

BIOSCIENCE FOR INDUSTRY STRATEGY PANEL**MEETING: 9 NOVEMBER 2009****SUBJECT: EVALUATION OF BBSRC RESEARCH FUNDING SCHEMES****SUMMARY**

The BBSRC Evaluation and Policy Unit regularly review the performance of the Council's research funding schemes. Two recent reviews, of the Plant and Microbial Sciences (PMS) Committee and the Bioprocessing Research Industry Club (BRIC), have produced reports that are relevant to the BSI Panel. The attached reports set out the views of the specialist Review Panels convened to provide an independent scientific evaluation of the research supported in responsive mode through the PMS Committee and of the BRIC initiative. The PMS Committee evaluation is the last in a series of reviews covering all former BBSRC Research Committee responsive mode portfolios.

ACTION

The Bioscience for Industry Strategy Panel is invited to **NOTE** the PMS Committee evaluation report. In particular, BSI is invited to:

- i. **NOTE** the sections on interaction with industry and knowledge exchange (Annex 1, pages 22-25, paragraphs 58-68)
- ii. **NOTE** the section on research impacts in BBSRC's response (Annex 2, page 49)

The Bioscience for Industry Strategy Panel is invited to **NOTE** the BRIC evaluation report.

ANNEXES

Annex 1	Evaluation of BBSRC Plant and Microbial Sciences Committee Responsive Mode Portfolio
Annex 2	BBSRC Response to the Panel's Report
Annex 3	Evaluation of the Bioprocessing Research Industry Club

**Innovation and Skills
November 2009**

EVALUATION OF BBSRC RESEARCH FUNDING SCHEMES

EVALUATION OF BBSRC PLANT AND MICROBIAL SCIENCES COMMITTEE RESPONSIVE MODE PORTFOLIO

BACKGROUND

1. BBSRC has an ongoing evaluation programme and conducts regular evaluations of its Research Committee responsive mode portfolios, Research Initiatives and other funding schemes. Evaluation is an important tool for examining the relevance, performance, efficiency and impact of these programmes in relation to their stated objectives and BBSRC's wider strategic aims. Evaluations are managed by the Corporate Policy and Strategy Group.
2. In 2005, BBSRC Strategy Board put in place procedures to evaluate the entire BBSRC responsive mode portfolio. In 2008, an independent Review Panel was set up to evaluate the Plant and Microbial Sciences (PMS) Committee portfolio, the last in the series. The Panel was chaired by Professor Peter Gregory from SCRI, and comprised members who together have expertise across the PMS Committee's remit.
3. The objectives of the evaluation were to assess the quality of the research supported, to identify major outcomes arising from the research, to consider whether the PMS Committee is funding the most appropriate areas of UK bioscience, and to identify ways to build on successes and ways to address identified gaps and issues.
4. The Panel's analysis was based on a sample of 126 completed and 72 current PMS Committee responsive mode grants, with start dates covering a ten year period from 1996 to 2006. The sample was random from the point of view of the science, but was structured to ensure it was representative of the whole in terms of years started and final report grades. The evidence presented to the Panel was sample final reports (completed grants), surveys of grantholders (completed and current grants), surveys of former and current Committee members, surveys of other UK funders of plant and microbial sciences, and data from BBSRC databases.
5. The Panel produced a report of its findings and recommendations. The report was presented to BBSRC's Executive Team who referred the sections on interaction with industry and knowledge exchange to the Bioscience for Industry Strategy Panel for consideration. The report and a formal BBSRC response were published on the BBSRC website in August (see www.bbsrc.ac.uk/researchevaluation).

ACTION

The Bioscience for Industry Strategy Panel is invited to **NOTE** the report. In particular, BSI is invited to:

- i. **NOTE** the sections on interaction with industry and knowledge exchange (**Annex 1**, pages 22-25, paragraphs 58-68)
- ii. **NOTE** the section on research impacts in BBSRC's response (**Annex 2**, page 49)

BIOPROCESSING RESEARCH INDUSTRY CLUB INTERIM EVALUATION**BACKGROUND INFORMATION**

1. BBSRC has an ongoing evaluation programme and conducts regular evaluations of its Research Committee responsive mode portfolios, Research Initiatives and other funding schemes. Evaluation is an important tool for examining the relevance, performance, efficiency and impact of these funding programmes and schemes in relation to their stated objectives and BBSRC's wider strategic aims.
2. In 2008, the Corporate Policy and Strategy Group was invited by the Innovation and Skills Group to conduct an interim evaluation of the Bioprocessing Research Industry Club (BRIC). An independent Review Panel was set up to evaluate the evidence, chaired by Dr Fiona Marston (RFM Associates). The Panel comprised five members who together have expertise across BRIC's remit, including two international members.
3. The objectives of the evaluation were to assess the quality and strategic relevance of BRIC research; to examine the extent to which BRIC is building capacity in UK bioprocessing; to assess the effectiveness of BRIC in promoting interactions between academia and industry; and to identify ways to build on successes and to address identified gaps and issues. As BRIC research projects are still ongoing, the Panel was asked to review the current achievements of BRIC and to consider the potential for future impact as the research develops.
4. The Panel's analysis was based on grantholders' annual reports and the survey responses from grantholders, post doctoral Research Assistants, unfunded applicants, workshop delegates, BRIC industry members and the BRIC Steering Group.
5. The Panel produced a report of its findings and recommendations (**Annex 3**). The report was presented to the BRIC Steering Group in September 2009 and was also published on the BBSRC website (see: www.bbsrc.ac.uk/researchevaluation). The full report is presented to the Bioscience for Industry Strategy Panel for consideration; the sections of the report relevant to training and skills development will be presented to the Bioscience Skills and Careers Strategy Panel.

ACTION

The Bioscience for Industry Strategy Panel is invited to **NOTE** the BRIC evaluation report.

Evaluation of BBSRC Plant and Microbial Sciences Committee Responsive Mode Portfolio

August 2009

This document represents the views and conclusions of a Review Panel of experts in plant and microbial sciences.

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ABBREVIATIONS

AF:	Agri-Food Committee
ASC:	Animal Sciences Committee
BBSRC:	Biotechnology and Biological Sciences Research Council
BIS:	Department for Business, Innovation and Skills
BCB:	Biochemistry and Cell Biology Committee
BMS:	Biomolecular Sciences Committee
CASE:	Collaborative Awards in Science and Engineering
Defra:	Department for Environment, Food and Rural Affairs
DfID:	Department for International Development
EBS:	Engineering and Biological Systems Committee
EU:	European Union
fEC:	Full Economic Cost
FoF:	Follow-on Fund
GARNet:	Genomic Arabidopsis Resource Network
GDB:	Genes and Developmental Biology Committee
HEFCE:	Higher Education Funding Council for England
IF:	Impact Factor
IGER:	Institute of Grassland and Environmental Research
IPA:	Industrial Partnership Award
MRC:	Medical Research Council
MRSA:	Methicillin-resistant <i>Staphylococcus aureus</i>
NERC:	Natural Environment Research Council
NI:	New Investigator
PI:	Principal Investigator
PMS:	Plant and Microbial Sciences Committee
RA:	Research Assistant
RCUK:	Research Councils UK
RAE:	Research Assessment Exercise
REF:	Research Excellence Framework
TB:	Tuberculosis

EXECUTIVE SUMMARY AND KEY CONCLUSIONS

This document sets out the views of a specialist Review Panel convened to provide an independent evaluation of the research supported in responsive mode through the BBSRC Plant and Microbial Sciences Committee (PMS) since 1996. The objectives of the evaluation were to assess the quality of the research supported and to identify major outcomes arising from it; to consider whether the PMS Committee is currently funding the most appropriate areas of UK bioscience within its remit; and to identify ways to build on successes and address identified gaps and issues¹.

The Panel's analysis was based on the results of questionnaire surveys of a sample of 155 current and past grantholders, 26 current and past Committee members, three other UK funding organisations, and on the final reports of a sample of 126 completed grants.

KEY CONCLUSIONS

1. The PMS Committee has supported a broad range of excellent science across its remit

Overall, the research within the PMS Committee portfolio is of a very high quality. This is reflected in a variety of measures of success including final report grades, peer-reviewed research articles, publication citations, further funding to develop the research, training of researchers and their subsequent career development, new collaborations in the UK and overseas, development of intellectual property and the formation of spin-out companies.

2. The Committee has supported some outstanding scientists working in the fields of plant and microbial sciences

The highest quality research within the portfolio typically arose from individuals working in institutions with strong intellectual and capital infrastructure. These individuals have produced internationally significant discoveries that have ensured that the investments made by the Committee represented very good value for money.

3. Committee support has enabled researchers to access a wide range of other funds

The high quality of the research projects supported by the Committee has enabled researchers to access a wide range of other UK and international funds. The Committee has acted as an important connection between different funding agencies, and this has led to cross-boundary working and enabled researchers to broaden the impact of their research programmes. The PMS Committee and other UK funders have provided support that has contributed significantly to the strong international standing of the UK in plant and microbial sciences.

¹ In addition to funding responsive mode grants, BBSRC funds research relevant to the PMS Committee remit via separate initiatives and via the core funding of some BBSRC-sponsored institutes. However, this funding is delivered independently of the PMS Committee and does not form part of this evaluation.

4. The Committee has primarily supported basic research, with an appropriate balance of high-quality, innovative and incremental science

The Committee has supported high-quality basic research across its remit and has not behaved in a risk-averse manner. It is important that the commitment to fund innovative and high-risk research is maintained.

5. There is an opportunity to support more strategic and applied research through responsive mode funding

The Committee's support for strategic and applied research within responsive mode was relatively limited. There are opportunities to build on the knowledge base provided by the high-quality basic research, by supporting more strategic research within the responsive mode portfolio. This includes ensuring that the findings from basic research in model organisms are translated to more strategic or applied systems. In particular, it is timely for discoveries made in *Arabidopsis* to be exploited in crops. The restructuring of BBSRC Research Committees should be used to promote and foster these changes, and it is essential that the remits of the new Committees reflect BBSRC's mission to support all types of research - basic, strategic and applied. Efforts must also be made to ensure that perceptions do not develop within the research community that particular Committees only support basic research.

6. There are weaknesses in the provision of support and training in specific areas of the PMS Committee remit

The PMS Committee remit is very broad and this inevitably meant that the portfolio could not cover all areas in sufficient depth. There were insufficient tools and resources available for microbiologists, especially for those working on non-model species. There were gaps in the training of new scientists, particularly in disciplines which focus on 'larger-scale' biological research at the organ or organism level. There was also a need to incorporate more training for 'softer', transferable skills within research projects and to increase the emphasis on the development of multi-disciplinary skill sets.

7. The research supported by the Committee has delivered economic and social impacts

Basic research supported by the Committee has underpinned advances in key areas of strategic importance to government and the UK, such as antibiotics and antimicrobials, bioenergy, biosecurity, emerging diseases of plants and animals, mitigating climate change, and sustainable agriculture. Research projects trained skilled, scientifically-literate personnel, many of whom went on to work in industry or the wider economy. Some researchers formed partnerships with industry and other organisations, exchanging knowledge and ideas, and ensuring that research was addressing the needs of a wider community of stakeholders. Public engagement activities helped improve awareness and understanding of plant and microbial sciences, and illustrated how BBSRC science is addressing issues of public interest such as 'superbugs' and climate change. Looking forward, many researchers believed that their research findings will ultimately benefit human health, the environment, or animal health and welfare.

8. There is a need to promote greater links to other stakeholders who benefit from plant and microbial sciences research

There are complex sets of stakeholders who benefit from the research supported by the PMS Committee. The scientific community faces a number of challenges and opportunities to ensure their research delivers greater impact to these stakeholders. There is a need to promote greater links to end-users, particularly those in industry and other funding agencies that support strategic research. More could also be done to address government priorities, contribute to government policy and engage with the public. BBSRC must assist grantholders by providing clear guidance of its expectations regarding the delivery of knowledge transfer and knowledge exchange. When developing grant applications, researchers should be encouraged to plan how their research project can deliver benefits to non-academic communities.

9. BBSRC must continue to support excellent and creative investigator-driven science

In the future, achieving the right balance of basic, strategic and applied research in responsive mode will be an exciting challenge which will require coordinated effort from BBSRC, its Research Committees and the research community. Funding of basic research is essential, and the serendipitous nature of scientific investigation means that such work can lead to exhilarating discoveries with unimagined impacts. Support for strategic and applied work is also important, and can similarly deliver excellent research and innovation. It is clear that scientific excellence will remain the key driver for funding all the types of research within BBSRC. In this respect, the high quality of the research within PMS Committee portfolio places UK plant and microbial scientists in a very strong position, and it is important to sustain and build on this success.

CHAPTER 1. BACKGROUND

Introduction

1. The Biotechnology and Biological Sciences Research Council is one of seven Research Councils sponsored through the Department for Business, Innovation and Skills (BIS) of the UK government. Its principal aim is to foster a world-class biological science community in the UK. The mission of the BBSRC is to fund internationally competitive research, to provide training in the biosciences, to encourage opportunities for knowledge transfer and economic impact, and to engage the public and other stakeholders in dialogue on issues of scientific interest.
2. BBSRC supports research in a number of ways, including research grants, studentships, fellowships, and strategic grants to BBSRC-sponsored institutes. In the 2007-08 financial year, 38% of BBSRC research funding (£143 million) was spent via the 'responsive mode' scheme, whereby research grants are awarded to unsolicited research proposals from eligible applicants in any area relevant to the mission of the Council. BBSRC also supports research through directed initiatives, where money is 'ring-fenced' to fund research grants that will deliver specific strategic objectives.
3. Researchers can receive support for basic, strategic and applied research projects through responsive mode:

Basic:	Research conducted for the advancement of knowledge
Strategic:	Research conducted with the expectation that it will form a broad base of knowledge likely to underpin the solution of recognised or expected current or future problems
Applied:	Research that is directed primarily at addressing a specific, practical problem or objective
4. For organisational purposes, the BBSRC research remit has historically been divided into seven key areas each covered by a Research Committee: Agri-Food; Animal Sciences; Biochemistry and Cell Biology; Biomolecular Sciences; Engineering and Biological Systems; Genes and Developmental Biology; and Plant and Microbial Sciences. In a restructuring exercise completed in 2008, the number of Research Committees was reduced from seven to four. The new Committees met for the first time in May 2009.

Evaluation context

5. Evaluation is of growing importance to BBSRC and, with its emphasis on evidence based decision making, to the UK government. Evaluation plays a central role in:
 - justifying BBSRC funding allocation and contributing to the evidence that all Councils are required to submit to BIS
 - informing internal funding decisions, providing evidence of progress and achievement, and facilitating the development of a strategic overview for future funding decisions
 - enabling BBSRC to account to government, the public, the scientific community and other stakeholders for the funds it allocates
 - helping BBSRC to improve its policy and practice, through informing policy decisions and the design of new schemes, programmes and processes; and through identifying good practice, lessons learned, and ways to improve processes.

Formal evaluation of research is currently conducted at a number of levels in BBSRC:

- | | |
|--------------|--|
| Project: | <ul style="list-style-type: none"> • Evaluation of final reports from grants |
| Scheme: | <ul style="list-style-type: none"> • Evaluation of Research Committee responsive mode portfolios • Evaluation of Research Initiatives (time-limited research funding in strategically significant areas), 2-3 years after the grants have ended • Evaluation of funding schemes (e.g. New Investigator, international Partnering Awards, Research and Technology Clubs) |
| Institution: | <ul style="list-style-type: none"> • Institute Assessment Exercise, conducted every five years at the BBSRC-sponsored Research Institutes |
6. BBSRC's Evaluation Strategy² outlines the Council's approach to evaluation and the methodology used. The responsive mode portfolios of individual Research Committees are evaluated on a rolling basis, whereby two Committee portfolios are evaluated every year. PMS is the sixth Committee portfolio to be evaluated, following evaluations of the Animal Sciences, Biochemistry and Cell Biology, Genes and Developmental Biology, Agri-Food, and Engineering and Biological Systems Committee responsive mode portfolios carried out between 2005 and 2008³.
7. This evaluation covers research grants supported in responsive mode through the PMS Committee which have been given a final report grade since 1996. The objectives of the evaluation were to:
- assess the quality and international standing of research funded through the PMS Committee
 - assess the economic and social impacts of research supported by the PMS Committee
 - identify the major outputs and, where possible, outcomes of the PMS Committee responsive mode portfolio over the past 10 years
 - identify strengths, weaknesses and gaps in the PMS Committee remit and the way it is structured
 - consult with the research community and other relevant bodies (government and non-government) to assess whether the PMS Committee is currently funding the most appropriate areas of UK bioscience within its remit
 - identify ways to build on successes, and ways to address identified gaps and issues.
8. BBSRC evaluations are evidence-based, and conducted by independent Review Panels comprising scientists not closely involved with the BBSRC. The expertise of each Review Panel covers the remit of the Research Committee being evaluated (for the PMS Committee Review Panel membership, see page 48). Review Panels are asked to provide an independent scientific evaluation of the evidence presented. For PMS this was:
- 126 sample final reports (representing 28% of all PMS Committee responsive mode grants that had been completed and graded at the time of sampling). See Appendix 1 for a list of sample grants (p.48).
 - Questionnaires returned by 83 principal investigators (PIs) of completed grants (representing 18% of all completed and graded PMS Committee responsive mode grants) and 72 current PIs (47% of all current PMS Committee grants that have been active for more than one year).

² http://www.bbsrc.ac.uk/organisation/policies/reviews/funded_science/bbsrc_evaluation_strategy.pdf

³ The Biomolecular Sciences Committee was not included in this round of Research Committee portfolio evaluations. However, the non-structural biology aspects of the BMS Committee responsive mode portfolio were reviewed as part of a pilot evaluation. The methodology and lessons learned from the pilot evaluation formed the basis for subsequent evaluations of the other Committee portfolios. The structural biology supported by the BMS Committee has been reviewed extensively (e.g. BBSRC Review of UK Structural Biology).

- Final reports and questionnaire responses from seven PIs who had received significant support (£1.2 million - £2.2 million) from PMS Committee responsive mode over the evaluation period (55 grants, representing 8% of the funded portfolio)
- Questionnaires returned by 26 current and past PMS Committee members
- Questionnaires returned by the Department for Environment, Food and Rural Affairs, the Natural Environment Research Council, and the Wellcome Trust.
- Additional information about the grants funded through the PMS Committee responsive mode drawn from BBSRC databases.

CHAPTER 2. STANDARD OF RESEARCH

Summary

- The overall quality of the research within the PMS Committee responsive mode portfolio was very good, with many examples of internationally significant research
- The outputs that arose from the funded grants were very good and reflect the high standard of the research in the portfolio
- The highest quality research typically arose from gifted individuals working in institutions with strong intellectual and capital infrastructure
- The research funded by the PMS Committee made significant contributions to the UK's strong international standing in plant and microbial sciences
- The PMS Committee facilitated important connections between different funding agencies, resulting in cross-boundary working and enabling researchers to broaden the impact of their research

Overview

9. The past ten years have been an exhilarating time for plant and microbial sciences, both internationally and within the UK. Extraordinary advances have been made as a new era of genomics has empowered scientists to address long-standing and novel biological questions with new technologies and resources. The PMS Committee has contributed significantly to enabling UK researchers to take advantage of these unprecedented opportunities. A programme of *Arabidopsis* research produced a step-change for plant scientists, fostering a new community of researchers conducting outstanding work in molecular plant science. Support for microbial sciences maintained a vibrant community of non-medical microbiologists, who took advantage of genome sequences and new genetic tools to make impressive breakthroughs in their fields. Moreover, the Committee supported a variety of exciting research projects that resulted in internationally significant work studying plant-microbe interactions and increased our understanding of plant health and disease. The Committee's support, working where relevant with other UK funders, has resulted in a highly productive period for plant and microbial sciences and has contributed to a strong international profile for UK research. The story of the research supported by the PMS Committee over the past decade is a tale of outstanding discoveries made by outstanding individuals and, if what's past is prologue, provides a tantalising glimpse of the even greater discoveries that are still to come.

Research quality

10. The general standard of the research funded by the PMS Committee in the sample grants assessed by the Review Panel was very good. Many grants made substantial, internationally-significant advances in their respective fields and some were of exceptional quality.

11. 82% of the final reports on PMS grants, submitted within three months of the end of the award, were graded either A or B by PMS Committee assessors⁴. 32% of final reports received an A grade, which was impressive. This high level of performance was reflected in the sample of grant final reports reviewed and the observation that the majority of sample grants met their original objectives.
12. Of the 126 final reports reviewed by the Panel, 40 grants were identified as being particularly successful (32%). Summaries of these are given in Chapter 5, pages 38-43. There were numerous measures of success within the highlighted grants. These went beyond publishing papers in high-ranking journals, and grants were often noted for a combination of factors. Research was highlighted for being particularly innovative or pioneering at the time, opening up a subject area for other researchers, providing tools and resources for the community, obtaining further funding to develop more strategic aspects of the work, industrial relevance, developing intellectual property, or successfully engaging with the public. The Panel also identified a number of additional notable grants (pages 44-45). Some of the research supported by the PMS Committee formed the basis for current systems biology work and there is potential to develop this further in the future. Other research highlighted links with animal systems, an area that will become increasingly relevant.
13. There were some common elements amongst the grants that produced the highest quality research. They tended to come from more established research groups, especially those with a critical mass of staff and other funded projects. The most successful PIs often had a strategic vision for their research programme, matching their research interests to the opportunities available from multiple funding streams and agencies. In addition, these groups were able to take multiple approaches to address biological questions and had a greater tendency to network with other scientists.

