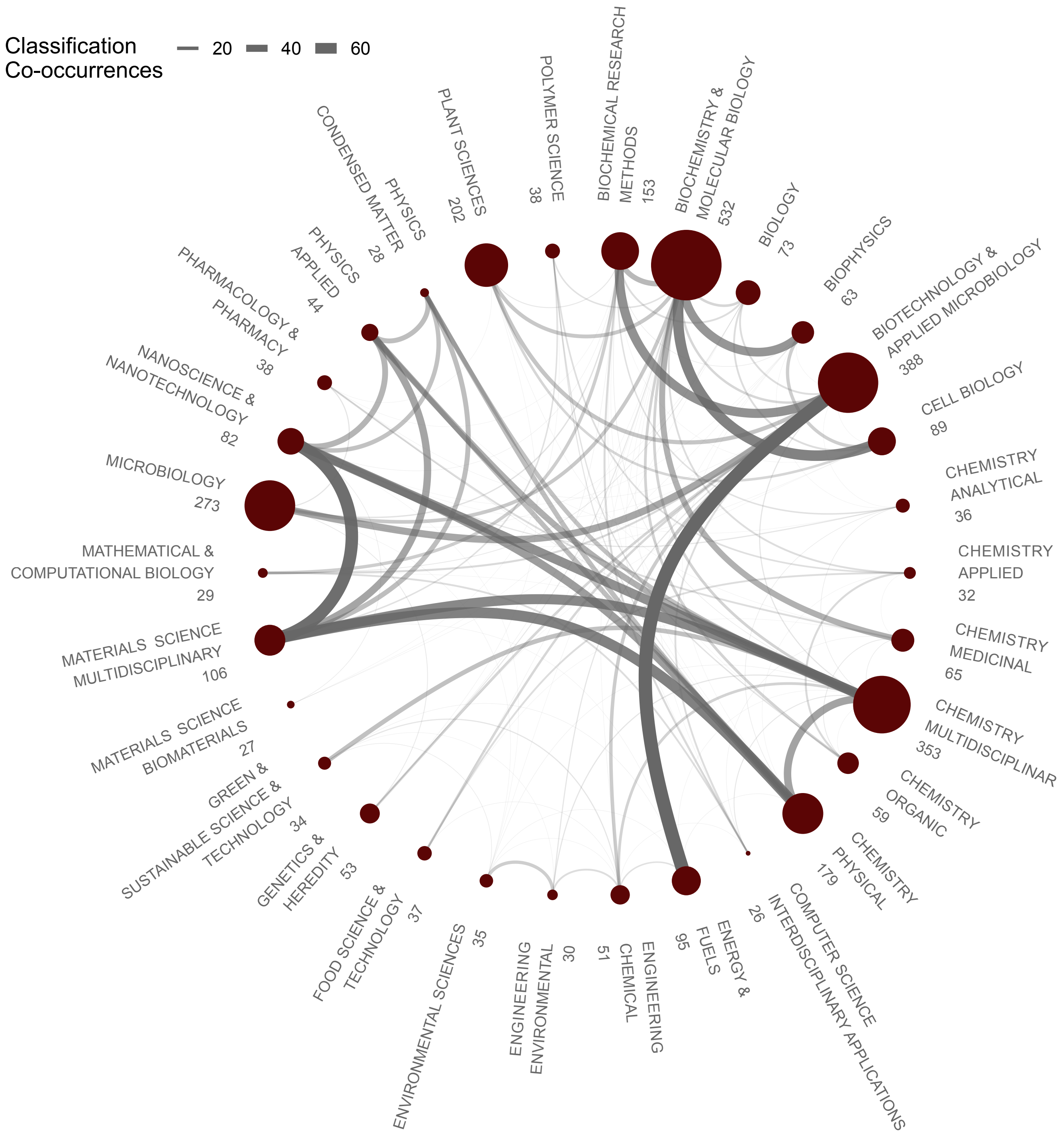
Further information on the science areas covered by the IB publication portfolio was obtained using the Web of Science subject categories. Each publication mapped to one or more subject categories, based on the journal it is published in (i.e. this is not an article-specific classification).