Research outputs

Summary

14. The high standard of the research within the PMS Committee portfolio was demonstrated by the quality of outputs arising from the sample grants. There were many papers published in high quality peer-reviewed journals, a good number of staff trained and wide-ranging tools and technologies developed for the scientific community. In addition, there was a significant number of new UK and international collaborations, substantial further funding to develop the research, support for early-career researchers to establish new research programmes, the development of intellectual property and the formation of spin-out companies.
15. Data on research outputs from completed grants were collected from final reports and questionnaire responses for the sample of 126 PIs. However, it should be noted that figures are likely to be underestimates because while they include data from the final report forms for all 126 PIs, they only include survey responses for the 83 PIs who returned the questionnaire.

⁴ Reports are given a grade from A-D. The definition of these grades is as follows:

A: Very high class work that has produced results of considerable scientific importance in a cost-effective way and met all or almost all of the agreed or related key objectives.

B: Work that has significantly added to knowledge in the field and met the majority of its agreed or related key objectives.

C: Work that has fallen short of the contribution to knowledge or cost effectiveness expected from the original proposal even though it may have met some or all of its agreed or related key objectives.

D: Work that has not added significantly to knowledge in the field and/or has failed to address the agreed or related objectives.

Publications

16. A total of 526 original research articles in refereed journals are known to have been published and reported so far from the completed and current sample grants. The median number of original research articles per completed grant was three, rising to four when review articles were included. This is in line with the level of published outputs from the evaluations of BBSRC's other Research Committee portfolios.
17. The Panel was impressed by the quality of the journals in which publications appeared, a view strongly endorsed by the international Panel members. The Panel identified a list of high ranking multi-disciplinary journals and prestigious journals in the field of plant and microbial sciences⁵ (for details see p. 46). 58% of original peer-reviewed articles from completed and current grantholders were published in these journals and an impressive 4% of grantholders published original research articles in the multi-disciplinary journals 'Nature' or 'Science'. This was excellent, as it is challenging for any scientist to publish in these journals and research within the PMS Committee remit is not necessarily considered 'fashionable' by the journal editors.

Researchers at the John Innes Centre received support from the PMS Committee to investigate the response of bacteria to nitric oxide. Nitric oxide is produced at high concentrations by specialised human cells known as macrophages to poison engulfed bacteria or tumour cells, and bacteria have evolved special mechanisms to protect themselves against its toxic effects. The research discovered that nitric oxide interacts directly with a bacterial regulatory protein to activate the expression of genes involved in nitric oxide detoxification. The findings were published in a range of high-impact journals, including 'Nature'.

Researchers at the University of Manchester conducted research into the structural basis of cell division in trypanosomes, microbial organisms that cause a variety of diseases including sleeping sickness in humans. When a trypanosome divides, two daughter cells of similar shape are produced. The researchers showed that structural information in the old cell is used to influence the shape and form of the new cell. The findings were published in the high-impact, multi-disciplinary journal 'Science'.

A research project at the University of Leicester investigated light signalling between chloroplasts and the nucleus in the model plant Arabidopsis. The researchers studied how porphyrin IX, which is involved in far-red light responses, is used as a signal, and examined the role of a plastid-localised protein in signalling regulation. The results were published in several research articles in prestigious journals, including 'EMBO Journal', 'Journal of Biological Chemistry' and 'Proceedings of the National Academy of Sciences of the USA'.

18. 33% of grants published just one or two original research articles, but the evidence indicated that the majority of these were in good journals and were well cited. Some of these grants were identified as research highlights, and some articles had very impressive citation records.

A research project at The Sainsbury Laboratory (University of East Anglia) investigated mechanisms of plant disease resistance in Arabidopsis. Researchers identified a key component of disease resistance to the pathogen Peronospora parasitica. This internationally significant research produced two research articles, both of which were published in the 'Proceedings of the National Academy of Sciences of the USA'. Together, these articles have been cited over 350 times.

⁵ In determining the list of journals the Panel noted that journal impact factors vary considerably across disciplines due to factors other than research quality.

19. In terms of international standing of plant science research, an analysis of European publications in ISI-indexed plant science journals between 1999 and 2005⁶ ranked the UK very highly. England, Scotland and Wales were placed first, third and fourth, respectively, for citations per plant science article. England and Scotland also had higher citations per article than all other G8 countries. A comparable analysis of the twenty most cited countries in ISI-indexed microbiology journals between 1994 and 2004⁷, placed the combined output from England and Scotland second amongst the G8 countries with respect to citations per article, behind only the USA. These data indicate that plant and microbial science in the UK is very competitive internationally. Although this impressive UK performance is not wholly attributable to the support of the PMS Committee (see Chapter 4, p. 34), the Committee has undoubtedly played an important role in enabling UK researchers to conduct very high-quality, internationally significant research.
20. 35% and 4%, respectively, of publications arising from PMS Committee grants had international or industrial co-authors. The international figure was similar to the proportion of PIs who reported formal collaborations with international researchers. The industrial figure was slightly lower than the proportion of PIs reporting formal links with industry (see Chapter 3, paragraphs 58-64).

New contacts and collaborations

21. The research supported through the PMS Committee has played an important role in building strong research communities in the UK. Over half of PIs who responded to the survey established new or improved contacts with fellow academics in the UK. Approximately one third of PIs reported contacts that resulted in formal collaborations, leading to joint funding applications and/or joint publications. In addition, participation of plant scientists in the BBSRC-funded Genomic Arabidopsis Resource Network (GARNet)⁸ programme has been very beneficial: GARNet is an exemplary model of providing community support.

Researchers at the University of York collaborated with scientists at the University of Lancaster and the University of Durham to study stomata in Arabidopsis. Stomata are small pores on plant leaves that enable gas exchange, and their opening and closing must be tightly regulated to enable uptake of carbon dioxide whilst minimizing water loss. The research project exploited the York group's experience in 'chromosome walking' to clone three genes involved in the regulation of stomatal response to reduced atmospheric humidity. The cloning of these genes provided greater insight into this important area of science and helped to widen the scope of their collaborators' research programmes.

22. Similarly, over half of PIs established new or improved contacts with overseas academics, and about one third reported contacts which resulted in a formal collaboration. 25% of grantholders reported new or improved contacts with researchers from other European countries and 12% reported contacts with researchers in the USA. A small number of contacts were also reported with researchers in Australia, Argentina, Canada, China, Japan, Mexico, New Zealand, Pakistan, the Philippines, South Africa and Thailand. The number of international collaborations provides additional evidence of the strong reputation of UK plant and microbial sciences within the international research community.

⁶ http://www.lab-times.org/labtimes/issues/lt2007/lt01/lt_2007_01_38_40.pdf

⁷ <http://www.in-cites.com/countries/top20mic.html>

⁸ The GARNET programme was funded as part of BBSRC's Investigating Gene Function Initiative. It has provided support and resources to UK *Arabidopsis* researchers, including those supported through the PMS Committee.

Researchers at the Wellcome Trust Sanger Institute, University of Oxford and University of Birmingham sequenced the complete genome of the bacterium Pseudomonas fluorescens SBW25. Members of this species are commonly found in association with plants and are capable of promoting plant growth. The researchers initiated a collaboration with scientists in the USA who were sequencing another strain of the same bacterium. This enabled the research groups to maximise the data that could be acquired from comparison between the sequences, and also ensured sequence annotation was coherent between the two strains. The international collaboration subsequently developed to examine the induction of plant genes by P. fluorescens, adding value to the original project.

23. The level of new and improved collaborations within the portfolio and the number of joint publications generated were good; collaborations benefitted individual research projects as well as PIs' wider research programmes. The extent of networking and collaboration within the UK was impressive, but more could be done to increase the level of international collaboration. There can be difficulties with obtaining funding for collaborative activities⁹, but to be productive international interactions do not necessarily require additional funding. The strengths of the PMS Committee portfolio provide particular scope to establish partnership links with developing countries to tackle global challenges such as environmental change and emerging diseases. In this respect, the recent interaction between BBSRC and the Department for International Development (DfID) to fund research projects contributing to sustainable agriculture in the developing world is a very welcome development.
24. New contacts and collaborations were also established with industrial researchers, both in the UK and overseas; further details of these contacts are given in Chapter 3 (p. 22).

Further funding

25. The broad range of research supported by the Committee meant that there was a variety of opportunities available to obtain further funding to develop research projects. It is noteworthy that 60% of the holders of completed grants received further funding to develop the research supported by their grant. Funding was received from many sources, including the PMS Committee, other BBSRC Committees, the European Union (EU), the Wellcome Trust, the Natural Environment Research Council (NERC), industry, the Royal Society, the Leverhulme Trust, and the Department for Environment, Food and Rural Affairs (Defra). 36% of grantholders received further funding from BBSRC, 16% from other UK funding agencies, and 14% from international funding sources.
26. It is clear that the PMS Committee has provided important connections between funding agencies, which has led to cross-boundary working and enabled researchers to broaden the impact of their research. It was significant that a third of PIs supported through the PMS Committee received funding from more strategically orientated funding sources such as BBSRC Agri-Food (AF) and Engineering and Biological Systems (EBS) Committees, Defra and industry, suggesting that they were looking to translate the knowledge from the basic research funded by the PMS Committee. PIs were also seeking to increase the impact of their research through funding applications to the Medical Research Council (MRC), the Bill and Melinda Gates Foundation and other charities (see Chapter 3).

⁹ BBSRC provides support for international exchanges through a variety of mechanisms including the International Scientific Interchange Scheme (ISIS) and Partnering Awards (with China, India, Japan and the USA). For further details see: <http://www.bbsrc.ac.uk/science/international/index.html>. It should be noted that BBSRC can only fund the UK-aspects of collaborative research. Support for the partner country must come from their government (which may be challenging for developing countries) or other funding agencies (such as DfID).

Scientists at the University of Leeds conducted research into the genes that are involved in the interactions between nematode pests and plants. Every year, nematodes are estimated to cause £80 billion of damage to crops worldwide. This project identified nematode genes that are activated during the initial infection of plants, and used RNA interference technology to show that they are involved in the infection process. The researchers obtained further funding through the Agri-Food Committee to develop plants with sustainable resistance to nematode pests. They also received a Sustainable Agriculture Research for International Development Initiative grant, to exploit their findings in the development of nematode resistant plantain crops for African subsistence growers.

Researchers at the University of Newcastle upon Tyne investigated the bioremediation of the highly-toxic industrial pollutant selenate. They characterised a novel membrane bound selenate reductase from a bacterium present in contaminated drainage water. The project was successful in obtaining further funding from the EBS Committee. The current EBS Committee project has the long-term objective of bioengineering a thermo-stable selenate reductase for use in an enzyme based thermo-extraction bioremediation strategy.

A joint research project between the University of Nottingham and the University of Warwick revealed knowledge of an important new control step in the abscisic acid biosynthesis pathway in tomato. The findings have potential use in the development of crops with more efficient water usage. The researchers obtained substantial further support of over £1.7 million from other organizations, including Defra and an industrial partner, to pursue this strategic research direction.

New products, processes, resources, tools and technologies

27. About one half of PIs reported that their grant had led, or could lead to, the development of new products, processes, resources, tools or technologies, similar to that reported by most other BBSRC Committee portfolio evaluations. The outputs varied widely but included methods, reagents, transgenic and mutant lines, constructs, libraries, genome sequences and software. The users identified were primarily other academic researchers both within the UK and internationally, but also included industrial researchers, biomedical researchers, plant breeders and biotechnology companies. The new tools and technologies were made readily available to the wider community via publication in peer-reviewed journals or in online databases. Most of them remain readily accessible and relevant.
28. The most accessible outcomes to the wider community were those that arose from larger “-omics” activities (e.g. genome sequences, databases and genetic resources). Although the initial investment in these resources was expensive, it delivered good value for money. Genomics resources have stimulated hypothesis-driven research across the PMS Committee remit and opened up important new areas of scientific investigation. The availability of freely accessible data drives open scientific enquiry, and it is important for data from genomics activities such as sequencing and transcriptomic analysis to be made publicly available as soon as possible. The Panel therefore welcomed BBSRC’s Data Sharing Policy¹⁰, which sets out the Council’s expectations relating to data sharing; all PIs seeking research grant funding from BBSRC must submit a statement on data sharing as part of their application.

*Researchers at the University of York, University of East Anglia and the Wellcome Trust Sanger Institute sequenced the complete genome of the bacterium *Rhizobium leguminosarum*. Rhizobia are important agricultural organisms, allowing many crops to be grown without nitrogenous fertiliser, an energy-expensive and potentially polluting agent. This research provided the sequence for a strain of the bacterium that is widely used by scientists, and is descended from a strain obtained from the roots of a pea plant in the UK.*

¹⁰ http://www.bbsrc.ac.uk/publications/policy/data_sharing_policy.pdf

A research project at the University of Leeds produced over 21,000 gene sequences from the moss Physcomitrella patens. There are few non-flowering plants with extensive sequence data, and therefore the 'Expressed Sequenced Tags' generated through this project provided important materials for the study of the evolution of gene function in land plants.

29. The Panel noted that a wide variety of tools and resources are available for plant scientists as well as for researchers working with several model microbial species. However, in general, there are considerably fewer resources available for microbiologists, and in some areas, such as soil microbiology, more support is needed. This is limiting the progress of microbiology research and BBSRC might consider reviewing its current support for tools and resources developed for microbiologists¹¹.

Intellectual property and spin-out companies

30. 7% of sample grants resulted in applications to secure intellectual property, with a further 6% of PIs planning this in the future. Of the 14 reported patent applications, three were licensed and one received income. This is similar to the level observed in the evaluations of other BBSRC Research Committee portfolios.
31. Grantholders reported that PMS Committee funding contributed to the establishment of four spin-out companies. This figure is higher than reported in all other BBSRC Research Committee portfolio evaluations with the exception of the Engineering and Biological Systems Committee portfolio, which is significantly more user-orientated. Another spin-out company was generated from the research of those PIs with significant support from the PMS Committee (see page 17), and PMS Committee support for *Streptomyces* genomic research had contributed to the development of a further two spin-out companies.

Researchers at the University of Durham used knowledge from their basic research programmes to establish Creative Gene Technology Ltd. This company is exploiting new techniques in plant genomics and proteomics to develop strategic targets for the agrochemical and food industries, including oil yield in rapeseed and the identification of novel herbicide targets.

Research at the University of Sheffield identified a unique group of surface exposed proteins of the bacterium Staphylococcus aureus which are essential for the bacterium's survival. The researchers have formed the company ABSynth Biologics to help exploit these research findings, and in particular, explore the potential of the proteins to provide novel targets for vaccine or antibody treatments against the 'superbug' MRSA.

32. The Panel noted that the pursuit of intellectual property rights can hinder research and innovation, rather than promote it. Applications for patent protection can often be made too early, when the intellectual property has limited value. This is illustrated by the very small proportion of patents that are ever licensed or receive income. Institutions and grantholders should think carefully about the best approaches for developing intellectual property rights: for example, it could be better for researchers to work with industry or other stakeholders to develop their intellectual property before seeking patent protection, ensuring that awarded patents had real value. Industrial Panel members commented that universities often have unrealistic expectations of their intellectual property, and this could be a barrier to the uptake of research findings by small and medium enterprises. In addition, in recent years, the proliferation of Material Transfer Agreements for

¹¹ BBSRC is in the process of establishing a comprehensive database of tools and resources developed from BBSRC funding as part of a wider review of data sharing policies. This should enable a more accurate picture of the resources available to microbiologists to be developed.

exchange of basic biological materials has been an unwelcome development, creating additional bureaucracy over materials which have little likelihood of being commercially exploited.

33. Despite these reservations, the high standard of research across the PMS Committee portfolio meant that there was potential for greater development and exploitation of intellectual property than had been realised to date. Striking the correct balance between the free flow of information and the protection of intellectual property is challenging, but it is important that BBSRC promotes a culture where researchers are encouraged to develop and exploit their intellectual property, as appropriate.

Principal Investigators with significant funding from the PMS Committee

34. The Review Panel examined the contributions to research outputs and outcomes from seven PIs who have received significant support (£1.2 million - £2.2 million) from the PMS Committee responsive mode funding over the evaluation period. It considered 39 final reports from 55 grants, which accounted for 8% of the portfolio funded during the period.
35. The standard of work produced by these PIs was impressive, and was generally of even higher quality than the majority of the other completed grants. The research led to highly-cited publications in high-ranking journals, as well as an impressive range of other outputs, including the development of tools and resources for the wider community and intellectual property. The decisions of the Committee to fund these grants were strongly endorsed and this research serves as a prime example of the value of responsive mode funding: PIs had defined research programmes with a clear direction and focus, which were sustained through competitive responsive mode funding applications.
36. There was evidence that the PIs' research groups were more involved with knowledge transfer and exploitation of their research findings than the wider sample of grantholders. For example, four of the seven PIs made applications to BBSRC's Follow-on Fund, a funding stream that supports 'proof-of-concept' work at the very early stage of turning research outputs into a commercial proposition, and three were successful. One of these awards contributed to the formation of a spin-out company. However, there was some concern that not all seven PIs were actively involved in the knowledge transfer of their research and, considering the degree of financial support received from BBSRC, more could be expected in this area.
37. The research grants represented excellent value for money and also added value to the PIs' wider research programmes. The PIs used a variety of funding models to support their research: some were heavily reliant on PMS Committee and other BBSRC funding, whereas others used mixed funding models, with BBSRC support representing less than a third of their research income. For researchers who had significant non-BBSRC funding, support from responsive mode grants had contributed to the critical mass of their research groups and enabled a broader range of research activities to be conducted. It is therefore highly likely that PMS Committee funding contributed to some of the impressive outputs and outcomes arising from the PIs' wider research activity. This group of PIs demonstrates the synergy between PMS Committee funding and other agencies and organisations, which was also observed within the wider portfolio of PMS Committee research grants.
38. The strength of the research conducted by these PIs highlights a general theme throughout the portfolio: the most successful research has arisen from outstanding individuals (both PIs and post-doctoral researchers), and these individuals were working in institutions with a strong intellectual and capital infrastructure. BBSRC and academic

institutions must provide adequate support for plant and microbial science research to ensure that such exceptional scientists remain within the UK and that the critical mass of excellent research groups is maintained.

Less successful grants

39. Although the general standard of the research funded by the PMS Committee was very high, there was still some potential to improve research quality throughout the portfolio. The quality varied across the sample projects and some less competitive grants were funded. A small but significant number of grants were less successful than expected, either failing to meet their original objectives or resulting in little or no tangible output.
40. 12% of grantholders who had completed grants reported no original research articles arising from their project. This was disappointing, even though some failure is inherent to the nature of scientific investigation and the figure is in line with the performance observed in other Research Committee portfolio evaluations. The apparently unproductive grants came from across the PMS Committee remit, and the majority (87%) were from PIs who had not returned questionnaires to update their final reports. The grantholders included both established and less well-established researchers, although there was a bias towards less-experienced PIs. The median number of previous BBSRC research grants received by these researchers was one.
41. The most common reasons given by PIs who identified that their projects were less successful than anticipated were experimental, methodological or technical. In a small proportion of less successful projects, poor performance resulted from grants being naïve or unrealistically ambitious at the outset. However, in the main, limited success in meeting objectives was an inevitable consequence of conducting creative, innovative or high-risk research. It should be expected that researchers using novel or state-of-the-art technologies, or tackling challenging questions will encounter some problems; if no researchers experienced any experimental difficulties, it would be a clear indication that the portfolio was too conservative and risk-averse.
42. In some grants, difficulties were encountered with recruiting staff with the appropriate training or experience. There were also problems with the retention of Research Assistants (RA), which were often a major contributing factor to poor performance. Poor career development prospects and lack of employment stability for RAs are particularly relevant to staff retention, and therefore directly impact on grant performance. Although the majority of grants awarded by the PMS Committee were for 36 months, the median length of employment for a post-doctoral research assistant was 28 months.
43. Several projects changed direction owing to developments from other research groups (e.g. publication of new data). This is inevitable, and most grantholders showed flexibility and initiative to agree new priorities with BBSRC. Projects in which significant changes were made were often as productive as projects that went as planned.
44. BBSRC should ensure that it fosters an environment where researchers feel able to report significant problems with their research and agree new project objectives. This may be particularly important for less-experienced PIs who may not have the confidence to report issues until it is too late to change the direction of the project.

CHAPTER 3. RESEARCH IMPACTS

Summary

- The research funded through the PMS Committee is of interest to wide and complex sets of stakeholders
- The training and skills development of researchers was a significant impact of PMS Committee funding and contributed to the wider economy
- The level of interaction with industry was appropriate given the basic nature of the research portfolio, but more should be done to encourage an increased level of interaction in the future
- The research funded through the PMS Committee had economic and social impacts
- The basic research supported by the Committee underpinned advances that support key government priorities in areas such as antibiotics and antimicrobials, bioenergy, biosecurity, emerging diseases of plants and animals, mitigating climate change, and sustainable agriculture
- There are now significant opportunities to deliver greater impact from the portfolio of high-quality research, and it is timely to make a step-change in this area

Overview

48. The research supported by the PMS Committee is primarily basic in nature. Nevertheless, it is of broad interest to complex sets of stakeholders and provides benefits to many groups of end-users. The research within the PMS Committee portfolio has impact beyond the supply of high-quality scientific research to the knowledge base, and has contributed to the UK economy and the wider public good. Research projects trained skilled personnel who conduct research and work within the wider economy. The knowledge from research findings was transferred to stakeholders in industry and elsewhere, and led to the production of patents and the formation of spin-out companies. In addition, research projects underpinned advances that are addressing key government priorities such as antibiotics and antimicrobials, biosecurity, bioenergy, emerging diseases of plants and animals, mitigating climate change and sustainable agriculture.
49. This Chapter examines how PMS Committee grantees are addressing the needs of stakeholders. In particular, the following sections describe the impact of PMS Committee research in training and skills development, support for early-career researchers, interactions with industry, knowledge exchange, public engagement and longer-term economic and social benefits.

Training and skills development

50. Training of post-doctoral researchers and PhD students is a vital function of BBSRC funding. It provides the skilled scientists who conduct research, as well as contributing scientifically-literate personnel to the wider economy. 76% of PIs reported an increase in the skills base of their research group as a result of their grant. The majority of completed grants employed one RA, with a small number of grants employing two or three RAs. 96% of RAs worked full time on the project. Technicians were employed on

undergraduate students will have negative impacts on the recruitment of high-quality PhD students and post-doctoral researchers in the future. Although training in schools and at the undergraduate level do not fall within the remit of the PMS Committee, they are within the interests of BBSRC. Through RCUK, BBSRC supports a number of mechanisms to make science accessible to young people, including encouraging greater involvement of researchers in schools and in the bodies that influence the school curriculum, but there could be scope to do more.

Support for early-career researchers

56. There are opportunities within PMS Committee responsive mode funding for early-career researchers to establish themselves in academia. This is important, as new investigators often inject fresh and exciting ideas into the portfolio and are essential to the long-term health of the research community. The Panel highlighted several grants that had enabled early-career researchers to build independent research programmes, including a number of BBSRC New Investigator (NI)¹⁴ grants. However, there was evidence that the Committee could do more to support new researchers. The PMS Committee had the lowest success rate for NI applications of all the Research Committees and was funding fewer NI grants relative to its size than other Committees. For example, the PMS Committee funded 8% of all BBSRC NI grants between 2003 and 2007, which is lower than the proportion of all BBSRC responsive mode grants funded by PMS during this period (13%).

A New Investigator grant at the University of Glasgow aimed to develop an integrated view of potassium nutrition in Arabidopsis plants by investigating gene expression using microarrays. Potassium is an essential macronutrient for plants, and its supply in the field impacts on crop yield and nutritional quality. The project helped the researcher establish a productive research programme, and led to further funding from BBSRC.

A research project investigating the role of aquaporins in the regulation of water supply to growing leaf cells helped establish the academic career of a researcher at the University of Paisley. The project led to further funding from BBSRC and the Leverhulme Trust.

57. Funding for three years is not sufficient to establish a sustainable research programme, and BBSRC may wish to consider different funding structures for new researchers. For example, five year funding schemes may be more appropriate with the final two years dependent on a progress review at the end of the third year. Such '3+2' schemes are used in France and Germany to support new researchers.

Interaction with industry

58. New or improved contacts with industry in the UK were reported by 12% of sample PIs, and 8% of PIs reported similar contacts overseas. 5% and 4% of PIs established new formal collaborations with industry in the UK and overseas, respectively. 13% of PIs received financial support from industry, either at the outset of the project or subsequently to develop the work. The majority of this funding was through CASE

¹⁴ The New Investigator scheme is aimed at university lecturers and researchers at BBSRC and NERC institutes, within three years of their first appointment. Its purpose is to assist those individuals to obtain their first research grant. Applications are judged against the same criteria as other responsive mode proposals, but research potential rather than track record is taken into account.

studentships¹⁵, but grantholders also received support from industry through the LINK scheme or Industrial Partnership Awards (IPA). The level of interaction with industry was reasonable, given the basic nature of the research that accounts for the majority of the portfolio.

Researchers at Aberystwyth University and the University of Manchester received an Industrial Partnership Award to investigate proteins that resuscitate dormant mycobacteria. These bacteria include Mycobacterium tuberculosis, the causative agent of tuberculosis (TB). Dormant TB is able to persist in the body and is resistant to antibiotic treatment. The findings from this project contributed to potential targets for novel TB vaccines.

A LINK project provided support for researchers at Rothamsted Research to examine how plant cell wall enzymes interact with synthetic man-made chemicals, such as herbicides. The research identified an enzyme with a key role in detoxification, and the results were made available to the industrial partner to assist with their crop protection chemical discovery programme.

A LINK project provided support for scientists at the University of Cambridge to investigate the plant cell cycle, the process which a cell undergoes in order to divide. The researchers used a multi-tool approach to examine a complex set of interacting gene expression patterns among cell cycle regulators. A collaboration agreement was signed between the University and the industrial partner governing any future exploitation of the work.

59. The high quality of the basic scientific research within the PMS Committee portfolio provides a strong bedrock of knowledge of which a significant proportion is of potential use to end-users in industry. Over the evaluation period, the interaction of researchers with industry had a relatively narrow focus, concentrating on a few key areas such as plant disease protection or the development and production of antibiotics. However, the research supported by the Committee could make important contributions to industry across a large number of other strategically important areas, including bioenergy, biomaterials, bioreactors, bioremediation, diagnostics, diet and health, fermentation, microbial inoculants, pharmaceuticals, pesticides, plant breeding, renewable materials, sustainable agriculture, and vaccine development.
60. Several grants produced scientific knowledge that was exploitable by the wider community, but in many cases PIs chose not to pursue such opportunities. It was not clear whether this was due to a lack of interest from PIs or whether the barriers to industrial or commercial interactions were too high. Some researchers could have been more imaginative in broadening the impact of their PMS-funded research, and it was disappointing that PIs had not sought more in-kind support from industry and other organisations (for example using growth facilities in industry or agricultural faculties to support research on species other than *Arabidopsis*).
61. However, it should be noted that much of the industrial interaction in the plant and microbial sciences is driven by research that falls within the remit of BBSRC's AF and EBS Research Committees. Over the evaluation period, 32% of all researchers funded through the PMS Committee responsive mode also received support from the AF or EBS Committees. This was encouraging as it was likely that some of these researchers were using the PMS Committee to support research that underpins more strategic elements or their research programmes.
62. The limited size of the plant science industry within the UK is a barrier that inhibits plant and microbial scientists from increasing the level of interaction with that sector. In

¹⁵ Collaborative Awards in Science and Engineering (CASE) allow students to receive high quality research training in collaboration with an industrial partner. Students spend a period of between 6 and 18 months working with the company, and the company makes a financial contribution to the costs of the project and the training of the student.

particular, public concern within Europe over the use of genetic modification technology has contributed to a significant decline in the UK plant science industry. It is vitally important that the UK retains a strong research base in the plant and microbial sciences, to ensure that the existing industry remains in the UK and as an incentive to encourage new industry to invest in the UK.

63. The Panel noted that industry also places a high value on quality basic research, a view strongly endorsed by the industrial Panel members. In this respect, the research funded by the PMS Committee has made an essential contribution to the knowledge base that underpins UK industry.
64. There were several examples of the commercialisation of research outputs within the portfolio and in PIs' wider research programmes. 9% of all PIs funded by PMS Committee responsive mode during the evaluation period made applications to the BBSRC Follow-on Fund (FoF), and 3% were successful. The Panel noted that the technology management company Plant Bioscience Limited, which has been partly funded by BBSRC, has made an important contribution to furthering the exploitation of research by PMS Committee grantholders, as had other university-based technology transfer offices. Overall, it was encouraging that PIs were engaging in the commercialisation of research outputs, and it is important that BBSRC provides support to PIs to incorporate this type of activity into their research programmes.

Researchers at the John Innes Centre and The Sainsbury Laboratory (University of East Anglia) have used the findings from their research programmes to establish Norfolk Plant Sciences Ltd. This company is using transgenic technology to develop blight-resistant nutritionally enhanced potatoes. A key part of the initial work is being funded through BBSRC's Follow-on Fund.

Knowledge exchange

65. There are further opportunities for knowledge exchange from the PMS Committee portfolio. For example, there is significant scope to transfer the findings from basic research with model organisms to more applied or strategic systems, bringing the research closer to needs of other funding agencies and end-users.
66. About one quarter of sample PIs reported some knowledge transfer of the research supported by their grant to more strategic or applied biological systems. In addition, about half of all PIs supported by the PMS Committee over the evaluation period had, as part of their wider research programme, obtained some funding from sources that support strategic or applied research. Although the general level of knowledge transfer within the funded projects was limited, it should be noted that knowledge transfer was not an essential objective of responsive mode research during the evaluation period. It is now important to demonstrate a step-change in this area and it is timely, for example, to increase the focus on transferring the high-quality knowledge generated from basic plant science research into *Arabidopsis* to crop species. It would also be worthwhile to increase the use of UK-specific crop species in research.
67. Encouraging knowledge exchange between researchers and end-users is not solely the responsibility of BBSRC. Other organisations and end-users must help by informing researchers of their strategic aims, and by providing appropriate opportunities and incentives for researchers to explore knowledge exchange activities; the knowledge of the applied problems end-users are attempting to solve that is gained through these exchanges is very valuable. BBSRC-funded researchers must also recognise their obligations to ensure that relevant publicly-funded science, with benefits for society and the economy, is more explicitly recognised and used.

68. The main driver for Higher Education Institution funding is the Research Assessment Exercise (RAE)/Research Excellence Framework (REF), with the majority of universities' financial support for research coming from quality-related research (QR) funding. There is currently an opportunity for BBSRC to work with the Higher Education Funding Council for England (HEFCE) to increase the role of knowledge exchange in the Funding Council reward system. However, changes to university funding mechanisms could create new challenges for the PMS community. They may prove beneficial for researchers who can interact with medical and pharmaceutical industries, but damaging to other areas, such as agricultural research, where very few UK-owned large companies remain within the UK.

Public engagement

69. The public is an important stakeholder in the research supported by the PMS Committee. As a result, there is a need for scientists to engage with the public, to inform people about complex scientific issues, to understand and address current and emerging attitudes to bioscience research, and to make a compelling case for the public funding of research. BBSRC requires all PIs, or a member of their group, to conduct public engagement activities as a condition of their grant. PIs report on their activities in their final report, but these aspects are not subject to formal evaluation.
70. The majority of grantholders funded by the PMS Committee was involved in public engagement during the course of their grants. There was participation in a wide range of activities, including shows, open days, public dialogue events, school visits, publicity in non-scientific media, and responding to media inquiries. These activities were conducted by PIs and the post-doctoral researchers from their groups. There was, however, evidence that the definition of public engagement was not universally understood by researchers: some PIs reported activities which do not constitute public engagement, such as departmental websites, articles in scientific journals, and UCAS recruitment days.

Researchers at the University of Nottingham investigating how the microscopic parts of bacterial flagellar motors interact to make them work were very active in presenting their work to schools. The Research Assistant participated in the Researchers in Residence Scheme, and was based in a school for one week. The researchers also presented a practical demonstration on bacterial swimming at the Leicester Science Learning Centre to school technicians. In addition, the researchers made many other presentations to school pupils, school teachers and school technicians explaining the molecular genetics of bacteria.

Researchers at the University of Bath established a 'Café Scientifique' in Bath. Café Scientifiques provide an opportunity for the public to explore the latest ideas in science and technology. An expert speaker gives a short talk on a particular topic, and this is followed by questions from the audience and a general discussion. The meetings are informal and accessible, and provide the opportunity for members of the public to discuss their views with the speaker.

71. There was significant involvement by grantholders with activities in schools, covering a range of age groups, with the majority based around talks and lectures. There was also a limited number of activities that included significant 'hands-on' practical elements. These were very valuable, and concentration on activities with a practical focus in the future would be very helpful. There was evidence that researchers were hosting Year 12/13 students and first year undergraduates in their research groups to conduct work experience, which was encouraging. There are wide-ranging benefits from the interactions between researchers and schools, including making science accessible to young people and inspiring them to consider scientific research as a career.

72. A significant proportion of the public engagement carried out by researchers was opportunistic or responsive, rather than pro-active. PIs had used agricultural shows, British Association for the Advancement of Science (BA) Festivals, 'Science Week', and university or institute open days. Many PIs also had responded to media enquiries. While the degree of responsiveness is heartening, the Panel would have welcomed more evidence of PIs initiating and developing their own public engagement activities.
73. PIs who developed activities that could easily be re-used were often very active in public engagement, delivering the same activity to many audiences. Researchers have to balance many competing demands in their work, and the time needed to develop public engagement activities is a major barrier to researchers' participation. This could be addressed by establishing a web-based repository for resources, enabling researchers to incorporate material developed by others into their own public engagement activities.
74. Approximately 20% of grantholders reported no public engagement activity in their final reports, which was disappointing. The lack of any involvement by a significant proportion of grantholders highlights an important issue with BBSRC's policy on public engagement: the requirement for grantholders to conduct public engagement activities cannot be fully effective if there is no sanction against PIs who fail to meet their obligations. The Panel also noted that BBSRC offers no incentives, rewards or professional recognition for conducting public engagement activities, and it is likely that researchers' involvement has been driven primarily by personal interest and the culture within grantholders' institutions rather than BBSRC. It is important for BBSRC to clarify whether it regards PIs' participation in public engagement as a serious grant condition. If so, it must ensure that there are sanctions against grantholders who do not comply.
75. Learned societies often have very good public engagement programmes. In particular, the Society for General Microbiology has a range of excellent materials and advice available on its website. BBSRC should encourage researchers to participate in the public engagement programmes of these societies, as well as with other organisations, such as National Science Learning Centres or RCUK.
76. Encouraging a culture of public engagement amongst researchers must begin early in scientific careers. PhD students and post-doctoral researchers should receive training in scientific communication, learning how to relate complex issues to a general audience. There was a lack of accessible, non-scientific literature for the lay public in the grantholders' reported public engagement activities, and increased training may help address this. It was pleasing that 25% of sample PIs attended a media training course.
77. PIs are not required to discuss the specific research conducted during their grant as part of their public engagement activities. This is appropriate, as different people have different interests and priorities, and it is important that scientists interact with the public on general issues of scientific interest. Nevertheless, the Panel felt that there were potential benefits in researchers explaining the specific details of their own research to the public, such as justifying their individual research programmes to the wider community and building confidence in the research that BBSRC funds.

Economic and social impacts

78. Economic and social impacts relate to the overall objectives of BBSRC as a funding body, and are generally expected to arise in the longer-term. The following ultimate impacts (relating to the objectives in the BBSRC ten-year vision) might arise from BBSRC support for plant and microbial sciences through responsive mode funding:
- research findings are used for the 'public good' e.g. medical research, advances in biotechnology, government policy
 - exploitation of research brings income to the research community and broader economic benefit to the UK e.g. from new technologies, intellectual property, spin-out companies, etc.
 - the UK maintains high international standing in plant and microbial sciences research
 - BBSRC maintains its role as a key funder of plant and microbial sciences research in the UK
 - public confidence in UK plant and microbial sciences research is maintained.
79. These impacts relate to how effectively BBSRC is functioning and delivering the impact expected of publicly funded research, and it is therefore very important that they are identified and, where possible, attributed to BBSRC funding. It is recognised that measurement and attribution of these impacts is difficult and imprecise.

Contributions to the public good

80. The support provided by the PMS Committee contributes to the public good in a number of ways; it:
- trains scientists in basic research; provides the next generation of scientists as well as scientifically literate personnel who have gone on to work in the wider economy
 - provides a bedrock of fundamental knowledge that underpins future research, commercial and other applications, and helps shape government policy
 - helps maintain a vibrant higher education sector that contributes to the economy; foreign students are attracted to work in UK universities with exciting and dynamic research environments
 - contributes to public engagement with science, and supported science of public interest (e.g. 'superbugs', climate change)
81. An essential part of BBSRC's mission is to contribute to the UK's knowledge based society by ensuring new knowledge is generated. The high standard of research within the PMS Committee portfolio demonstrates that BBSRC is meeting this obligation. The research supported by the PMS Committee provides the knowledge for meeting future challenges, both expected and unexpected, and the expertise and skill base to exploit this knowledge. Over the evaluation period, the basic research supported by the PMS Committee has underpinned advances in key areas of strategic importance to government and the UK, such as antibiotics and antimicrobials, bioenergy, biosecurity, emerging diseases of plants and animals, mitigating climate change, and sustainable agriculture.
82. Scientific research often requires time before the impacts are realised. Nevertheless, there are examples of research within the portfolio that have already made a significant contribution to the public good:
- Research into proteins that resuscitate dormant mycobacteria, including the causative agent of tuberculosis (TB), has been incorporated into the AERAS Global

- TB Vaccine Foundations vaccine development programme. AERAS has taken an exclusive licence to the grantholder's intellectual property for these purposes.
- Research into the bacterium *Staphylococcus aureus* has provided potential for new vaccine and antibody treatments against the 'superbug' MRSA. The findings are being taken forward through the spin-out company ABSynth Biologics. The market for a vaccine against *S. aureus* is estimated to be worth \$2 billion by 2020, and nearer to \$3 billion for an antibody treatment.
 - Basic research on plant viruses contributed to the ground-breaking discovery of a class of small RNA molecules that 'silence' the expression of other genes. The findings were subsequently shown to have important roles in other organisms including humans, and have opened the door for other scientists to discover specific RNAs involved in cancer, heart conditions and viral infections. These RNA molecules are also used routinely as tools by other researchers
 - Research that improved the understanding of the resistance risk in key plant pathogens to commercially important Quinone outside inhibitor (QoI) fungicides has contributed to the improved used and durability of these fungicides.
83. Looking forward, 42% of sample PIs stated that their research has the potential to make contributions to the public good; 20% thought that their research will benefit the environment; 13% felt their research could contribute to human health; 6% identified benefits to animal health and welfare; and 3% cited potential to contribute to government policy or meeting other government priorities.

UK standing in plant and microbial sciences research

84. The PMS Committee is the primary funder of molecular plant science and a vital supporter of non-medical microbiology within the UK. A significant proportion of the portfolio is of international standing as demonstrated by the quality of research outputs and metrics comparing publication citations between countries (see Chapter 2, p. 13). It is clear that the research funded through the PMS Committee has significantly enhanced the standing of UK plant and microbial sciences internationally. The Committee's support, together with that of other UK funders, has contributed to UK research being highly regarded internationally. This view is reinforced by the significant number of international researchers who have chosen to collaborate with researchers supported by the PMS Committee.
85. Several factors may help explain the international strength of UK plant and microbial sciences research. The UK has centred its research activities on a relatively limited number of key species, and this focussed approach has strengthened research communities and enabled rapid progress to be made. The funding system in the UK is less bureaucratic than in some other European agencies, and this reduces the barriers for researchers seeking support to pursue exciting research directions. UK researchers also have the scientific freedom to address their own research objectives. A combination of researcher independence and stability in funding provides the best environment to conduct the highest quality research.

Delivering greater impact from research

86. There is an increasing need for UK researchers to demonstrate the wider impacts of public funding of research to government and other stakeholders. Over the evaluation period, the PMS Committee has supported an impressive range of high-quality basic research that has benefitted the UK. Researchers have developed skills and provided training; they have developed and exploited intellectual property, formed links with industry, transferred knowledge to end-users, translated the findings from basic

research to applied or strategic biological problems, underpinned research conducted by other funding agencies, promoted public understanding of science, contributed to government policy and addressed key government priorities.

87. There are opportunities for the strong base of basic research supported by the PMS Committee to deliver even greater impact to UK society, and it is timely to demonstrate a step-change in this area. Scientists have a responsibility to help realise wider benefits from their research findings and to think more carefully about how curiosity-driven research programmes might address needs of other stakeholders. High-quality basic research should remain a cornerstone of BBSRC research funding, and it was clear that the greatest impacts within the portfolio have been founded in excellent science. However, researchers must also recognise that scientific excellence and strategic relevance are not mutually exclusive.
88. A large number of stakeholder groups benefit from the research supported by the PMS Committee. It is unlikely that individual researchers will be able to interact with all groups of stakeholders, nor would it be appropriate for them to do so. However, it is important that all researchers seek to broaden the impact of their research or to identify explicitly the potential benefits. In parallel, BBSRC must be clear about its expectations regarding the delivery of knowledge transfer and knowledge exchange, and must ensure that the research community understands how this will be incorporated into the assessment of research grant applications.
89. To date, the delivery of impact within the majority of responsive mode research projects has involved relatively little planning or management. The effectiveness of identifying increased impact from research funding could be improved by incorporating coherent plans for knowledge exchange within grant applications, at the outset. Activities to increase the impact of research should be planned and costed, and then funded as part of the grant award. At the end of a grant, the success in meeting the plan's objectives should form part of the assessment process.
90. BBSRC must ensure it provides the appropriate support for grantholders and Committees to enable them to demonstrate increased impact of BBSRC-funded research. Wider involvement of the non-academic research community in Research Committees could be beneficial, although in the past it has been difficult to attract these individuals. The new Committee structure may reduce the commitment required from individual Committee members and consequently facilitate the recruitment of more industrialists and other stakeholders.

CHAPTER 4. BALANCE AND COVERAGE OF THE PORTFOLIO

Summary

- The overall coverage of the PMS Committee remit by the funded grants was good
- The balance between plant and microbial sciences was appropriate and reflected the number of applications received from each area
- The Committee primarily supported basic research
- There was evidence that the research community viewed the PMS Committee as supporting basic research, and had therefore not submitted applications for strategic or applied work
- The research supported by the PMS Committee was complementary to those of other funders, although there are gaps between organisations that prevent the impact of research being fully realised

Overview

91. Since its inception, the role of the PMS Committee has been to support integrative studies of physiology and biochemistry to gain an understanding of the way in which plants and microorganisms function in both terrestrial and aquatic environments.
92. The overall coverage of the PMS Committee remit by the funded grants was good. The remit is very broad and it was noteworthy that the Committee had been generally successful in allocating funding across the remit. However, the breadth of the remit inevitably meant that the portfolio could not cover all areas with sufficient depth and there was evidence that some aspects of the remit were insufficiently addressed over the past ten years. The funded grants had all been within the remit, although a few were surprisingly narrow and it might have been more appropriate for these to have been funded by another BBSRC Committee.

Coverage of the portfolio

93. The balance between plant and microbial sciences in the portfolio was appropriate and reflected the number of applications received from each area. The interface between plant and microbial science (e.g. plant-microbe interactions) benefitted considerably from the structure of the Committee, and it was important that these interactions were not at the expense of either of the individual disciplines. In future, new and emerging technologies will provide significant opportunities for truly integrative research between plants and microbes, and it is important that these synergies are not lost in the Committee restructuring exercise.
94. The Committee had primarily supported basic research within the portfolio. Supporting basic research is an essential part of BBSRC's mission and funding for creative, investigator-driven, basic science must be maintained; the serendipitous nature of scientific investigation means that such work can lead to exciting discoveries with unimagined impacts. The high quality of the basic research funded by the PMS Committee also provides an opportunity to deliver research with greater strategic

impact. Although the quality of research proposals must always remain the primary criterion on which funding decisions are made, there is scope to improve support for strategic and applied work within responsive mode funding. Researchers should also be encouraged to think more carefully about how basic research can be more closely aligned with addressing strategic objectives. There were many cases of high-quality basic research within the portfolio that could have delivered greater strategic impact with relatively minor changes to the research project.