Figure 5.4 shows a co-occurrence network highlighting the relationship between Web of Science assigned classifications to BBSRC IB publications.

The Top 30 classifications are shown.

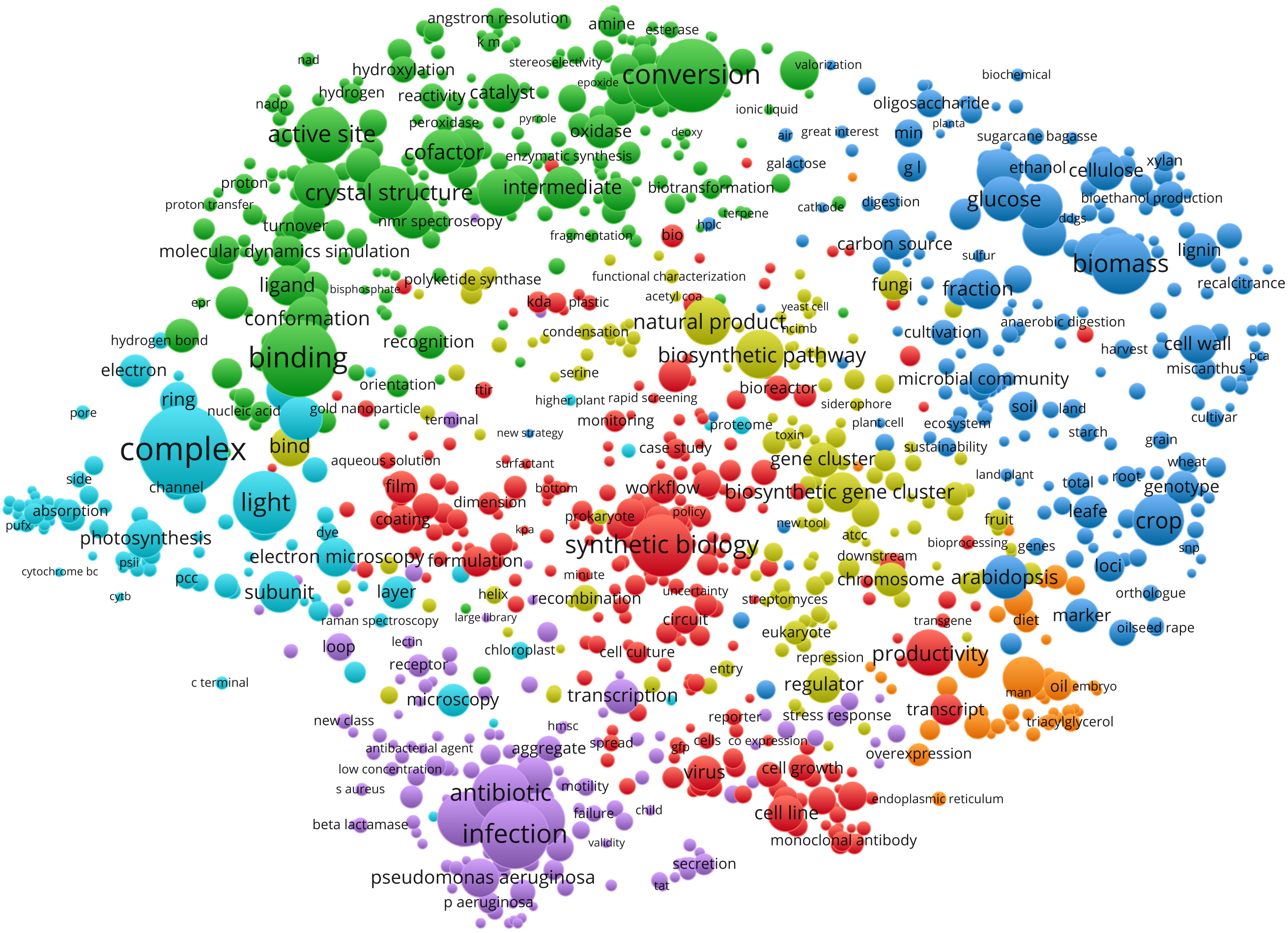
Note: these classifications are assigned at the level of the journal not the individual research article.