95. It was apparent that the research community views the PMS Committee as supporting basic research, and therefore they had not submitted applications for more strategic or applied work. This perception needs to be addressed, as the Committee can only fund strategic work if it receives high-quality proposals. BBSRC's mission is to promote and support high-quality basic, strategic and applied research relating to the understanding and exploitation of biological systems. However, the description of the PMS Committee remit does not provide a clear indication that the Committee supports strategic and applied research. BBSRC's Committee restructuring exercise provides the opportunity to address this issue, and to ensure that the principle for support of all types of research, basic, strategic and applied, is enshrined within the remit of the new Committees. The proposed Plant, Microbes, Food and Sustainability Committee will bring together research from the PMS Committee and AF Committee remits, and this should be used to encourage researchers supported by the PMS Committee to increase the strategic relevance of their science. However, it is important that this is not at the expense of the strategic focus of research from the former AF Committee.
96. High quality basic, strategic and applied research funded by BBSRC can be identified through a range of outputs and outcomes that it delivers. The publication of research articles in high impact journals is a measure of international excellence for basic research; other outputs are equally valid for identifying high quality strategic and applied research. Research Committees must ensure that they recognise all types of excellent research, and user relevance and the potential economic and social impacts of research should be explicit criteria in the assessment of applications.
97. The Committee had achieved an appropriate balance of high-risk, innovative research and high quality, incremental developments within the portfolio, and had not behaved in a risk-averse manner. In the future, there is a concern that financial pressures and falling application success rates across BBSRC could make all Research Committees more conservative and less inclined to fund more risky research. It is important that a commitment to fund innovative and high-risk projects within responsive mode funding is maintained.
98. As indicated above, some areas of the PMS Committee remit were not covered adequately in the portfolio over the evaluation period. These included: bacterial morphogenesis, bacterial structures, biohazardous bacteria (such as MRSA), fungal physiology, industrial microbiology, marine microbiology, metagenomics, unculturable microbes, photosynthetic/primary carbon metabolism, plant breeding, plant-invertebrate interactions, and soil/rhizosphere biology. BBSRC must also ensure there is adequate support for genomic activities, especially as the Wellcome Trust Sanger Institute will no longer sequence plant genomes.
99. Apparent gaps in the responsive mode investment may be addressed by funding from other BBSRC Research Committees, Research Initiatives, and Strategic Grants made to BBSRC research institutes, particularly at the John Innes Centre, Rothamsted Research, and the former Institute of Grassland and Environmental Research (IGER)¹⁶.

¹⁶ During the evaluation period IGER was a BBSRC sponsored institute. The site at Aberystwyth has subsequently joined with the Institute of Rural Sciences and Biological Sciences at Aberystwyth University to become the Institute of Biological, Environmental and Rural Sciences (IBERS), managed by Aberystwyth University.

For example, over 80% of responsive mode applications within the area of soil science are submitted to the AF Committee, and this area is also supported by BBSRC through the Sustainable Soil Function (SoilCIP) Institute Strategic Programme Grant, based at Rothamsted Research, that will receive funding of £15 million over five years.

100. Several disciplines where there were shortages in the number of skilled staff were apparent: bacterial physiology, microbial ecology, virology, crop science, plant breeding, plant-invertebrate interactions, plant virology, and whole plant physiology. In general, these disciplines focus on 'larger-scale' biological problems at the organism or organ level. Over the evaluation period, there has been a drive towards investigating cellular and molecular biological mechanisms, stimulated by the use of new '-omics' technologies. Research at the organism level has not been investigated to the same extent with these modern technologies, and may be regarded as less attractive or 'old-fashioned' by the universities and other institutions. However, a lack of trained scientists in these areas will create problems in the future. There was also a need for greater emphasis on bioinformatics and multi-disciplinary training. About one third of sample PIs reported some difficulty with staff recruitment, including difficulties finding a qualified individual, accepting someone with less experience than required, or that there were no suitable UK candidates for the position. Staff recruitment was a particular problem when a project required an RA to use multiple skills.
101. The lack of Committee input into the allocation of studentships was a weakness with the current system and was partially responsible for the failure to address the gaps in specific areas of the remit and in multi-disciplinary training. In addition, researchers at many institutions that receive substantial BBSRC funding are unable to bid for studentships, and this has resulted in missed opportunities for training and research.
102. The Panel noted the severe lack of trained plant breeders within the UK and agreed that this situation needs to be addressed urgently. The existing skill base is disappearing rapidly, at a time when agricultural challenges are increasing and the availability of plant breeders is of growing strategic importance. Although training new plant breeders is primarily the responsibility of the plant breeding industry, BBSRC supports research that underpins developments in plant breeding. The Panel welcomed the fact that, as part of its Crop Science Initiative, BBSRC is funding targeted priority studentships to develop a new cohort of crop researchers, trained in plant molecular biology as well as crop genetics and breeding, who will be able to bridge the gap between plant and crop science. The lack of plant breeders is a worldwide problem, and the UK needs to do more to ensure its own needs will be met in the future.
103. The Committee had acted professionally and fairly in its assessment of proposals and allocation of funding. However, there was some evidence that insufficient representation for specific areas of research on the Committee had influenced the portfolio coverage. For example, relatively few projects had been funded in the theme of 'Photosynthesis, respiration and partitioning of resources', despite a relatively large number of applications in this area. This may be related to insufficient expertise in plant physiology on the Committee. It was also apparent that the community had fixed perceptions about which aspects of the remit were most likely to receive funding, and that this has resulted in a low number of applications in some areas. BBSRC must ensure the whole scientific community is aware of the opportunities that are available from its Committees across its entire remit. In addition, the Panel urged all researchers working within the PMS Committee remit to submit applications in their areas of strength, to avoid such perceptions becoming a self-fulfilling prophecy.
104. The division between the PMS Committee and other BBSRC Research Committees, and in particular the AF Committee, was clear to the community. However, there were some areas that spanned Committee remits, with soil science a notable example, and

the Panel felt that this was not ideal. There are opportunities within the current BBSRC Committee restructuring exercise to provide greater integration of plant and microbial sciences funding. For example, providing greater coherence to funding opportunities in microbial science and removing potential issues where areas of plant science sit between the remit of the PMS and AF Committees. BBSRC must avoid any further dilution of the microbial science community during Committee restructuring.

105. The number of responsive mode applications to the PMS Committee has been declining over recent years. A higher proportion of PIs obtained subsequent funding from other BBSRC Committees than from the PMS Committee, suggesting that PMS-funded researchers are seeking support from other BBSRC Committees. This is the opposite of the observations from all other BBSRC Committee portfolio evaluations, where a higher proportion of PIs obtained further funding from the original funding Committee than from other BBSRC Committees.
106. As was the case in other portfolio evaluations, the role and importance of Priority Areas in the PMS Committee remit was unclear. There was evidence that the scientific community did not understand how Priority Areas were determined or how they affected funding decisions. The Panel therefore welcomed BBSRC's withdrawal of Committee Priority Areas as part of the Committee restructuring exercise. They will be replaced with a smaller, focussed list of Council-wide strategic priorities that cut across the whole BBSRC remit.
107. Over the evaluation period, the research funded by the PMS Committee has supported researchers working on a variety of organisms. There has been a focus of activity on a limited number of key species, including several model organisms. Given limited resources, this was appropriate. However, the focus of activity has had some unwelcome consequences. In particular, whilst the strong support the Committee provided to the *Arabidopsis* community has been very beneficial, it inevitably resulted in some important areas of crop science being overlooked. In recent years, BBSRC has made significant efforts to address this issue, which is welcome.

Multi-disciplinary research

108. Multi-disciplinary science involves research that crosses between traditionally separate disciplines, such as biology, chemistry, mathematics or physics. In an analysis of all seven BBSRC Research Committees, PMS was ranked fourth with twenty multi-disciplinary grants live on 1 April 2007 (8% of all multi-disciplinary grants). This analysis is based on the PI's or co-PI's department, and will be an underrepresentation of the true figure¹⁷. The majority of multi-disciplinary grants were with chemistry departments, although there were also collaborations with computing, engineering, mathematics, and physics departments. The Panel noted that more multi-disciplinary research would add further value to the portfolio.
109. Although more support was needed for multi-disciplinary research, the Panel noted that the PMS Committee supported a variety of projects where post-doctoral researchers received broad training across biological sub-disciplines. This was particularly the case for the work on plant-microbe interactions, which was a clear strength of the portfolio.

¹⁷ This metric is not an ideal way to capture multi-disciplinary research, but is a working definition that enables data to be fairly easily extracted from BBSRC grant database, and analysed.

Overlap with other funders

110. The PMS Committee is the primary source for funding molecular plant science within the UK, and is an essential source of funding for basic microbiological research. However, several other organisations fund research that potentially overlaps with the research funded by the PMS Committee, and these funders have made vital contributions to the success of plant and microbial sciences research in the UK. Defra, the Gatsby Foundation, NERC and the Scottish Government are key funders of UK plant and microbial science, and MRC and the Wellcome Trust are important funding agencies for microbiology. These funders were invited to comment on potential gaps and/or overlaps between their organisation and BBSRC's PMS Committee.
111. The strengths of other funders of research in the PMS Committee area were complementary to those of BBSRC. No significant areas of inappropriate overlap were identified between BBSRC and other funders, and where small overlaps existed the Panel felt that these were important to ensure that there were no gaps in funding. The research funded by PMS Committee through responsive mode grants supports the basic end of the research spectrum, which underpins the work of other funding bodies. This has been most widely realised through the provision of trained personnel and the dissemination of knowledge through high quality scientific publications. Other forms of knowledge exchange have been relatively limited to date.
112. The interfaces between BBSRC and other Research Councils were largely satisfactory. However, the fragmentation of microbiology funding across Research Councils was an issue for microbiologists. Panel members mirrored the concern of the PMS Committee that the MRC had reduced support for microbiology research, and this has limited the opportunities for microbiologists within the UK. The Panel noted that these issues were exacerbated by divisions within the microbial community itself, and in particular the failure of microbiologists to speak with a united voice.
113. NERC did not identify any gaps in cover, but noted that there was potential overlap between remits when research on plants or microbes is relevant to natural environments and ecosystems. However, the boundaries between the remits and responsibilities of both Councils were well defined and understood by the research community.
114. There were notable gaps in cover between BBSRC and some other funders, in particular between BBSRC and Defra. Whereas BBSRC research was at the basic end of the spectrum, Defra funding was heavily weighted towards strategic work, and there could be gaps in the 'research pipeline' between the organisations. Defra felt that there were several areas within the PMS Committee remit that needed more support: environmental and climate challenges (especially resource use efficiency in respect to nitrogen fertiliser, pesticides and water), crop science, root physiology, pesticide resistance, modelling of interactions between plants and other organisms, renewable materials, and remote sensing for crop management. In addition, Defra endorsed a shift from model organisms to crops, and felt there should be a greater emphasis on integration of aspects of the PMS remit.
115. It is important for BBSRC researchers to contribute to narrowing the gaps in the overall 'research pipeline' between Research Councils and other organisations that support more strategic research. There are several examples of good practice adopted by scientists in the UK, which are helping to address these issues. For example, the UK-Brassica research community and the MONOGRAM Network are addressing the ways to support end-user needs, for UK-grown brassicas and cereals, respectively. The Genomic Arabidopsis Resource Network (GARNet) has also enabled closer collaboration between the *Arabidopsis* community and scientists working with other

model species and crops. These networks could serve as good models for other research communities.

116. The gaps between the basic research supported by BBSRC and the end-user focus of other organisations are barriers to the potential benefits and impact of BBSRC-funded research being widely realised. Greater links between organisations are needed to bridge these gaps, which will require more linked strategic thinking between funding bodies.

Summary of gaps and weaknesses within the PMS Committee portfolio

117. Although the standard of research, research impact, and coverage within the PMS Committee portfolio was very good, there were several areas where the Panel identified gaps and weaknesses. The following text summarises the issues raised throughout the report. It should be noted that many of the issues cannot be addressed by BBSRC, but should be recognised by universities and other institutions.

Standard of research	<ul style="list-style-type: none"> • A small proportion of grants were less successful than expected • The primary causes of underperformance were experimental, technical and methodological reasons, or staffing difficulties
Tools and Resources	<ul style="list-style-type: none"> • There are insufficient tools and resources for microbiologists, especially for those working with non-model species
Intellectual Property	<ul style="list-style-type: none"> • Inappropriate pursuit of intellectual property rights could hinder research and innovation, rather than promote it
Training and skills development	<ul style="list-style-type: none"> • There were gaps in the training of researchers and PhD students, notably in disciplines which focus on 'larger-scale' biological research at the organ or organism level • There is a need for training in 'softer' transferable skills, such as project management and communications • Short term contracts of three years or less do not encourage staff retention, and the emerging practice of employing Research Assistants for less than the duration of the grant award is exacerbating this problem • The lack of Committee input into allocation of studentships had contributed to gaps in training in certain disciplines as well as multi-disciplinary research • There is no mechanism available to track the scientific careers of PhD students or post-doctoral researchers • There is insufficient emphasis on plant and microbial sciences within university and school curricula

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| Support for early-career researchers | <ul style="list-style-type: none"> • The PMS Committee had a lower success rate for New Investigator research grant applications than all other Research Committees • The three year funding provided by New Investigator grants is not sufficient to establish a sustainable research programme |
| Interaction with industry | <ul style="list-style-type: none"> • There was scope for greater interaction with industry within the portfolio • The interaction with industry had a relatively narrow focus, despite the potential of the research to make contributions to industry across a large number of areas |
| Knowledge exchange | <ul style="list-style-type: none"> • The level of knowledge transfer within the portfolio was limited • It is timely to increase the focus on transferring high-quality basic plant science research from <i>Arabidopsis</i> to crop species |
| Public engagement | <ul style="list-style-type: none"> • 20% of grantholders had not conducted any public engagement activity, despite this being a condition of grant funding • The requirement for grantholders to conduct public engagement activities cannot be fully effective if there is no sanction against PIs who fail to meet their obligations |
| Economic and social impacts | <ul style="list-style-type: none"> • There are opportunities for the strong base of basic research supported by the PMS Committee to deliver even greater impact to UK society • The delivery of impact within responsive mode research projects has involved relatively little planning or management • All researchers should seek to broaden the impact of their research or identify explicitly the potential benefits |
| Coverage of the portfolio | <ul style="list-style-type: none"> • The breadth of the PMS Committee remit inevitably meant that the portfolio could not cover all areas with sufficient depth • There are opportunities to increase support for strategic research within the responsive mode portfolio, building the high-quality basic research supported by the Committee • There was a perception within the research community that the Committee would only support basic research, and this had probably affected the number of applications submitted for strategic or applied research • Perceptions had developed within the research community about which areas of the remit were most likely to be funded, and this probably reduced application submissions in certain areas • In a few cases, insufficient representation for specific areas of research on the Committee had possibly influenced the portfolio coverage (e.g. photosynthesis) • There were gaps in cover between BBSRC and some other funders, in particular between BBSRC and Defra |

Final Reporting

- A final report submitted three months after a grant ends is not a particularly effective way to identify a grant's output and outcomes
- There was over-reporting of outputs, particularly publications, within final reports
- Final reports failed to set the work in a broader context, hence understating the degree to which the work was tackling fundamental problems or how it was addressing BBSRC strategic objectives
- The lay summaries of reports were often poorly written
- Final reports did not capture the extent to which the Committee supported high-risk, innovative research within the portfolio
- Final reports did not capture the contribution associated PhD student projects had made to the research, or the contribution research projects had made to student training

CHAPTER 5. RESEARCH HIGHLIGHTS

Research highlights from completed responsive mode grants

A complete genome sequence of Pseudomonas fluorescens

Pseudomonas fluorescens encompass a diverse group of bacteria found in a wide range of terrestrial and aquatic habitats. Members of the species are commonly found in association with plants and are capable of promoting plant growth. The project sequenced the genome of *Pseudomonas fluorescens* SBW25 and a megaplasmid originally isolated from this strain. The genome sequence is available online and complements the published sequence from another strain of the same bacterium. During the project, the researchers established a collaboration with scientists in the USA who were sequencing the PfO-1 strain of *P. fluorescens*. This enabled both research groups to maximise the data that could be obtained from comparison between the sequences, and also ensured sequence annotation was coherent between the two strains. The international collaboration subsequently developed to examine the induction of plant genes by *P. fluorescens*, adding value to the original project.

An analysis of chloroplast-nuclear signalling using aplastidic guard cells in Arabidopsis

Although the majority of proteins in a plant cell are encoded in the nucleus, in photosynthetic cells many nuclear-encoded proteins are targeted to photosynthetic plastids or chloroplasts. This New Investigator grant examined the intracellular signalling between the plastid and the nucleus by exploiting mutants that lack plastids in specific cell types, which suggested that plastids produce a signal that is able to pass between cells through plasmodesmata. The research resulted in a notable publication that has been well cited by other researchers.

Assembly of infectious bluetongue virion from cDNA clone

Bluetongue virus is a double stranded RNA virus and an important animal pathogen. It is one of the few viruses in which mutations are unable to be introduced by genetic techniques. The project aimed to develop a reverse genetics system for this virus (manipulating cDNA). Despite expressing all 10 of its genes in mammalian cells it was not possible to synchronise their assembly. Six peer-reviewed articles were published – two in the high-profile journal 'PNAS'. There was also a good amount of public engagement, nationally and internationally

Characterisation of a nitric oxide responsive transcription factor

Nitric oxide (NO) is a key molecule used as a defence against bacterial infection. It is sensed by the bacterial cell leading to a global stress response. Using parallel *in vivo* and *in vitro* approaches the activator of this response was shown to be generally inactive due to a C-terminal domain with a non-haem iron center which masks the ATPase catalytic center. NO binding induces a conformational change uncovering the catalytic site resulting in transcription activation of the network. This work resulted in several publications in good quality journals.

Control of fimbriation in E. coli in response to alanine, leucine, nitrogen and stress

Fimbriae are used by bacteria to adhere to one another and to animal cells. This research analyzed molecular mechanisms of the reversible ON/OFF switching in the production of type 1 fimbrial adhesin in the context of the protein-DNA and protein-protein interactions, which generate either stimulative or antagonistic effects. This research also tried to highlight the physiological significance of this genetic circuit by investigating the effects of the amino acid and nitrogen status on gene expression in *E. coli*. The work was published in good quality journals that included 'PNAS'. The unique regulatory system described by this research would serve also as a good model and tool in systems biology and synthetic biology.

Coupled translation termination and re-initiation of overlapping open reading frames

This research identified a novel translation process called coupled translation. It occurs when a ribosome finishes the translation of the first protein, moves back towards the 5' end of mRNA and then translates a second protein in a human respiratory virus. This process is common to all pneumoviruses. Surprisingly, this research showed that a *cis* element, which is 150 nucleotides away from the translation start site, controls this coupled translation process. The findings were very exciting, demonstrating that a simple system, such as a virus, embeds very sophisticated gene expression machinery.

Disarming the glucosinolate-myrosinase system in the cabbage aphid – consequences for tritrophic interactions

The cabbage aphid is a serious pest of brassica crops such as commonly grown cabbages and oilseed rape, and it spreads viral diseases to these crops. This research used a chemical approach to investigate methods of interfering with the aphid defence mechanisms. The work provided insights into interactions between plant, aphid and aphid predators such as ladybirds, and showed how the aphid's glucosinolate-based defence impacted on ladybird fecundity. The work also generated industrial interest.

Elucidating signalling pathways in plant K homeostasis on the basis of gene expression patterns

Potassium (K) is an essential macronutrient for plants, and its supply in the field impacts on crop yield and nutritional quality. This New Investigator grant aimed to develop an integrated view of plant potassium nutrition, and the research examined potassium signalling pathways by investigating gene expression by microarrays. The results showed that K-starved plants mount a constitutive defence response against herbivores. The findings were of international significance and had potential applications for plant breeders in disease resistance. The project also resulted in a large number of refereed papers.

*Excision and insertion of pathogenicity islands in *Pseudomonas savastanoi*: the *avrPphB* model*

Bacteria secrete effector proteins directly into plant cells, some of which are encoded by avirulence genes that can activate resistance responses in the plant. This work studied the evolution of virulence in a bean pathogen, in particular by examining a chromosomal region (pathogenicity island) containing an avirulence gene. The research provided a molecular explanation of how exposure to resistance mechanisms in plants drives the evolution of new virulent forms of pathogens. This was an exciting and focussed study, which resulted in a publication in the high impact journal 'Current Biology'.

*Expressed sequence tags for homologous recombination in the moss *Physcomitrella patens**

The project produced over 21,000 expressed sequence tags from the moss *Physcomitrella patens* (and nearly 1,700 from another moss, *Ceratodon purpureus*). There are few non-flowering plants with extensive sequence data, and therefore this project provided important materials for the study of the evolution of gene function in land plants. The project was very productive: there were several good publications, including one in 'Science'; extensive data-sets were deposited in public databases; fruitful links were developed with UK and international academic research groups; materials have been provided to industrial partners; further funding obtained from a charitable foundation; and there was active involvement in public engagement activities.

*Functional analysis of a novel disease resistance signalling gene, *EDS1*, in *Arabidopsis**

This research used genetic analysis to identify a central regulatory component of disease resistance to *Peronospora parasitica* in *Arabidopsis*. The *EDS1* gene was cloned and characterised, and this led to the cloning of a second gene involved in plant defence. The work is of international importance, and resulted in two papers in the high-ranking journal 'PNAS'. In addition, the research resulted in two patents, and increased links with industry, including an industrial CASE studentship.

*Functional analysis of transposon-tagged gametophytic fertility genes in *Arabidopsis**

Plant fertility and seed production are of vital importance both in the natural environment and for crop plants in agriculture. This research characterised the function of five genes important for pollen fertility, and identified biological roles in anchoring proteins to the pollen cell surface, modification of surface-associated polysaccharides, and pollen tube growth. The research was basic in nature but also had a strategic relevance, and resulted in papers in high-ranking journals.

Functional dissection of bacterial and chloroplast protein translocation mechanisms using GFP imaging

This research focused on the twin-arginine translocator protein transporter, responsible for exporting proteins out of the bacterial interior. The researchers developed and used a very effective non-invasive method using fluorescent reporter proteins to follow protein transport *in vivo*. This resulted in exciting details on the distribution of the transport apparatus on the bacterial cell membrane and showed a surprisingly high mobility of the separate parts of the translocation machine. The work resulted in a number of good publications and the resources generated in the grant are now used by many other researchers.

Identifying and characterising the function of novel guard cell signalling genes

Stomata are small pores, mainly at the base of plant leaves, which enable gas exchange. This research cloned three genes that are involved in the regulation of stomata opening by atmospheric relative humidity, and implicated abscisic acid in this regulation. The work resulted in a publication in the high impact journal 'Current Biology'. This was a side project for the group that carried out the work, but it opened up this important area of research to others.

Light regulation of glutamyl-tRNA reductase – the first committed step of chlorophyll synthesis

Chloroplast development requires the coordinated synthesis of the chlorophylls and chlorophyll-binding proteins that comprise the light harvesting complexes of the chloroplast. This research focussed on how light regulates the first committed step of chlorophyll synthesis through different photoreceptors, and identified a role for PhyA in plastid-nuclear signalling. This was a grant from an early-career researcher, and the research produced a series of well cited papers in good journals.

Light signalling and intercompartmental communication between chloroplasts and the nucleus

This research addressed the question of how porphyrin IX, which is involved in far-red (FR) light responses, is used as a signal for communication between plastids and the nucleus. For this the AtABC1 ATPase protein and gene was analyzed. It was shown that the protein functions as a homodimer and acts by interacting with other proteins. The results were published in high-ranking journals, including 'EMBO Journal' and 'PNAS'.

Mechanisms of ripening control through ethylene signalling and gene regulation

Ethylene is an important plant hormone involved in fruit ripening and as well as other biological processes such as senescence and the response to pathogens. This research aimed to improve the understanding of the perception, signalling and genetic responses to ethylene, using tomato as a model crop plant. The research used an integrated approach to elucidate a system with complex and unexpected regulation, and resulted in excellent science published in good journals. Furthermore the PI engaged extensively in communication with the media and the wider public on the sensitive issue of genetic modification, leaving very positive messages.

Microbial selenium cycling: characterisation of a novel membrane-bound selenate reductase

Selenate is a highly toxic industrial pollutant that can present a significant hazard to human health. One of the most successful ways to clean selenate contaminated areas is through bioremediation using microorganisms. This research used a combination of approaches to characterise a novel membrane bound selenate reductase from a bacterium present in selenium contaminated drainage water, and resulted in a large number of publications in high ranking journals. The work was followed up with further funding from the BBSRC Engineering and Biological Systems Committee.

Molecular basis of sporophytic self-incompatibility

Self-incompatibility is the most important mechanism that prevents fertilization in hermaphrodite flowering plants. This project identified a novel *Senecio squalidus* stigma-specific plant peroxidase (SSP). SSP was not the female determinant in self-incompatibility, but did point towards a role for reactive oxygen species in pollen-stigma interactions. The research provided new opportunities for plant breeders interested in plant reproduction, and resulted in a good number of publications. The Principal Investigator also received funding for a BBSRC Science Week Award to make the work accessible to the public.

Molecular identification of the genetic loci responsible for suppression of resistance in wheat

Yellow rust is a major fungal disease that affects wheat. Research from this Industrial Partnership Award generated wheat mutants with enhanced resistance to yellow rust, and developed additional tools for studying rust resistance in wheat. The work was strategic in nature, and the findings were published in 'Molecular Plant-Microbe Interactions', a journal that does not normally published applied research of this type. The project had a tangible impact, and resulted in further funding from the EU and an industrial CASE studentship.

Nitrate reduction to ammonia by fermentative bacteria: major new roles for the periplasmic nitrate and nitrite reductases

This project aimed to understand why enteric bacteria retain two biochemically and genetically independent pathways for nitrate reduction. The research combined expertise in the areas of microbial physiology, molecular genetics, biochemistry and electrochemistry, and was successful in meeting all of the initial objectives, as well as others. The research resulted in fourteen peer-reviewed papers, some in high-impact journals. The PIs were also actively involved in public awareness of science particularly through work with local schools.

Orchestrating cell cycle, cell growth and differentiation in Arabidopsis: the roles and targets of E2F transcription factors

The processes which a cell undergoes in order to divide are termed the cell cycle. This LINK project examined the role of the E2F genes in cell cycle control and how they integrate with the processes of proliferation, cell growth and differentiation. The research used a multi-tool approach to examine a complex set of interacting expression patterns among cell cycle regulators. The work was published in good quality journals, generated industrial interest and a good network of collaborators. There was also significant outreach activity from the group during the grant.

Protein targeting and mobility in the plant secretory system

The research aimed to tag and track proteins in the plant secretory system. This project was the first to target GFP to the Golgi apparatus, with the results suggesting targeting systems for Golgi are similar to mammalian systems. There were also unique studies on regulation of ER to Golgi transport in plants. The work was internationally very significant, and produced a high number of publications in good quality journals.

Regulation of a calcium channel in relation to polarised growth of root hairs

This project demonstrated the role of calcium channelling in root hair plasma membranes in regulating the calcium gradients causing polarised apical extension. During the course of the work it was discovered that root hair growth was associated with and required the production of reactive oxygen species. This finding led to work, not originally envisaged in the proposal, which characterised the interactions between the cellular production of reactive oxygen species and cell growth, as mediated via calcium channelling. This resulted in a highly cited paper in the journal 'Nature'.

Revealing structure/function relationships of a high affinity nitrate transporter, Nrt A, by site directed mutagenesis

The way in which a whole array of substances pass through the outer barrier of living cells is a major topic in biology and medicine. This research provided valuable insights into understanding the structure and function of the NrtA nitrate transporter, an important membrane protein that has been actively studied for 60 years. The researchers took advantage of comparative genomics to identify conserved amino acid residues. A combination of site-directed mutagenesis and biochemical analysis were then used to identify important residues for NrtA function. The research resulted in a number of publications in good journals, including the high impact journal 'PNAS'.

RNAi as a basis for defining both nematode and plant genes involved in compatibility and to provide novel control

Every year worldwide, nematodes are estimated to cause about £80 billion of damage to crops. This project identified genes that are activated in nematodes during initial infection of plants. RNA interference of the expression of some of these genes was associated with lower establishment of nematodes in plant roots, and also produced male-biased sex ratios compared with untreated nematodes. Plant genes activated after nematode infection were also identified. The work resulted in several good publications and intellectual property that may be used to develop commercial crops with increased resistance to attack by nematodes. There was also excellent public engagement, with the work being presented at several public events.

Role of reactive oxygen species in stress-induced signalling for APX2 gene expression in Arabidopsis
The *Arabidopsis* APX2 gene encodes an ascorbate peroxidase, a key component of cellular antioxidant defences. This research project identified hydrogen peroxide as the main reactive oxygen species for the induction of APX2 gene expression under light stress conditions. The results showed that this induction was restricted to bundle sheath cells in the leaf vasculature, and that there was a strong relationship to leaf water status. The results led to a drastic adjustment to the picture for light stress control through APX2.

Salicylic acid and hydrogen peroxide in abiotic stress acclimation in plants
Improved environmental adaption in crops would extend growing seasons and geographical limits, while reducing losses due to the increasing temperature variability caused by climate change. This research focussed on the role of salicylic acid and hydrogen peroxide in temperature stress acclimatisation in plants. Analysis of transgenic tobacco lines revealed salicylic acid to be a factor in signalling pathways between heat and disease responses, and new evidence was produced of hydrogen peroxide as a signal in heat tolerance. The research resulted in publications in good journals, as well as an industrial collaboration and further funding from the BBSRC Agri-Food Committee.

Sequencing the genome of Rhizobium leguminosarum
Rhizobia are important agricultural organisms, allowing many crops to be grown without nitrogenous fertiliser, an energy-expensive and potentially polluting agent. This aim of this research was to provide a fully annotated, publically available sequence of widely used strain of *Rhizobium leguminosarum*. The sequenced genome was found to comprise a circular chromosome of 5Mbp and six plasmids. The sequence data were made publicly available, although full annotation was completed after the end of the project. The grant also provided a focal point for several researchers, enabling networks to develop and spurring more wide-ranging collaborations in the UK *Rhizobium* community.

Sexual reproduction in Aspergillus and other Plectomycete fungi
The Aspergilli are a group of fungi which include a series of industrially, medically and agronomically important species. This research examined mating type genes involved in the sexual reproduction in the Aspergilli. The researchers also identified 'sex-related' genes in species that are supposedly 'asexual', a result that may have significance for disease control of pathogenic Aspergilli or for strain improvement for biotechnology and industry. The work resulted in a large number of publications in high impact journals that included 'Current Biology' and 'Nature'.

Shape and form in microbial cells: the structural basis for cell division in trypanosomes
Trypanosomes are small single celled parasitic protozoa, that can cause a variety of diseases, including the fatal sleeping sickness in humans. When a trypanosome divides, two daughter cells of a similar shape are produced upon division. This research discovered the structural information in the old cell is used to modulate the shape and form of the new cell, supported by the evidence from flagellum-cytoskeletal structure analysis. This research also presented genetic analysis on the FAZ gene, a strain-specific essential gene involved in flagellum production and cell division. The work was published in high ranking journals, including 'Science'. The group also actively brought the work to the public by presentations in several schools.

Signal transduction, microtubule dynamics and calcium signalling during vegetative hyphal fusion in Neurospora
Although much is known about fusion between non-identical cells (e.g. sperm and egg cells), little is known about 'self-fusion' between genetically identical cells. This research used the fungus *Neurospora crassa* as a model to improve our understanding cell fusion in animals, plants and microbes. The research resulted in a large number of papers in high-ranking journals. In addition, the research has potential to provide a mechanism to generate genetic variation in species (particularly plant pathogens) that do not undergo sexual reproduction in nature.

Studies into the role of aquaporins for regulating water supply to growing leaf cells and partitioning in mature tissues
This project investigated the molecular processes affecting water movement between xylem and expanding leaf cells. The research studied the biochemistry of barley leaf membrane proteins involved in water transport during leaf growth. This grant established the PI in an academic position in the UK, and helped them to build a productive research programme. The project led to further funding from BBSRC and the Leverhulme Trust, as well as five papers in refereed journals.

The function of histidine kinases during oxidative stress responses in Arabidopsis

This research focused on isolating *Arabidopsis* histidine kinases that may act as hydrogen peroxide sensors. The work identified ETR1, a central component in response to the plant hormone ethylene, as a potential target for hydrogen peroxide perception and signalling. The researchers also showed that ethylene induces the production of peroxide in guard cells during stomatal closure. The results strongly improved our knowledge on integration of signals during important conditional or developmental processes in plants.

The function of LuxS and its cognate autoinducer in bacterial central metabolism

This research brought new knowledge on the physiological roles of LuxS, an enzyme involved in the synthesis of the autoinducer AI-2 (a bacterial signalling molecule). The group developed a novel technique which can assess the levels of the intracellular metabolites. The technique is amenable to high throughput usage and is likely to be widely used. The projects research outputs were excellent, achieving good publications during the project period as well as later on. The group also brought the work to the public by taking part in a BBC radio programme.

The function of structural domains of pectic polysaccharides in growth and development

Pectin is a plant polysaccharide, familiar for its gelling properties in food preparations. This project studied the spatial arrangement of pectins in *Arabidopsis* cell walls and searched for genes and proteins involved pectin synthesis and assembly. The project resulted in a US patent for a monoclonal antibody specific for homogalacturonan and a large number of peer-reviewed papers. The work was followed up with further funding from the BBSRC Agri-Food Committee.

The programme underlying dormancy and autocrine resuscitation in Mycobacterium bovis BCG

Mycobacterium tuberculosis, the causative organism of tuberculosis (TB) is able to persist in a quiescent manner in the body, but under certain conditions becomes active and causes clinical TB. The research from this Industrial Partnership Award employed a safer model organism – the BCG vaccine strain – to investigate the proteins involved in the end of the period of dormancy. The research produced a large number of publications in high-ranking journals. In addition, materials generated by this group have had led to potential targets for novel vaccines against TB.

The role of soil physical conditions within the pathozone on fungal infection and biocontrol

The spatial and temporal dynamics of microbes in the complex and competitive soil environment dictate the outcome of many ecologically and economically important processes. This research aimed to interpret the effects of soil physical conditions on the dynamics of fungal infection. The findings linked epidemiological concepts of fungal dynamics to soil structure and soil physical properties, with the observations and resulting models published in high impact journals. The research influenced subsequent developments in biophysical soil science and the role of organisms in structure formation.

Trans-cellular Ca²⁺ transport and Ca²⁺ homeostasis in calcifying microalgae

This research focussed on coccolithophores, marine phytoplankton that form a calcium carbonate shell and can form massive blooms in oceanic water. The research identified a novel chloride current involved in regulating membrane potential in *Coccolithus pelagicus*. This research was published in high-ranking journals given its environmental niche. The importance of the work was also shared with a wider audience at several public engagement events.

Transcriptome analysis at the single cell level in embryonic cells of Arabidopsis

The development of the basic body plan of a plant occurs during embryogenesis, within the seed. This research used laser-capture microdissection, in combination with DNA microarray analysis to identify genes expressed in specific regions of the *Arabidopsis* embryo. The transcriptomic data generated in the project were of use to both the academic scientific community and industry. The research resulted in an industrial CASE award, a UK patent application, and contributed to the formation of a spin-out company, 'Creative Gene Technology Ltd.' that is developing strategic targets for the agrochemical and food industries.

Other notable grants

Biotrophy-related proteins specific to the intracellular hyphae of Colletotrichum lindemuthianum

Colletotrichum lindemuthianum is a plant pathogen that causes anthracnose of common bean plants. This research studied a major glycoprotein that is found at the interface between fungal infection structures and infected bean epidermal cells. The work resulted in several publications in high ranking journals.

Characterization of biofilm development in Rhodobacter sphaeroides

This research was based on the unique observation of significant morphological changes when the bacterium *Rhodobacter sphaeroides* forms a biofilm. Flagellum, chemotaxis and cell-cell communication have been shown to have a role in biofilm formation and structure. This project identified some novel genes specifically expressed within biofilms using recombinase-based *in vivo* expression technology.

Developing a functional flagellar toolkit by studying chimeric proteins

This project investigated how the microscopic parts of natural-rotary propeller engines from bacteria, called flagellar motors, interact to make them work. The research produced good publications in high-ranking journals. The researchers also made a concerted effort made to bring their work to a wider public audience.

Functional characterization of mutants of the PufX protein from Rhodobacter sphaeroides

Puf X is a protein responsible for the proper assembly of the reaction centre/light harvesting complex 1 photosystem in *Rhodobacter sphaeroides*. This research investigated the functional changes of the site-directed mutants of PufX, using a novel experimental system such as millisecond-timescale transient absorption spectroscopy and a TPP⁺ electrode to measure membrane potential.

Host plant selection by aphids

Aphids penetrate plant tissues with their mouthparts, locate the phloem elements and imbibe phloem sap. This research provided a fundamental insight that the reproductive decisions of aphids are made before feeding, without reference to chemical cues or nutritional factors associated with the phloem sap. The research also resulted in a large number of publications.

Insecticidal Photorhabdus toxins as alternatives to Bt

This New Investigator grant aimed to investigate the insecticidal activity of the Toxin complexes (Tc) from bacteria of *Photorhabdus luminescens*. The research enabled the functional expression of oral activity of Tc toxins by combining three genetic elements in *E. coli*. These toxins were shown to be capable of rearranging the actin cytoskeleton of both insect and mammalian cell lines. Outputs from this work included a US patent and a CASE partnership with Syngenta.

Mechanism of a nitric oxide sensor in Escherichia coli

Nitric oxide is produced at high concentrations by specialised human cells known as macrophages to poison engulfed bacteria or tumour cells. This research discovered that nitric oxide interacts directly with a bacterial regulatory protein to activate expression of genes required for nitric oxide detoxification. The findings from this project were published in a range of high impact journals, including Nature.

Molecular characterisation of the genes and enzymes of the gentisate pathway for aromatic catabolism

This research studied a pathway for the catabolism of naphthalene in *Ralstonia* bacteria at the biochemical and genetic levels. The work was published in good journals and has potential impacts on bioremediation.

Proteases as pathogenicity determinants of the cereal pathogen Stagonospora (Septoria) nodorum

Stagonospora nodorum is one of the world's major fungal diseases of wheat. The research from this Industrial Partnership Award examined the role of proteases in the infection process, and had industrial support until the company partner disbanded its fungicide development operation within the UK. The science produced was good quality and published in good journals.

The role of extracellular enzymes in xenobiotic metabolism and uptake in plants

This project investigated enzymes produced by plants around their cell walls that interact with the synthetic man-made chemicals, such as herbicides. The research demonstrated that a range of esterases are produced in several crop species, and also identified an esterase with a key role in detoxification. This was a LINK project and results were made available to the industrial partner to assist their crop protection chemical discovery programme.

Original peer-reviewed research articles published in prestigious journals

Journal Title	Completed	Current	Total
Highest impact multi-disciplinary journals			
Nature	3	1	4
Science	2	3	5
Total	5	4	9
Proportion of all original articles	1%	4%	2%

High impact prestigious or multi-disciplinary journals			
Chemical Biology	4	0	4
Current Biology	5	1	6
Development	0	1	1
EMBO Journal	3	1	4
Federation of American Societies for Experimental Biology Journal	1	0	1
Genes and Development	0	1	1
Genome Research	1	0	1
Genome Biology	1	0	1
Journal of American Chemical Society	1	1	2
Journal of Biological Chemistry	30	4	34
Molecular Biology of the Cell	1	0	1
Molecular Cell	1	0	1
Nanoletters	1	0	1
Nature Biotechnology	1	0	1
Nature Cell Biology	0	3	3
Nature Genetics	0	1	1
Nucleic Acids Research	2	1	3
PLOS Biology	0	1	1
PLOS ONE	0	1	1
Proceedings of the National Academy of Science of the United States of America	8	6	14
Total	60	22	82
Proportion of all original articles	14%	20%	16%

Prestigious journals in the field of plant and microbial sciences				
Plant Sciences	Journal of Chemical Ecology	1	0	1
	New Phytologist	11	3	14
	Plant Cell	12	12	24
	Plant Cell and Environment	4	1	5
	Plant Journal	32	7	39
	Plant Physiology	17	7	24
Plant-Microbe Interactions	Molecular Plant Pathology	4	0	4
	Molecular Plant-Microbe Interactions	7	2	9
	Plant Pathology	2	0	2
Agronomy	Theoretical and Applied Genetics	1	0	1
Soil Science	Soil Biology and Biochemistry	1	0	1
Microbiology	Applied and Environmental Microbiology	7	1	8
	Cellular Microbiology	1	2	3
	Environmental Microbiology	1	0	1
	FEMS Microbiology Ecology	1	0	1
	Journal of Bacteriology	17	9	26
	Microbiology	13	6	19
	Molecular Microbiology	17	2	19
Virology	Journal of Virology	7	0	7
Mycology	Fungal Genetics and Biology	4	4	8
Total		160	56	216
Proportion of all original articles		38%	51%	41%

Overall				
Total (All articles reported)		225 (416)	82 (110)	307 (526)
Proportion of all original articles		54%	75%	58%

APPENDIX 1**PANEL MEMBERSHIP**

Professor Peter Gregory (Chair)	Scottish Crop Research Institute
Dr Steve Barnes	SESVanderHave, Belgium
Dr Mick Chandler	Centre National de la Recherche Scientifique, Toulouse, France
Dr Jens Freitag	Genius GmbH, Germany
Professor André Goffeau	Université Catholique de Louvain, Belgium
Professor Sophien Kamoun	The Sainsbury Laboratory, University of East Anglia
Professor Peter Millard	Environmental Sciences, Macaulay Institute
Professor Fergal O’Gara	National University of Ireland, Cork
Professor Ian Poxton	Centre for Infectious Diseases, University of Edinburgh
Professor Christine Raines	Department of Biological Sciences, University of Essex
Dr Alan Raybould	Syngenta
Professor Nicola Spence	Plant Health Group, Central Science Laboratory
Dr Jane Taylor	Department of Biological Sciences, Lancaster University
Professor Peter Weisbeek	Department of Molecular Genetics, Utrecht University, Netherlands

Observer

Dr Sue Popple	Farming and Food Science, Defra
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ACKNOWLEDGEMENTS

The Panel would like to thank all of the respondents who gave their time to contribute to this evaluation. This includes Principal Investigators, Plant and Microbial Sciences Committee members and other funding organisations.

APPENDIX 2

TERMS OF REFERENCE

1. The task of the Review Panel is to carry out an independent scientific evaluation of the BBSRC Plant and Microbial Sciences (PMS) Committee responsive mode portfolio over the past 10 years. The Panel is asked to focus on the scientific aspects of the portfolio, including research outputs.
2. Specifically, the Panel is asked to review the information presented and to:
 - a. take an overview of the final reports and evidence from surveys to assess the quality and international standing of research funded through the PMS Committee
 - b. identify major highlights and, where possible, outcomes of the PMS Committee responsive mode portfolio over the past 10 years
 - c. in the context of research priorities in plant and microbial sciences research, and the availability of other support in the UK, assess the balance and coverage of the portfolio, identifying strengths and weaknesses
 - d. assess the economic and social impact of PMS-supported research including, where possible, contributions to the environment, human and animal health, relevant UK industrial sectors, and government policy
 - e. comment on the level of interaction between PMS-supported research and industry
 - f. comment on the level and quality of public engagement by PMS Committee grantholders
 - g. make recommendations to BBSRC on ways to build on successes and ways to address identified gaps and issues.