Figure 5.4 Topic co-occurrence network of BBSRC IB publications



The titles and abstracts from BBSRC IB research articles published between 2017 and 2021 were analysed using VOSviewer. Figure 5.5. shows a term map for the BBSRC IB publications.

Figure 5.5 Term map of IB research portfolio (publication data: 2017-2021)



Acronyms

ADNet	Anaerobic Digestion Network
BBSRC	Biotechnology and Biological Sciences Research Council
BioCatNet	Network in Biocatalyst Discovery, Development and Scale-Up
BioProNet	Bioprocessing Network
BRIC	Bioprocessing Research Industry Club
C1Net	Chemicals from C1 Gas
CBMNet	Crossing Biological Membranes
cNCI	Category Normalised Citation Impact
CPI	Centre for Process Innovation
ECR	Early Career Researcher
EPSRC	Engineering and Physical Sciences Research Council
ERA	European Research Area
FoodWasteNet	Food Processing Waste and By-Products Utilisation Network
GCRF	Global Challenges Research Fund
HVCfP	High Value Chemicals from Plants Network
IB	Industrial Biotechnology
IBCarb	Glycoscience Tools for Biotechnology and Bioenergy
IBLF	Industrial Biotechnology Leadership Forum
IBTI	Integrated Biorefining Research and Technology Club
IP	Intellectual Property
IPA	Industrial Partnership Awards
KTN	Knowledge Transfer Network
LBNet	Lignocellulosic Biorefinery Network
Metals in Biology	Metals in Biology: The elements of Biotechnology and Bioenergy
MRC	Medical Research Council
NGO	Non-governmental Organisation
NIBB	BBSRC Networks in Industrial Biotechnology and Bioenergy
NPRoNet	Natural Products Discovery and Bioengineering Network
P2P	A Network of Integrated Technologies: Plants to Products
PDRA	Postdoctoral research assistant/associate
PET	Polyethylene terephthalate
PhycoNet	Unlocking the Industrial Biotechnology potential of microalgae
PI	Principle Investigator
REF	Research Excellence Framework
RSE	Royal Society of Edinburgh
SME	Small and Medium-sized enterprise
TRL	Technology Readiness Level
UKRI	UK Research and Innovation
WoS	Web of Science