EVALUATION OF BBSRC'S PLANT AND MICROBIAL SCIENCES COMMITTEE RESPONSIVE MODE PORTFOLIO 2009

BBSRC RESPONSE TO THE PANEL'S REPORT

This document sets out BBSRC's response to the findings of the Review Panel convened to provide an independent scientific evaluation of the research supported in responsive mode through BBSRC's Plant and Microbial Sciences Committee since 1996.

BBSRC thanks the Panel members for their hard work and commitment to this exercise. We are pleased to note the Panel's views that the overall quality of research funded through the PMS Committee was very good, with many examples of internationally significant research. The remainder of this document sets out our response to the Panel's key conclusions.

KEY CONCLUSIONS

Research Quality

- *The PMS Committee has supported a broad range of excellent science across its remit*
- *The Committee has supported some outstanding scientists working in the fields of plant and microbial sciences*

BBSRC welcomes the Panel's assessment of the overall quality of the research in the PMS Committee portfolio, and in particular, the world-leading quality of plant and microbial sciences research within the UK. We note the observation that the highest quality research has arisen from individuals working in institutions with strong intellectual and capital infrastructure, and that these individuals have been able to develop exciting research programmes through competitive responsive mode grant applications. BBSRC will continue to support excellent and creative investigator-driven science through responsive mode; in 2007/2008 BBSRC invested £143 million in responsive mode funding, of which over £17 million was delivered through the PMS Committee.

- *The outputs that arose from the funded grants were very good and reflect the high standard of the research in the portfolio*
- *The research supported through the PMS Committee has played an important role in building strong research communities within the UK*
- *PMS Committee support has enabled researchers to access a wide range of other funds*

We welcome the Panel's views on the outputs and outcomes of the research supported by the PMS Committee and note the variety of measures of success which supported those views including peer-reviewed research articles, citations, further funding, training of researchers and their subsequent career-development, new collaborations in the UK and overseas, the development of intellectual property and the formation of start-up companies.

- *A small but significant number of grants were less successful than expected either failing to meet their original objectives or resulting in little or no tangible output*

We share the Panel's concern over the less successful grants. It should be noted that the evaluation covered a ten year period during which application success rates were higher compared with today. The relatively high success rate may have resulted in some less competitive grants being funded and is likely to have contributed to the proportion of underperforming grants. We are partly reassured, however, by the small number of grants in this category, and agree with the Panel's conclusions that limited success in meeting

objectives is sometimes the inevitable consequence of conducting innovative or high-risk science, and that it is important to continue to invest in such research.

Research Impacts

- *The research supported by the Committee has delivered economic and social impacts*

BBSRC recognises that basic research in the plant and microbial sciences underpins developments in many of our key strategic priorities, including bioenergy, food security, global security, living with environmental change, health and wellbeing, and animal health. We are pleased that the research supported through the PMS Committee has delivered important economic and social impacts in these areas, and that researchers recognise that their research can ultimately benefit agriculture, the environment, human health, or animal health and welfare.

We welcome the observation that the majority of grantholders was involved in public engagement activities; we share the Panel's view that these activities help to improve awareness and understanding of plant and microbial sciences, and illustrate how BBSRC science is addressing issues of public interest. BBSRC is committed to encouraging grantholders to engage with the public and requires that one to two days per year of the grant is spent on these activities. We provide a wide range of mechanisms to assist grantholders with this commitment, including funding schemes, web-based resources and communications training. We also participate in cross-Council schemes to which our grantholders can apply. See www.bbsrc.ac.uk/society for further details.

- *There are opportunities for the strong base of basic research supported by the PMS Committee to deliver even greater impact to UK society*
- *The effectiveness of identifying increased impact from research could be improved by incorporating coherent plans for knowledge exchange within grant applications at the outset*
- *There is a need to promote greater links to other stakeholders who benefit from plant and microbial sciences research*

BBSRC is committed to delivering and demonstrating increased economic and social impact from our research funding. From 2009, all applications will have to include statements about the impact of the research which will be assessed as part of the refereeing process. We are also introducing other measures to encourage a change of culture within the academic community including, for example, the impact incentive schemes 'Innovator of the Year' and 'Excellence with Impact Awards' (see www.bbsrc.ac.uk/business/impact_incentive). BBSRC recognises that the delivery of impact is dependent on supporting high quality research; scientific excellence remains the primary driver in the assessment of grant proposals.

One mechanism BBSRC is using to deliver increased impact from research is Research and Technology Clubs. These support high quality, innovative research in areas identified as strategically important by BBSRC and industry, and encourage closer links between academia and industry. They operate by establishing funding pots, supported jointly by BBSRC, other funding bodies and consortia of companies. Plant and microbial scientists are participating in the Integrated Biorefinery Technologies Initiative Research and Technology Club (IBTI Club). The IBTI Club supports research aimed at developing biological processes and feedstocks that will reduce our current dependence on fossil fuels as a source of chemicals, materials and fuel. In addition, BBSRC is currently talking with plant breeders and end users (bakers and millers) with a view to setting up a new Research and Technology Club for crop improvement. This funding stream will support innovative crop science research in areas such as quality, yield and disease resistance. See www.bbsrc.ac.uk/business/collaborative_research/industry_clubs for details.

Training and skills development

- *The training and skills development provided by PMS Committee grants was good, and this was reflected in the high quality scientific outputs arising from individual projects*
- *There are issues with the retention of trained individuals within the research environment*
- *BBSRC should encourage universities and other institutions to take a more professional approach to the training and skills development of postdoctoral researchers and PhD students*

We welcome the finding that PMS Committee grants have achieved a long-term investment in the skills and development of the researchers working on the projects, and BBSRC has introduced a new grant assessment criterion to emphasise this important role of responsive mode grants.

BBSRC has been working with Research Councils UK to address the issue of the career development of postdoctoral researchers. In 2008, Research Councils UK and Universities UK published their revised *Concordat to Support the Career Development of Researchers*. The Concordat sets out the responsibilities of researchers, their managers, employers and funders. It aims to increase the attractiveness and sustainability of research careers in the UK and to improve the quantity, quality and impact of research for the benefit of UK society and the economy. See www.researchconcordat.ac.uk for further details. The movement of postdoctoral researchers out of academia into commercial research careers and other employment sectors needs to be seen, however, as an important form of knowledge transfer. BBSRC works with the other Research Councils to fund the *Vitae* career development programme, which aims to help both PhD students and postdoctoral researchers to transfer their skills out of academia. See www.vitae.ac.uk for further details.

- *There is a severe lack of trained plant breeders in the UK*

BBSRC acknowledges that the lack of trained plant breeders in the UK is a concern which could significantly impact the UK's future food security. There are also related 'niche' areas of expertise (such as plant virology) which are becoming vulnerable in the UK, and which we will be seeking to investigate through a niche skills consultation in 2009. In parallel, we are already exploring the funding of a professional doctorate in agricultural science supported by a wider Advanced Training Partnership. Professional doctorates combine research and advanced tuition in areas of professional practice, and help bridge the gap between basic science research and its translation by ensuring that students develop research expertise in a context informed by end-user needs. We will therefore be seeking to work with university partners, commercial partners and levy bodies to create a new form of doctorate in agricultural practice – the 'AgD'. As part of developing Advanced Training Partnerships, BBSRC will also be seeking to strengthen knowledge transfer mechanisms between research-intensive universities and the teaching-intensive agricultural colleges. This is to ensure that this related lower-level skills provision is also informed by the needs of R&D in the sector.

- *There is insufficient emphasis on plant and microbial sciences within university and school curricula, and in particular, there is insufficient training for undergraduates in microbiology.*

BBSRC recognises that high-quality education in universities and schools is vital to the future success of UK science, and BBSRC-supported scientists participate in a number of schemes to help foster school-scientist links (see www.bbsrc.ac.uk/society/schools). We are also exploring possible mechanisms to influence the university and school curricula, working where appropriate with other partners. BBSRC will continue to raise issues related to

undergraduate education and training with universities, for example, through meetings we hold with university heads of department.

Balance and coverage of the portfolio

- *There is an opportunity to support more strategic and applied research through responsive mode funding*

In autumn 2008, BBSRC announced the restructuring of its Research Committees. An important driver for these changes was the need to deliver more multi-disciplinary and strategically focused science with greater impact within responsive mode. Under the new structure, a greater number of proposals for strategic and applied research are anticipated. The restructuring should also address the Panel's concerns over potential gaps in support where an area of science was seen to sit between the remits of two Committees (for example, PMS and Agri-Food). See www.bbsrc.ac.uk/funding/grants/roadshows for details.

- *There is scope to transfer the findings from basic research with model organisms to more applied or strategic systems*

BBSRC believes that it is important for researchers to ensure that their research findings are utilised and deliver broader benefits to the public good, and we recognise the need for research with model plants to be translated into crops. However, this will be most effective if it is informed by first identifying and understanding the challenges facing crops; crop science is an important BBSRC strategic priority.

- *There are insufficient tools and resources for microbiologists, especially for those working with non-model species*

BBSRC believes that the provision of tools and resources for microbiologists has improved since the evaluation period, and should improve further under the new Committee structure. The Committee restructuring brought together areas of microbiology that were previously split between the PMS and Agri-Food Committee remits, and this should enable a more coherent overview of support for tools and resources support to be developed. It should also be noted that researchers are able to apply to BBSRC's Tools and Resources Development Fund which supports small or short-duration pump priming, technology or method-driven research projects (see www.bbsrc.ac.uk/funding/opportunities).

- *BBSRC must ensure that there is adequate support for genomic activities within the plant and microbial sciences*

In April, BBSRC announced that the establishment of a new national centre to analyse plant, animal and microbial genomes. The Genome Analysis Centre (TGAC) will be based on the Norwich Research Park and will provide genome sequencing to underpin advances to improve food security, to protect UK agriculture from exotic animal disease and exploit weaknesses in microbes to develop new ways to kill superbugs. It will also be a centre of excellence in bioinformatics to ensure that the data generated by its genome analysis, and that of other facilities, can be effectively collected and analysed.

TGAC will be a BBSRC national centre in partnership with the East of England Development Agency, Norfolk County Council, South Norfolk Council, Norwich City Council, and the Greater Norwich Development Partnership. BBSRC is providing the majority of the £13.5 million investment in the Centre. See www.tgac.bbsrc.ac.uk for details.

Evaluation of the Bioprocessing Research Industry Club

September 2009

This document presents the views and conclusions of a Review Panel of experts.

The views expressed are those of the members of the Panel.

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ABBREVIATIONS

BBSRC:	Biotechnology and Biological Sciences Research Council
BIG-T:	Bioscience Innovation and Growth Team
BIS:	Department for Business, Innovation and Skills
BRIC:	Bioprocessing Research Industry Club
CASE:	Collaborative Awards in Science and Engineering
DRINC:	Diet and Health Research Industry Club
DSP:	Downstream processing
EBS:	Engineering and Biological Systems Committee
EPSRC:	Engineering and Physical Sciences Research Council
HEFCE:	Higher Education Funding Council for England
IM:	Introducing Member
IP:	Intellectual property
KE:	Knowledge exchange
QR:	Quality-related
RA:	Research Assistant
RAE:	Research Assessment Exercise
REF:	Research Excellence Framework
SG:	Steering Group
SMEs:	Small and Medium-sized Enterprises
TPS:	Targeted Priority Studentships
USP:	Upstream processing

EXECUTIVE SUMMARY

This document reports the findings of the independent Review Panel set up to provide an expert evaluation of BBSRC's Bioprocessing Research Industry Club (BRIC). The objectives of the evaluation were to assess the quality and strategic relevance of BRIC research; to examine the extent to which BRIC is building capacity in UK bioprocessing; to assess the effectiveness of BRIC in promoting interactions between academia and industry; and to identify ways to build on successes and to address identified gaps and issues. As BRIC research projects are still ongoing, the Panel was asked to review the current achievements of BRIC and to consider the potential for future impact as the research develops.

KEY CONCLUSIONS

1. BRIC is an effective and timely scheme that is achieving its objectives and is on track to deliver future impact

In the three years since its inception, BRIC has made very good progress towards achieving its objectives. BRIC is supporting high-quality, industrially-relevant research in a strategically important area, and this research has the potential to deliver significant impact. BRIC has already produced a number of promising achievements: strengthening the UK bioprocessing research community; encouraging new academics to conduct bioprocessing research; providing relevant training to postdoctoral researchers; and developing networks and partnership links between academia and industry. BRIC management and administration are effective and the scheme has developed over time to ensure it is addressing the needs of the bioprocessing community. Overall, BRIC is a very successful scheme which has reenergised the UK bioprocessing community.

2. BRIC is supporting high-quality research which is of broad relevance to the UK bioprocessing industry

The overall standard of research funded through BRIC is very high. BRIC is supporting international-quality science and is contributing to the emergence of centres of excellence in UK bioprocessing research. BRIC research is addressing key bioprocessing challenges and is of broad strategic relevance to the UK bioprocessing industry. Research projects are almost all on track to meet their stated objectives and are likely to deliver long-term economic and social impacts, for example, through the improved manufacture of biopharmaceuticals and regenerative medicine therapies.

3. BRIC grantholders are developing intellectual property and it is important that this is protected

BRIC research projects are producing knowledge and other outputs that are potentially commercially exploitable. It is important that this intellectual property (IP) is protected and there must be more explicit consideration of IP protection within BRIC. The Steering Group should continue to emphasise the importance of IP protection to researchers, and grantholders should provide more details of their plans for IP protection within annual reports. BRIC should also provide Research Assistants (RAs) with IP awareness training. Although there is pressure for researchers to produce outputs such as publications, this must not compromise the protection of their IP.

4. Training of postdoctoral researchers within BRIC is good, although there is scope to improve training in transferable skills

There is a marked need to provide bioprocessing skills training, as demonstrated by the observation that the majority of BRIC RAs had no previous bioprocessing experience. BRIC is starting to meet this need, delivering good quality training to postdoctoral researchers, particularly in practical and technical skills. However, there is scope to improve transferable skills training and RAs would benefit from some standard industry training including, for example, project management training. Existing training modules for BBSRC Enterprise Fellows and at Doctoral Training Centres could be modified to provide this.

5. BRIC should encourage Research Assistants to spend time in industry as part of their training

BRIC has made good progress in promoting direct interactions between RAs and industry. However, it is disappointing that so far only a small proportion of RAs have spent time in an industry environment. Industry placements should form part of BRIC's training strategy and, ideally, these should be long-term placements (e.g. minimum six months) occurring at an early stage of each project. There is also significant value in RAs participating in shorter placements and site visits, and these should be encouraged. It was a concern that fewer than a third of BRIC RAs were considering industry as their next employment destination and greater exposure to industry should help to improve this.

6. The lack of postgraduate training opportunities within BRIC is a weakness and could have a negative impact on building capacity in UK bioprocessing

In order to build capacity and critical mass in UK bioprocessing, there is a need to support training at several levels, including PhD studentships. Although bioprocessing is a priority area for BBSRC's PhD funding, postgraduate training is formally outside BRIC's remit and this is potentially a serious weakness with the scheme. As a key BRIC objective is to develop core bioprocessing skills and expertise, Research Councils should consider funding studentships that are aligned to individual BRIC grants. The Diet and Health Research Industry Club, which aims to develop research skills for the UK's food sector, funds Targeted Priority Studentships that are directly associated with grants, and a similar model would be suitable for BRIC.

7. BRIC has strengthened the UK bioprocessing community and is successfully promoting partnership links between academia and industry

BRIC research funding and other BRIC activities have strengthened the UK bioprocessing community. A prior lack of Research Council support for bioprocessing research led to a 'missing generation' of UK researchers with bioprocessing experience and BRIC has made noteworthy progress towards rectifying this, with new academics and postdoctoral researchers entering the community as a result of BRIC. BRIC has also successfully promoted networks and partnership links between grantholders and industry members, aided in part by the Knowledge Transfer Network 'bioProcessUK'. The development of partnership links was most difficult for research groups with few or no previous links to industry, and BRIC should provide more support to these groups at the earliest possible stage. Knowledge exchange between BRIC members is good given the relatively early stage of the research projects. As projects develop BRIC should seek to deliver a greater level of knowledge exchange.

8. The research projects provide good coverage of most of the BRIC remit, although there are gaps in a few specific areas

Over the three rounds of funding, the balance and coverage of the BRIC research portfolio was good. The funded research projects cover the majority of the BRIC remit, although there is a lack of coverage in some areas, particularly whole process modelling. Any future BRIC scheme should pursue areas that have not received funding and, if necessary, conduct specific activities to encourage or commission high-quality cross-disciplinary proposals.

9. BRIC dissemination events are a highlight of the scheme and are highly regarded by grantholders and industry members

BRIC organises regular meetings where project results are shared with grantholders and BRIC industry members. These dissemination events are highly regarded by all participants, and provide excellent opportunities for networking and knowledge exchange. The events are very successful and are evolving as the scheme develops and matures. There is a slight concern that dissemination events may be perceived as exclusive by other members of the research community, and there is scope for BRIC to organise additional open events to showcase its achievements to a broader audience.

10. The Research and Technology Club model is an effective way to support industrially-relevant research

BRIC was the first of the Research and Technology Clubs to be launched by BBSRC, and its success demonstrates the effectiveness of this funding model. It is unlikely that similar progress to that achieved by BRIC could have been realised through responsive mode. BRIC is supporting a coordinated programme of research which is addressing key bioprocessing challenges, aided by industry input in setting the research agenda. Additional BRIC activities including dissemination events, workshops, networking, and contact with the BRIC Programme Manager and bioProcessUK are adding value to research grants and, as a result, BRIC is substantially more than a portfolio of 25 individual research projects.

11. Research Councils should continue to support bioprocessing research of this kind through a BRIC successor scheme to ensure that progress is not lost and the potential for impact is maximised

The community supported by BRIC is currently vibrant but there is a high risk that without further ring-fenced funding for bioprocessing research the community will dissipate and opportunities for impact may be lost. Research Councils should build on the success of BRIC by funding a successor scheme, both to ensure continuity through follow-on funding and to broaden the bioprocessing community. Many academics working in related fields could contribute to BRIC and they should be encouraged to participate; BRIC should approach other professional bodies to help identify and attract these scientists. Greater involvement from small and medium-sized enterprises (SMEs) would also be beneficial, especially in the field of regenerative medicine. Research Councils should also ensure that funding opportunities are available for early-career researchers conducting bioprocessing research to establish their own research groups and obtain permanent academic positions.

12. Research Councils should publicise the success of BRIC to a wide audience

BRIC enables companies to gain exposure to a large amount of science for a relatively small investment, and is an excellent example of how academia and industry can work more closely together for mutual benefit. The accomplishments of BRIC should be publicised to government, relevant industry and other academics. In particular, the Department for Business, Innovation and Skills should be made aware of the success of the Research and Technology Clubs in delivering the Research Councils' 'Excellence with Impact' agenda.

CHAPTER 1: BACKGROUND

Introduction

118. The Biotechnology and Biological Sciences Research Council is one of seven Research Councils sponsored through the Department for Business, Innovation and Skills (BIS) of the UK government. Its principal aim is to foster a world-class biological science community in the UK. The mission of the BBSRC is to fund internationally competitive research, to provide training in the biosciences, to encourage opportunities for knowledge transfer and economic impact, and to engage the public and other stakeholders in dialogue on issues of scientific interest.

Evaluation context

119. Evaluation is of growing importance to BBSRC and, with its emphasis on evidence based decision making, to the UK government. Evaluation plays a central role in:

- enabling BBSRC to account to government, the public, the scientific community and other stakeholders for the funds it allocates
- demonstrating achievements
- justifying BBSRC's funding allocation and providing evidence to BIS, the Treasury, and government of achievements and successes from public investment in bioscience research
- informing internal funding decisions, providing evidence of progress and achievement, and facilitating the development of a strategic overview for future funding decisions
- helping BBSRC to improve its policy and practice, through informing policy decisions and the design of new schemes, programmes and processes; and through identifying good practice, lessons learned, and ways to improve processes.

120. Formal evaluation of research is currently conducted at a number of levels in BBSRC:

- | | |
|--------------|--|
| Project: | • Evaluation of final reports from grants |
| Scheme: | • Evaluation of Research Committee responsive mode portfolios |
| | • Evaluation of Research Initiatives (time-limited research funding in strategically significant areas), 2-3 years after the grants have ended |
| | • Evaluation of funding schemes (e.g. New Investigator, international Partnering Awards, fellowship schemes, Research and Technology Clubs) |
| Institution: | • Institute Assessment Exercise, conducted every five years at the BBSRC-sponsored Research Institutes |

121. BBSRC's Evaluation Strategy¹⁸ outlines the Council's approach to evaluation and the methodology used. Along with reviews of the responsive mode portfolio and research initiatives, funding schemes such as the Bioprocessing Research Industry Club (BRIC) form an important part of BBSRC's evaluation programme.

122. The objectives of the BRIC evaluation were to:

- assess the quality and international standing of the research funded through BRIC
- comment on the extent to which BRIC is supporting research relevant to the UK bioprocessing industry

¹⁸ http://www.bbsrc.ac.uk/organisation/policies/reviews/funded_science/bbsrc_evaluation_strategy.pdf

- comment on the extent to which BRIC is building capacity in UK bioprocessing
- assess the effectiveness of BRIC in promoting interactions between academia and industry
- assess the balance and coverage of the BRIC portfolio
- comment on the BRIC application, assessment and administration procedures
- comment on the potential long-term economic and social impacts of BRIC research
- identify ways to build on successes and address any gaps and issues

123. The evaluation was conducted by an independent Review Panel comprising scientists and other experts who between them have expertise relevant to the BRIC remit (see Appendix 1 for Panel membership). The Review Panel was asked to provide an independent scientific evaluation of the evidence drawn from:

- questionnaires returned by 14 out of 19 Principal Investigators (PIs) on BRIC grants funded in the first or second BRIC calls (74% response rate)
- questionnaires returned by nine out of nine PIs awarded funding in the third BRIC call (100% response rate)
- questionnaires returned by 14 out of 21 postdoctoral Research Assistants (RAs) employed on BRIC grants (67% response rate)
- questionnaire responses or telephone interviews of 17 out of 61 unfunded applicants (28% response rate)
- questionnaires returned by 8 out of 16 workshop delegates who attended a BRIC launch workshop, but who did not subsequently make an application as a PI (50% response rate)
- questionnaires returned by 8 out of 15 BRIC Steering Group members (53% response rate)
- questionnaires returned by 19 out of 19 BRIC industry members (100% response rate)
- collated data from 16 grantholder annual reports¹⁹
- additional information obtained from BBSRC databases

124. The remainder of this report presents the findings of the Review Panel, in five broad areas:

- a) standard of research
- b) building capacity in UK bioprocessing research
- c) developing partnership links between academia and industry
- d) balance and coverage of the portfolio
- e) application and administration processes

¹⁹ All BRIC grantholders submit annual reports at the same time each year (during the summer). However, as the start date of each BRIC project varies, the length of time covered by individual reports is not identical.

CHAPTER 2: STANDARD OF RESEARCH

Summary

- The quality of research within the BRIC portfolio is very high
- The strategic relevance of BRIC research projects is very clear
- BRIC is facilitating the emergence of centres of excellence in UK bioprocessing
- BRIC research projects are developing new intellectual property which must be more explicitly protected
- BRIC research is likely to deliver future impacts which will benefit the UK bioprocessing industry

Overview

125. The Bioprocessing Research Industry Club (BRIC) was established in 2005 as part of the Research Councils' response to recommendations contained in the Bioscience Innovation and Growth Team (BIG-T) report: *Bioscience 2015*²⁰. It is the first of several Research and Technology Clubs²¹ established by BBSRC to invest funds in industrially-relevant bioscience research. Since 2006, BRIC has funded 25 research projects through three annual funding calls, and the overall quality and strategic relevance of the supported research is very good. BRIC research projects are on track to produce a variety of outputs that will benefit the UK bioprocessing industry and are likely to deliver important long-term economic and social impacts.

Research quality

126. The overall quality of the research funded by BRIC is very good. BRIC is supporting international quality research projects which are making significant advances in the field of bioprocessing. Some projects in the BRIC portfolio are already very successful and are delivering research at the top end of the international scale.

The crystallisation of biopharmaceuticals is poorly understood and is a rarely used commercial process for the primary separation and purification of proteins. Researchers at Imperial College London are investigating novel solid templates for protein crystallisation and have developed a circulatory system that maximises the yield of crystals obtained. This exciting research shows signs of being an advance over static crystallisation systems; it offers promise not only for the optimisation of crystal growth in bioprocessing, but also for structural studies.

Scientists at the University of Birmingham are conducting excellent research into novel manufacturing and bioseparation technologies for biopharmaceuticals, and are generating world-leading 'multifunctional' chromatography technology. The next-generation materials that are being developed by the BRIC project have the potential to improve downstream processing and greatly advance the separation of contaminants that are very similar to the desired product.

Viruses dominate the types of vectors currently being tested in clinical gene therapy trials and of these, retro- and lentiviruses are the most numerous. Scientists at the University of Cambridge and King's College London are collaborating to develop a novel lentiviral packing cell line, in which manufacturability is built into the genome of the cell line and co-expressed

²⁰ www.bioindustry.org/bigtreport/

²¹ www.bbsrc.ac.uk/business/collaborative_research/industry_clubs/

on the surface of the viruses produced thereafter. The researchers are making excellent progress, and there is significant potential for patents and high-quality publications.

127. Almost all BRIC projects are making good progress and are on track to meet their stated objectives; 82% of project milestones²² are either complete or on track. There was some slippage in progress towards meeting long-term objectives, partly because grantholders had difficulty in estimating the timing of their third year deliverables at the project's outset. To an extent this is to be expected, as scientific investigation is inherently unpredictable.
128. So far, the most successful BRIC projects are those that have a focused set of objectives or strong links to industry partners. In general, research groups with pre-existing links to industry partners are making very good progress. Moreover, researchers who are new to the bioprocessing field are establishing links with industry through their participation in BRIC (see Chapter 3, p. 16). It is likely that over time these links will have a positive impact on their projects.

Scientists at the University of Birmingham have partnered with industrial collaborators to deliver important research relating to optimising the production of 'difficult' proteins. The primary objective of the project is to develop improved generic production methods and define physiological, biochemical and genetic factors that limit or enhance recombinant protein production. The project's milestones have been reached significantly ahead of schedule, and this is attributable to the close interactions between the academic and industrial groups.

129. There is evidence of centres of excellence being established in UK bioprocessing research, particularly in London universities. BRIC support has made an important contribution to the emergence of these centres of excellence, and this reflects the high standard of research in the BRIC portfolio.

Strategic relevance and potential for future impact

130. The strategic relevance of BRIC research projects is very clear. BRIC grantholders are conducting research which is addressing key challenges in bioprocessing and which is directly relevant to the UK bioprocessing industry. An important aspect of the Research and Technology Club model is that industry helps define the research agenda, and this has ensured the industrial relevance of the funded projects. The feedback provided to researchers during the application process has also helped to improve the strategic relevance of BRIC research.
131. A principal objective of BRIC is to support research that will deliver benefits to the UK bioprocessing industry. The expected outcomes of BRIC research are:
- a greater systems-based understanding of biology for improved bioprocessing
 - increased predictability of biological processes for bioprocessing, including improved scale-up and reproducibility
 - improved cost efficiency – both in manufacturing and development
 - increased flexibility to improve product characteristics and reduce product heterogeneity
 - increased speed to clinic and market
 - tools and methodologies for bioprocessing which may have potential for application in related fields
132. The evidence from annual reports and stakeholder surveys indicates that BRIC is highly likely to deliver these outcomes. In the long-term, BRIC research has the

²² Gantt charts in annual reports are used to monitor the progress of BRIC projects

potential to produce substantial economic and social benefits to the UK, for example, by contributing to the improved manufacture of biopharmaceuticals and regenerative medicine therapies.

Researchers at the University of Strathclyde are developing methods of protein purification which aim to provide faster throughput and lower costs. They have shown that co-crystallisation can be used to remove proteins from complex fermentation mixtures, allowing separation from undesirable contaminants. The protein crystals can then be removed for further processing. The findings offer potential for significant improvements in industrial protein recovery technology.

133. In general, BRIC research which is addressing downstream processing (DSP) is more likely to deliver an immediate impact than research focusing on upstream processing (USP). The DSP projects are more directly aligned to challenges facing industry and therefore have greater potential for short-term impact. The USP projects tend to focus on more basic biological processes and are developing the bioscience understanding which underpins bioprocessing. There are more opportunities for the USP projects to go 'off course' and they could be considered as higher risk. The impact of USP projects may not be fully realised for many years but, over the long-term, the research has the potential to deliver great benefits and possibly even step-changes in bioprocessing. It is positive that BRIC has funded a broad portfolio of work that is likely to deliver both short and long-term impacts.
134. Some USP projects are using proteins that are not representative of those used in industry and this could limit the long-term impact of the work. BRIC researchers need greater access to industrially-relevant proteins, but this requires more openness from industry.

Research outputs

135. As BRIC projects develop, they are expected to deliver a variety of outputs including: publications; new products, processes, resources, tools and technologies; intellectual property; further funding to develop the research; and training for postdoctoral Research Assistants. The data for the evaluation were collected in December 2008, when the majority of grants from the first BRIC call had been running for less than two years; the annual reports reviewed by the Panel were submitted in July 2008. The following comments are therefore based on researchers' progress towards delivering the anticipated outputs.

Publications

136. To date, about half of BRIC projects funded in the first call had resulted in an original research article being published. Researchers who had previous experience conducting bioprocessing research were more likely to have published their work at this stage; this is as expected because they were building on pre-existing research and they had a greater critical mass of bioprocessing experience in their research groups.
137. BRIC grantholders are publishing in journals that are appropriate for bioprocessing research. It is unlikely that BRIC research will be published in high-impact multi-disciplinary journals such as 'Nature' or 'Science'; this is a consequence of the field of research and is not a reflection of the quality of BRIC science, which is of an international standard. It is also important to recognise that the outputs of basic and strategic / applied research are different, and publications are not necessarily the main output of BRIC grants.

138. It is a concern that universities often evaluate research performance primarily on the basis of published outputs and associated journal impact factors. This has been driven to a large extent by the Research Assessment Exercise (RAE) and its subsequent allocation of HEFCE 'QR' funding. The RAE places a strong emphasis on the publication of research in high-impact journals as a measure of scientific excellence, and does not readily reward researchers for other equally valid outputs and impacts of their work. Under the new Research Excellence Framework (REF) greater emphasis will be accorded to other outputs. This is welcome and should benefit academics who are conducting strategic research or working closely with industry.

New products, processes, resources, tools and technologies

139. 93% of grantholders reported that their grant had led or could lead to the development of new products, processes, resources, tools, and technologies; this is a good and anticipated outcome of BRIC. The outputs varied depending on the nature of the grant, but included cell lines, equipment, methods, new materials and software. The users identified were primarily the bioprocessing industry, but also included other academic researchers. The outputs will be made accessible to others through various means, including patents and intellectual property rights, licensing to industry, a commercial service, publication in peer-reviewed journals and material transfer agreements.
140. So far, the majority of new products, processes, resources, tools and technologies reported by grantholders are conceptual in nature. This is to be expected at this stage: progress is encouraging and the development of these types of outputs is notably higher than reported for responsive mode research in the former Engineering and Biological Systems (EBS) Committee and other former BBSRC Committees²³. However, there was a slight concern that the nature of BRIC's remit may create additional pressure to report these types of output and some anticipated outputs may be unrealistic.

Intellectual property

141. BRIC research projects are generating knowledge which is contributing to the development of new intellectual property (IP), and the majority of grantholders stated that the new products, processes, resources, tools and technologies arising from their grant had the potential to be commercially exploitable. 93% of grantholders indicated that they are likely to apply, or had applied, to secure IP rights. This is very encouraging, and is substantially higher than reported by researchers with responsive mode grants from the former EBS Committee or other former BBSRC Committees²⁴.

Researchers at University College London are developing new microfluidic tools to rapidly analyse protein stability and integrity in bioprocesses. This is important research as current methods are slow and require too much of an exceedingly valuable biopharmaceutical to be useful in guiding bioprocess development or control. The BRIC project has highly focused objectives and this has contributed to the excellent progress that has been made. Two patent applications for analytical devices have already arisen from the research.

142. It is essential that the intellectual property developed by BRIC grantholders is protected. There must be more explicit consideration of IP protection within BRIC to ensure that the UK benefits from its investment and that companies based outside the

²³ 71% of grantholders in the EBS Committee responsive mode portfolio evaluation reported that their grant had or could result in new products, processes, resources, tools or technologies; across all former Research Committees, the figure was 47%.

²⁴ 42% of grantholders in the EBS Committee responsive mode portfolio evaluation reported that they had applied or were likely to apply to secure IP rights as a result of their grant; across all former Research Committees, the figure was 17%.

UK do not exploit the published data from BRIC projects. The Steering Group (SG) should continue to monitor progress towards IP protection and ensure grantholders' positive intentions are followed through; although the conversion of research into published outputs is usually good, the conversion into IP is often patchy. In particular, in their annual reports, researchers should provide a greater narrative on their plans for, and progress towards, IP protection.

143. BRIC has not established a rigid mechanism to deal with the IP arising from grants. However, IP is being actively managed and BRIC is likely to develop its own procedures as the need arises. There are opportunities within BRIC for industry members to learn about potential IP, including dissemination events, the BRIC web-portal, and previews of publications. The SG's encouragement of grantholders to protect IP is very welcome although, as with most Research Council grants, the responsibility for IP protection ultimately resides with individual institutions. The emphasis placed on IP protection can vary substantially between institutions and their associated Technology Transfer Offices, and BRIC and the Research Councils should work with institutions to facilitate IP protection where appropriate.
144. A potential weakness within BRIC is a lack of IP awareness amongst Research Assistants (RAs). BRIC should provide RAs with IP awareness training to ensure that they adopt best practice, for example, ensuring lab books are counter-signed and presentations at conferences do not disclose information prematurely.
145. There is understandable pressure for researchers to produce outputs such as publications. However, this must not compromise IP protection. The terms and conditions of BRIC grants require grantholders to provide industry members with a 28 day period to review publications before they are submitted. This is very welcome, as it provides an opportunity for industry to identify potentially valuable IP.
146. Two BRIC grantholders reported that the research from their grant is likely to contribute to the formation of a start-up company. This demonstrates another mechanism by which BRIC research can be commercialised and deliver impact and is very positive. However, the number of start-up companies should not be used alone as a measure of BRIC's success; the primary route for delivering impact is likely to be through knowledge transfer to existing UK industry.

Further funding

147. It is currently too early for BRIC grantholders to have applied for and secured further funding to develop the research from their grant. However, 25% of grantholders from the first BRIC call have received some associated funding. This was primarily for CASE studentships²⁵ running alongside the BRIC grant.

Researchers at the University of Sheffield are developing a systems-level understanding of how mammalian cells both influence and adapt to their environment, which will underpin further developments in bioprocessing. The researchers have a good record of other successful project applications that are associated with the BRIC-funded work, and they have received major financial contributions from industry, including a number of CASE studentships. These related grants and industrial collaborations are directly benefiting from the technical expertise and research outcomes derived from the BRIC project.

²⁵ Collaborative Awards in Science and Engineering (CASE) allow students to receive high quality research training in collaboration with an industrial partner. Students spend a period of between 6 and 18 months working with the company, and the company makes a financial contribution to the costs of the project and the training of the student.

Researchers at the University of Manchester are using a metabolomics approach to investigate cell-environment interactions in recombinant mammalian cell lines producing antibodies. They have close links with several BRIC industry members and have been awarded CASE studentships from two individual companies since their grant began.

Training

148. An anticipated output of BRIC is an increase in the number of personnel trained in bioprocessing research. This is discussed in detail in Chapter 3 (p. 16).

Issues affecting grant progress

149. BRIC projects have experienced several issues which could affect performance and result in slower progress towards meeting objectives. These include issues with staff retention, technical challenges, and over-ambitious project objectives. In the majority of cases, grantholders dealt with these problems effectively, ensuring that the overall impact on the project was limited.
150. About one third of grantholders stated that an RA left the project during the course of the grant, so they had to re-recruit. Such issues with staff retention often resulted in spend on the project being frozen for a substantial period of time and slowed progress. Research Councils should monitor why RAs are leaving the grants and determine whether this was primarily due to dissatisfaction with their employment, personal circumstance, or recruitment into better jobs, including those in industry.
151. A small number of grantholders were forced to make changes to their project because of technical challenges. This is inherent in the nature of scientific investigation and should be viewed sympathetically. However, based on the interim assessment of the information available, the Panel considered that in one or two cases these changes may have lessened the potential impact of the research; for example, where an industrially-relevant protein was replaced with a model protein that has less strategic relevance.
152. For a few grants, progress was affected because the original objectives were too broad or over-ambitious. It would have been more productive if these grants had focused on a more limited set of objectives, and it should be possible for the SG to provide feedback to researchers at the outline application stage to address this. It was noted that the application process has evolved over time, and in later calls more effort was made to ensure that feedback from the SG was acted on by applicants.

Less successful grants

153. The general standard of research funded through BRIC is very high and almost all projects are making good progress. However, based on the interim assessment of the annual reports, the Panel was concerned that the performance of two or three grants appeared less successful than expected. It should be noted that all projects were still active at the time of the evaluation and a final assessment of performance should be reserved until after they are complete. It is encouraging that there are opportunities within BRIC to identify and address issues affecting project performance while the research is still ongoing, for example, through annual reports, dissemination meetings, and interactions with the Programme Manager.

CHAPTER 3: BUILDING CAPACITY IN UK BIOPROCESSING RESEARCH

Summary

- BRIC is building capacity in UK bioprocessing research and has brought new academics and postdoctoral researchers into the bioprocessing community
- The training of postdoctoral researchers within BRIC is good, although there is scope to improve transferable skills training
- Postdoctoral researchers should be encouraged to spend time in an industrial environment as part of their training
- There is a gap in provision of postgraduate training within BRIC
- The training provided through BRIC will have a positive impact on the recruitment of skilled engineers and scientists within the bioprocessing sector

Overview

154. Prior to BRIC, Research Councils' support for bioprocessing research was relatively limited, and this resulted in a weakened bioprocessing community. BRIC is helping to rectify this, and has made noteworthy progress in reenergising the bioprocessing community. New academics have entered the bioprocessing field as a result of BRIC, and BRIC is providing essential bioprocessing training to postdoctoral researchers. In general, postdoctoral training is good, although there are several areas where there is some scope for improvement, most notably through the provision of industry placements. In addition, postgraduate training is formally outside BRIC's remit, and this is potentially a serious weakness of the scheme.

New academics conducting bioprocessing research

155. A skilled bioprocessing research base is vitally important for both UK industry and academia. However, a prior falling away of Research Council support for bioprocessing weakened this research base and resulted in a 'missing generation' of UK researchers with bioprocessing experience. Academics in the bioprocessing field found it very challenging to win funding for their research, and many moved abroad. It is currently very difficult to recruit senior bioprocessing research scientists.
156. BRIC is making noteworthy progress towards rebuilding capacity in the UK bioprocessing research community. BRIC has attracted and funded applications from researchers without previous bioprocessing experience; 43% of funded BRIC applications were from academics who had not previously received funding to conduct bioprocessing research. In addition, 71% of RAs employed on BRIC grants had not previously been involved with bioprocessing. The engagement of researchers without long-term exposure to bioprocessing was very good, particularly for postdoctoral researchers, and demonstrates the success of BRIC in broadening the appeal of bioprocessing research.
157. There was a perception among some of the wider research community that BRIC had not really helped to broaden the bioprocessing research community and that only established bioprocessing researchers had received BRIC funding. The Panel did not

share this view. The first BRIC round had supported a number of established researchers, possibly because they were more experienced at writing high-quality bioprocessing research proposals. However, in subsequent rounds a substantial number of researchers new to the field were supported.

Training and skills development

158. An essential BRIC objective is to build capacity in the UK bioprocessing research base through the provision of relevant training to postdoctoral RAs. There is a marked need to provide this training, given that the majority of BRIC RAs had no previous bioprocessing experience and the difficulties with recruitment experienced by BRIC grantholders and industry members.
159. BRIC is delivering good quality bioprocessing training to postdoctoral RAs, particularly for practical and technical skills. However, there is scope to improve transferable skills training and RAs would benefit from some of the standard training that is available in industry, including training in project management, communication skills, design of experiments, six sigma, lean sigma, statistics, and quality by design. Existing training modules could be modified to provide this training, for example, those for BBSRC Enterprise Fellows or at Doctoral Training Centres.
160. BRIC should seek to deliver the highest quality training in bioprocessing to RAs and this cannot be achieved if their training is based only in universities. There is a need to involve industry in RAs' training, although this will require a willingness from industry to participate. It was especially disappointing that so far only a very small proportion of RAs have spent any time in an industrial environment.
161. Industry placements should form part of BRIC's training strategy. Ideally, these should be long-term placements of at least six months, to enable RAs to conduct research which is related to the BRIC project. The placements should occur at an early stage of the BRIC project, so that the skills learned can be transferred back to academia and benefit the future development of the research. It was noted that PhD students who have participated in industry placements tended to be more project and goal oriented when they returned to the academic environment. Industry placements could also enable RAs to gain practical experience that cannot be achieved in university laboratories, such as process scale experience. In addition, there is significant value in RAs participating in shorter placements and site visits, and these should be encouraged.
162. Although the lack of industry placements is a current weakness with the scheme, it is encouraging that RAs have received a wider exposure to industry through BRIC. All RAs reported direct interactions with industry. These were varied, and included technical advice, exchange of experimental materials, participation in workshops, visits to industry facilities, and informal conversations and discussions. However, fewer than a third of RAs reported that they were considering a career in industry as their next employment destination. This is a concern, as one expected impact of BRIC was the provision of trained individuals to the bioprocessing industry, but greater exposure to industry should help to improve this.
163. The bioprocessing training provided to BRIC RAs is very valuable. However, BRIC has only supported 25 research projects, which represents a relatively small amount of training. This is unlikely to meet the overall demand for trained individuals in academia and industry, and there is a clear need for Research Councils to provide additional, long-term support for training in this area.