References

1. UKRI strategy 2022 to 2027: transforming tomorrow together.
2. Category Normalised Citation Impact (cNCI) is calculated by dividing an actual citation count by an expected citation rate for documents with the same document type, year of publication, and subject area. A cNCI value of one represents performance at par with world average, values above one are considered above average, and values below one are considered below average.
3. Growing the UK Industrial Biotechnology Base.
4. BBSRC Strategic Delivery Plan.
5. Net Zero Strategy: Build Back Greener.
6. Researchfish.
7. The sample of interviewees was selected from individuals who completed the survey. The sample included individuals with active and completed IB grants and covered a broad variety of funding mechanisms.
8. This includes £39.7m co-funding from EPSRC and £2.7m co-funding from Innovate UK.
9. BBSRC responsive mode research grants.
10. BBSRC strategically supported institutes.
11. BBSRC fellowships.
12. Networks in Industrial Biotechnology and Bioenergy.
13. IB portfolio refers to all grants excluding the BBSRC NIBB grants.
14. Citation data captured May 2022.
15. Minimum Information about a Biosynthetic Gene cluster.
16. Microbial Fuel Cell Data: Recalibration & Effect of Resistance & Substrate.
17. This figure includes a small number of very high-value awards (>£4.5m). These grants were typically indicative of large consortium funding or centre funding, for example the GCRF One Health Poultry Hub (£20m), the National Biofilms Innovation Centre (£12.8m) and the Centre for Environmental Biotechnology (£7.6m). PhD studentship programmes and training partnerships for entire organisations were also reported.
18. This figure includes two very high value awards for research hubs. When these awards are excluded, the value of further funding awards was £19.7m.
19. Financial contributions within collaborations may also be reported within the further funding data. As such, data for collaboration contributions and further funding should not be combined.
20. De-duplication of individuals with membership across multiple BBSRC NIBB was undertaken to ensure best efforts in obtaining accurate total membership numbers and proportions, however these numbers should still be viewed as close approximations.
21. Oxford Biotrans.
22. Colorifix.
23. Colorifix.
24. Colorifix.
25. $31.8m converted to GBP using xe.com/currencyconvertor on 16 February 2023 1USD = 0.829957 GBP
26. Growing the UK Industrial Biotechnology Base (page 13).
27. CellRev.
28. CellRev.
29. Deep Branch.
30. Deep Branch.
31. Deep Branch.
32. $10.9m converted to GBP using xe.com/currencyconvertor on 16 February 2023 1USD = 0.829957 GBP
33. LabGenius.
34. LabGenius.
35. $28.7m converted to GBP using xe.com/currencyconvertor on 16 February 2023 1USD = 0.829957 GBP
36. Developing a Strategy for Industrial Biotechnology and Bioenergy in the UK.
37. Growing the UK Industrial Biotechnology Base: A National Industrial Biotechnology Strategy to 2030
38. Protecting pigs and people through collaboration in Southeast Asia.
39. AD&BIORESOURCES NEWS Autumn 2019.
40. BBSRC impact showcase 2022.

41. BBSRC impact showcase 2023.
42. Research Excellence Framework.
43. Improving efficiency for alcohol producers: from raw materials to final product.
44. Commercialisation of synthetic biology research delivers sustainable economic growth and job creation in South West England.
45. Horizon Proteins: Circular economy innovation from whisky by-product to fish feedstock.
46. Innovation friendly regulation: Implementing proportionate and adaptive governance for innovation in technology in the UK (PAGIT).
47. Novel biorefining strategies for reprocessing agricultural waste, bioethanol production from sea water and the recycling of textiles.
48. Cultivation and genetic manipulation of cyanobacteria boosts production of natural blue food colouring, and investment at the SME ScotBio.
49. Driving the industrial biotechnology revolution: cheaper and more sustainable chemical manufacturing through enzyme discovery, engineering and scale-up.
50. Networks help spin-out take breakthrough eco-product to market.
51. Research and business collaboration helps turn biomass into plastic.
52. Fellowships were included with responsive mode grants for this dataset. Training grants and strategic institute investments were excluded from the analysis.
53. CPI.
54. High Value Manufacturing Catapult.
55. University and business collaboration agreements: Lambert Toolkit.
56. CMAC.
57. ICURe programme.
58. LearnLaunch Fund + Accelerator.
59. National Biofilms Innovation Centre.
60. Industrial Biotechnology Catalyst.
61. Growing the UK Industrial Biotechnology Base (page 10).
62. Growing the UK Industrial Biotechnology Base (page 24).
63. Bio-based and Biodegradable Industries Association.
64. The panel noted that policy makers were not surveyed for this study, although it is noted that policy makers are engaged in real-time through the Networks.
65. Bioprocessing Research Industry Club (BRIC).
66. Integrated Biorefining Research and Technology Club (IBTI Club).
67. The 13 original BBSRC NIBB were: ADNet, BioCatNet, BioProNet, C1Net, CBMNet, FoodWasteNet, HVCfP, IBCarb, LBNet, Metals in Biology, NProNet, P2P, PhycoNet.
68. ERA-IB.
69. ERA-IB-2.
70. ERA-CoBioTech.
71. Newton Fund.
72. Global Challenges Research Fund.
73. PIs were able to indicate more than one reason for objectives not being fully met.
74. The structure of BBSRC's doctoral training (lab rotations in the first year of a PhD and ability to switch projects) means that accurate classification information on the final topic of a studentship is not available for latest cohort years.
75. Company data captured July 2022.

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