Postgraduate training opportunities within BRIC

164. In order to build capacity and critical mass in UK bioprocessing, there is a need to support training at several levels, including PhD studentships. Although bioprocessing is a priority area for BBSRC's PhD funding, postgraduate training is formally outside BRIC's remit and this is potentially a serious weakness with the scheme. This was recognised by researchers, industry members, and the SG alike. There is a risk that BRIC is expanding the bioprocessing research sector without also increasing the number of postgraduate training opportunities.
165. BBSRC funds Targeted Priority Studentships (TPS) in bioprocessing and is currently supporting 23 PhD students. This is very welcome. However, because TPS in bioprocessing are allocated as groups of studentships via Doctoral Training Grants, they are focused in a small number of institutions and are not building capacity more widely.
166. Moreover, current BBSRC provision for postgraduate training in bioprocessing is not sufficient to meet the needs of academia and industry. The limited number of funding opportunities for PhD studentships in bioprocessing in the past has contributed to a lack of postdoctoral researchers with bioprocessing experience, and has probably resulted in a steep learning curve for many BRIC RAs. Increased support for studentships will increase the supply of experienced RAs, and should help to address the issues of staff recruitment and retention for bioprocessing research grants.
167. A key objective of studentship training in bioprocessing is to develop core skills and expertise applicable to industry. This could be best achieved by enabling students to work alongside exciting, varied and well-funded research projects. As such, Research Councils should consider funding studentships directly aligned to research grants within BRIC. The Diet and Health Research Industry Club, which aims to develop research skills for the UK's food industry, funds TPS that are associated with grants, and a similar model would be suitable for BRIC. The Panel shares the view of Research Councils that the primary focus of PhD studentships must be the training opportunities provided to the student, but aligning studentships to grants need not be incompatible with this goal.
168. Although BRIC cannot fund PhD studentships directly, many CASE studentships are aligned with BRIC grants. Grantholders were very positive about the benefits the associated studentships provide, both to the student and the research grant. For example, related PhD projects led to the exchange of ideas and techniques, helped foster closer links with industry partners, and contributed to the critical mass around a project.
169. There is also a need for Masters training in bioprocessing. The Panel noted the 2009 competition for BBSRC Masters Training Grants and was encouraged that 'strategically important training for industry' was a priority area in this competition.

Career development opportunities for early-career researchers

170. A vibrant UK bioprocessing industry cannot be sustained without a healthy academic research community and it is very important that the next generation of research leaders is supported. Research Councils should ensure that there are follow-on funding opportunities available to enable the highest calibre early-career scientists to establish their own bioprocessing research groups. They must also ensure there is a long-term

commitment to support bioprocessing research as otherwise researchers will be discouraged from pursuing academic careers in this field.

171. BBSRC provides funding opportunities for early-career scientists to establish independent research careers through the David Phillips Fellowship scheme²⁶. The competition for these awards is fierce, and the assessment criteria are perceived to have a strong academic focus that favours basic research. Successful candidates tend to have published in high-impact journals such as 'Nature' or 'Science'; this may disadvantage scientists who conduct strategic or applied research, as they are unlikely to publish in these journals despite the high quality of their science. Research Councils should ensure that Fellowship schemes for early-career scientists are supporting all types of excellent research – basic, strategic and applied. In particular, BBSRC must continue to ensure that industry is represented on the Training and Awards Committee.
172. Industry is another anticipated key employment destination for BRIC RAs. Industry currently experiences problems with recruitment because the number of skilled individuals within the UK is not sufficient to meet demand. BRIC industry members were positive about the about the future impact of BRIC on recruitment, and it was clear that industry is looking towards BRIC as a potential recruitment forum, both for their own company and the sector as a whole.

²⁶ www.bbsrc.ac.uk/funding/fellowships/david_phillips.html

CHAPTER 4: DEVELOPING PARTNERSHIP LINKS BETWEEN ACADEMIA AND INDUSTRY

Summary

- BRIC is an effective vehicle for promoting academia-industry and academia-academia partnership links
- BRIC is supporting knowledge exchange between its members and, as projects mature, more should be expected in this area
- Dissemination events, where researchers share their work with other BRIC members, are a highlight of the scheme
- Similar progress in networking and promoting partnerships would not have been achieved through responsive mode

Overview

173. In addition to supporting high-quality, industrially-relevant research, BRIC conducts a number of wider activities which are having a very positive influence on the development of the UK bioprocessing community. Participation in BRIC has enabled researchers to develop improved academia-industry and academia-academia partnership links, and these links have benefited their research programmes. BRIC has fostered the development of networks, aided by the Knowledge Transfer Network 'bioProcessUK'. In addition, academia and industry have been involved in knowledge exchange within BRIC, particularly through BRIC dissemination events. These are important achievements, and it is unlikely that similar progress could have been realised through responsive mode funding.

Academia-industry partnership links

174. BRIC is an effective vehicle for enabling academic researchers to engage with industry. All researchers funded through the first call have established new or improved academia-industry partnership links as a result of their grant, and 75% reported links to an industry member who was previously unknown to them. So far, fewer researchers funded in the second call have established academia-industry partnerships, but this is to be expected as it takes time for partnerships to develop. The establishment of new links is attributable to participation within BRIC; 90% of researchers who developed new or improved partnership links with industry stated that they would not have met one or more of their contacts without BRIC.

175. Grantholders reported a variety of new and improved academia-industry partnership links that have developed as a result of BRIC. These included CASE studentships, consultancy, exchange of materials, informal discussions, formal research collaborations and research contracts. In general, more researchers have established partnership links with large companies than with SMEs, and most grantholders have contacts with multiple industry partners. The lack of exclusivity in partnership links is positive and demonstrates that individual BRIC research projects are of broad interest to many bioprocessing companies.

176. Some grantholders already had well-established links with specific industry partners at the outset of the BRIC project from their previous research, whereas others, who were

often new to the field, had no prior contacts within the bioprocessing industry. Research groups with pre-existing links to industry were making the best progress in developing academia-industry partnership links. It was more difficult for researchers new to the bioprocessing field to establish such links, and it was taking them longer to do so.

177. Although groups without previous experience in the bioprocessing field have found it more difficult to finalise partnership links, they are open to developing such links and are keen to do so. Groups who are new to the field are likely to benefit to the greatest extent from developing partnership links, but they may need additional support or follow-up. BRIC should therefore focus its support on these researchers, and this support should be provided at the earliest possible stage. It was good that every grantholder who had not previously received funding for bioprocessing research has established new partnership links with industry, although so far many of these links are still at the discussion stage. It should be noted that without BRIC, it would have been very difficult for some of these researchers to form links with industry.
178. The Panel was encouraged by the feedback from the Programme Manager that the development of academia-industry partnership links is improving over time, and that partnerships can now form quicker than at BRIC's launch. For example, researchers funded in the first round are acting as 'role models' whose interactions with industry are observed by other researchers at dissemination events.
179. Although industry involvement in BRIC is an essential aspect of the scheme, this is not in itself sufficient. It is vital that industry involves enthusiastic representatives, who can devote sufficient time to develop links with BRIC researchers. It was pleasing that industry reported providing 400 person hours per annum to support visits to BRIC academics, and a further 200 person hours per annum to host visits by BRIC researchers.

Academia-academia partnership links

180. Innovative research in bioprocessing is likely to require substantial multi-disciplinary working. Consequently, one aim of BRIC is to encourage new academia-academia linkages, bringing together skills from different scientists and institutions.
181. BRIC is successfully promoting partnership links between academic members. 71% of researchers funded in the first or second BRIC calls have established new or improved academia-academia partnership links with other BRIC researchers. Some genuinely new partnerships have been formed as a result of BRIC, and 36% of researchers reported links to an academic who was previously unknown to them. The establishment of new links could be attributed to participation in BRIC; 70% of grantholders who developed new or improved academic links would not have met one or more of their contacts without BRIC.
182. 48% of BRIC research grants are multi-institutional (i.e. they either involve a co-investigator at a different institution to the PI or are classified as a joint grant²⁷). This is very positive, and is similar to the proportion of multi-institutional responsive mode grants funded through the former EBS Committee.
183. There was evidence that a number of smaller networks and sub-groups are developing within BRIC. For example, researchers working on animal cell expression had

²⁷ A joint grant is where two or more grants are awarded to different institutions for the same research project

established a forum to discuss their research. These smaller networks involved other members of the BRIC research groups, including PhD students.

Industry-industry partnership links

184. The opportunities for industry-industry networking within BRIC have enabled industry members to develop an increased awareness of one another, which is another positive outcome of the scheme. However, no applications involving two or more companies were submitted to BRIC, and no formal industry-industry collaborations have been formed. This is not surprising as encouraging industry-industry interactions is difficult; the commercial environment is competitive and an individual company's participation in BRIC will focus on their own interests.

Developing partnerships with non-BRIC members

185. Non-BRIC academics have also developed partnership links through BRIC, for example, at launch workshops or during the application process. This is an area where it is more difficult for BRIC to have an impact. However, 29% and 33%, respectively, of unfunded applicants and workshop delegates reported that they have established new or improved industry links as a result of their involvement in BRIC; 29% and 56%, respectively, of unfunded applicants and workshop delegates developed new or improved academic partnership links.

Knowledge exchange

186. An important objective of BRIC is to promote knowledge and skills transfer between the science and engineering base and industry. In the short term, BRIC aims to encourage the exchange of materials, expertise and ideas between its members. In the longer term, knowledge exchange (KE) is important to ensure that the full impacts of BRIC research are realised and research outputs are used by industry.
187. The current level of KE between BRIC members is good. 64% of BRIC grantholders have received material contributions from other BRIC members (academia or industry). These include systems knowledge, experimental samples or vehicles, experimental or analytical techniques, literature material and contacts with third parties. 47% of industry members have either made or received material contributions. However, a competitive commercial environment means that companies can be guarded about providing materials to academics and it has taken time for BRIC industry members to become forthcoming. The provision of relevant materials from industry is very important, as academics need access to the relevant genes, proteins and cell lines to ensure their research delivers the maximum possible impact.
188. In general, the majority of grantholders' annual reports describe plans for KE rather than specific examples of where it has taken place, which is reasonable given the relatively early stage of most research projects. Grantholders reported a variety of plans for the dissemination of the results and outputs of their projects, depending on whether there would be IP that required protection and taking into account the required dissemination within BRIC which is a grant condition. For example, grantholders' plans for dissemination included: BBSRC 'Follow-on Fund'²⁸, bioProcessUK meetings, BRIC

²⁸ BBSRC commits £2.1 million a year to the Follow-on Fund programme, a funding stream that supports 'proof-of-concept' work at the very early stage of turning research outputs into a commercial proposition. Typically grants are for £80K - £150K over twelve months.

dissemination events, commercialisation, formal publication, formal research collaborations, learned societies, national and international conferences, protecting IP rights, visits or talks to industry. As BRIC matures, there will be a need to improve the level of KE, and the SG should monitor progress in this area.

189. There are no formal relationships between BRIC academics and specific companies to exploit the research. This is appropriate, as the conditions of BRIC research grants state that the research must be available to all BRIC members. Some BRIC projects are an extension of previous research, for example, a CASE studentship sponsored by a specific company. Although this can result in a strong and focused project, such cases must be managed carefully to ensure that close links to an individual company do not cause concern to other BRIC members.

BRIC dissemination events

190. BRIC organises bi-annual meetings where project results are shared with other grantholders and BRIC industry members. These dissemination events are very successful and have evolved over time to meet the needs of the community. They are highly regarded by all participants and should be recognised as a major highlight of the scheme.
191. Dissemination events are a good vehicle for encouraging KE between academia and industry. They provide excellent opportunities for BRIC researchers to interact directly with industry and to develop one-to-one collaborations. The events provide companies with access to a wide variety of research and act as a 'shop window' for BRIC science. In addition, dissemination events allow industry to speak to academics about the specific research challenges in their company. This information is very valuable: it helps researchers learn about the research problems the bioprocessing industry needs to solve, and enables them to align their own research programmes accordingly. Further openness from industry within BRIC would be welcome, but it should be recognised that industry is usually very guarded about these issues and even limited KE of this nature is a notable achievement.
192. Only BRIC grantholders, research assistants and industry members are invited to attend dissemination events. This is appropriate, as BRIC industry members are paying for privileged access to the research and early sight of emerging IP through membership fees. However, closed events may reinforce a perception that BRIC is exclusive and not open to other members of the community, and there is scope for BRIC to organise additional open events to showcase its achievements to a wider audience. It is good that PhD students working alongside BRIC research projects have attended the most recent meetings.

CHAPTER 5: BALANCE AND COVERAGE OF THE PORTFOLIO

Summary

- The BRIC remit is appropriate and covers the major areas of UK bioprocessing activity
- The BRIC portfolio is balanced and provides good coverage of most of the BRIC remit
- The main gap in coverage is in whole process modelling
- BRIC is supporting an appropriate balance of conservative and higher-risk projects

Overview

193. BRIC is supporting a well coordinated programme of industrially-relevant research projects. The BRIC research agenda is focused on addressing generic bioprocessing issues, which ensures that individual projects are of interest to the whole bioprocessing industry, and the remit covers the major areas of UK bioprocessing activity. Over the course of the scheme, the SG has adjusted the calls for funding, with the result that the overall balance and coverage of the BRIC portfolio is good and all critical areas have been supported.

BRIC scientific remit

194. BRIC supports research in two priority research areas, within which there are a number of specific research challenges:
- Bioscience underpinning bioprocessing
 - Understanding, controlling and manipulating metabolism in microbial fermentation
 - Understanding, controlling and manipulating metabolism in mammalian cell culture
 - Growth of stem and tissue cells in vitro
 - Improved understanding of the properties of proteins
 - Improved tools for bioprocessing
 - High throughput process technologies
 - Effective modelling of whole bioprocesses
 - Analytical methods for bioprocessing
 - Improved downstream processing
 - Advances in downstream processing including formulation
195. This scientific remit is appropriate and covers the major areas of UK activity in biomedical bioprocessing. Some areas of translational medicine may overlap with the remit of the Medical Research Council, but the bioprocessing aspects are all within BBSRC's or EPSRC's remits. It is encouraging that emerging areas such as regenerative medicine are included as the central bioprocessing issue is the same as for more traditional technologies: how to make a large amount of pure product cost-effectively?
196. The BRIC research agenda is focused on addressing generic bioprocessing issues, rather than the development of individual products. This is welcome, as the results from BRIC research will benefit the whole bioprocessing industry. It is also consistent with

the Research and Technology Club model, where the results from BRIC research must be made available to all participating companies.

Balance and coverage

197. The balance and coverage of the BRIC portfolio is good, and all the critical areas of the remit have been supported. While the funded projects from the first call largely focused on the manipulation of mammalian cell expression, the SG adjusted the subsequent calls to focus on specific themes not covered in previous rounds.
198. There are some gaps in coverage within the BRIC remit. The most notable was whole process modelling, although there are other areas where more support would be welcome, such as understanding the properties of proteins. A lack of applications contributed to this, exacerbated by very few UK academics working in particular areas of the remit. Any future BRIC scheme should pursue areas that have not received funding and, if necessary, conduct specific activities to encourage or commission high-quality cross-disciplinary proposals. There are UK researchers whose work could contribute to addressing these challenges, and they should be made aware of the opportunities available to them through BRIC.
199. Research Councils and BRIC must use their limited resources in the most effective way to deliver the maximum impact. There are a few examples in the BRIC portfolio where there is overlap between funded projects, which is not ideal and could result in the duplication of effort. BRIC has also invested a substantial amount of resource into projects in the theme of understanding, controlling and manipulating microbial fermentation. This is a relatively advanced area of research, where many tools and resources are already available. Although BRIC should be funding research in this area, some of the resource invested might have been used more effectively supporting other areas of the remit.
200. Some members of the research community were concerned that the BRIC portfolio was too conservative, and did not reflect the adventurous nature of the remit. The Panel felt that the balance of conservative and higher-risk projects within the BRIC portfolio was appropriate and was consistent with responsive mode, where the majority of applications tend to build on pre-existing research. The first round of BRIC projects was relatively conservative, but in subsequent rounds the funding was more adventurous. The Programme Manager also noted that BRIC received very few unconventional, high-risk applications.
201. Research in some areas of the BRIC remit, such as regenerative medicine, is relatively expensive, and there was a risk that this might have discouraged the SG from supporting proposals in these areas. It was pleasing that this was not the case: scientific excellence and strategic relevance were the primary application assessment criteria, and the relative costs of specific research areas were not considered as part of the assessment process.
202. A very positive impact of BRIC is that it has broadened the scope of bioprocessing research in the UK. In particular, BRIC has supported researchers from other disciplines whose work can impact on bioprocessing challenges. BRIC must continue to do so in future, and must avoid the risk of developing an inward-looking, narrow definition of bioprocessing. For example, there are many academics who are conducting research which is not formally considered to be bioprocessing, but who are nevertheless seeking to develop products that will eventually need to undergo large-scale manufacture (e.g. gene therapy). BRIC could be a useful forum to help these

researchers identify what would constitute a bioprocess for their product, and how bioprocess issues could influence the development of their own research programmes.

CHAPTER 6: APPLICATION AND ADMINISTRATION PROCEDURES

Summary

- BRIC has attracted a good number of high-quality applications
- The application processes were fair and appropriate, but some aspects should be made more explicit to the research community
- The outline application process was popular with researchers, and provided opportunities to improve the application and increase the strategic relevance of proposals
- BRIC management is effective, and researchers' interactions with the BRIC Programme Manager and bioProcessUK have been beneficial
- Similar progress to that achieved by BRIC could not have been realised through responsive mode funding

Overview

203. BRIC was the first of several Research and Technology Clubs to be supported by BBSRC, and it introduced several modifications to the peer-review mechanism used in responsive mode. The application and assessment procedures were appropriate, and industry involvement and feedback from the SG during the application process helped to improve the strategic relevance of proposals and the funded research. The wider activities supported by BRIC have added value to research projects, and it is unlikely that a similar programme of coordinated research projects could have been supported through responsive mode funding. The success of BRIC illustrates the effectiveness of the Research and Technology Club model for supporting industrially-relevant research.

BRIC applications

204. BRIC has received a good number of applications for each of its three funding calls. In total, 125 outline applications were received and, of these, 56 were invited to make full applications and 25 awards were made. The success rate for outline applications was 20%; for full applications it was 45%. The number of applications rose between the first and second call, and then remained constant for the third call.
205. The quality of applications was generally high. For example, 59% of full applications were rated as being fundable and 44% were rated as 'being at the forefront of UK activity and internationally competitive in a significant proportion of the research proposed'. There were several high-quality applications that could not be funded because of limited resources, particularly in the third call.

Application and assessment processes

206. BRIC uses a two-stage application process. Researchers submit a brief outline proposal which is assessed by the SG. Authors of the most promising outline proposals are then invited to submit full applications which are externally peer-reviewed prior to final assessment by the SG. As with other Research Council grant proposals, applicants have the opportunity to respond to the reviewers' comments. Applications

are primarily assessed against two criteria: scientific excellence and strategic relevance.

207. The research community had mixed views about BRIC's application and assessment procedures. The use of outline applications was predominantly regarded as beneficial. However, there were concerns about the transparency of the assessment processes, the involvement of industry in the assessment of proposals, and the provision of feedback. The Panel felt the application and assessment processes were fair and appropriate, and industry involvement was important to ensure the strategic relevance of BRIC research. The majority of negative comments appeared to be related to researchers' unfamiliarity with the BRIC application process; similar feedback has been received regarding other schemes that modify the usual responsive mode peer-review mechanism.
208. Outline applications were popular with the majority of researchers: they take less time to prepare, they prevent researchers from writing uncompetitive full proposals, and they reduce the burden on peer-reviewers and the SG. They also provide a useful opportunity for the SG to provide feedback to researchers, and this helps to improve the quality and strategic relevance of full proposals. However, when some researchers incorporated the SG's suggested changes into their application, particularly the references to industrial relevance, these were subsequently criticised by peer-reviewers. This is unfortunate and efforts should be made to ensure peer-reviewers are fully briefed on the importance of industrial relevance to the BRIC research agenda. In addition, funded researchers were often disappointed that the outline process did not help to identify new academic or industrial collaborators.
209. Some members of the research community expressed concerns about the transparency of BRIC's application and assessment processes. This was surprising as details of these processes are readily available on the BBSRC website. There were, however, several areas where researchers' comments suggested that BRIC's application and assessment procedures were not well understood, and it may be helpful to make these more explicit, particularly:
- Weighting of assessment criteria: the criteria of scientific excellence and strategic relevance are given equal weight in the assessment of proposals, and applications must pass on both criteria to be considered fundable
 - SG Introducing Members (IMs): for the final assessment by the SG, each full proposal has two IMs. One IM is from academia and the other is from industry
 - SG conflicts of interest: the procedure for dealing with conflicts of interest (e.g. where an industry member has pre-existing links to an applicant) is the same as for BBSRC Research Committees. Conflicted individuals leave the room while the proposal is being discussed
210. Many unfunded applicants were not satisfied with the feedback they received on their application, noting that feedback was too slow or too generic. This is not unique to BRIC, and similar comments have been received for other Research Council funding programmes. The comments are understandable and Research Councils should endeavour to provide prompt and specific feedback to applicants. The BRIC Programme Manager helps to provide more explicit feedback to applicants than would be received in responsive mode.

BRIC management

211. Since its inception, BRIC has adapted to take account of emerging issues and to ensure that the scheme is addressing the needs of its community. The Research and Technology Club model was a new funding mechanism, and it has taken time for BRIC to realise its full potential. This 'directed evolution' of BRIC by the SG is positive and indicates that the management by the SG and Research Councils is effective.
212. Help with BRIC management is provided by the BRIC Programme Manager. This is recognised as a crucial role by BRIC stakeholders and the work of the Programme Manager is highly regarded. Contact with the BRIC Programme Manager has provided academics with a number of benefits including: advice during the application process; advice on potential industry partners; and regular feedback about their progress. RAs have also benefited from contact with the Programme Manager and, in particular, they noted the support and encouragement the Programme Manager had provided.
213. bioProcessUK²⁹ also provides BRIC with management support. bioProcessUK is a publicly funded Knowledge Transfer Network³⁰ supported by the Technology Strategy Board. It was established in 2005 to drive innovation performance across the UK biomedicine bioprocessing industry. It provides networking opportunities to connect companies, universities, funding bodies, national, regional and devolved administrations. bioProcessUK is highly regarded by academic and industrial BRIC members, and the close relationship between BRIC and bioProcessUK has provided valuable benefits. For example, bioProcessUK has raised awareness of BRIC among the bioprocessing community and facilitated contacts with industry. In addition, bioProcessUK's Technical Director provides representation for industry members who are not members of the SG.
214. The Research Council staff who support BRIC were regarded as very helpful by the research community. In addition, the SG was very impressed by the support they received from BBSRC staff in the Innovation and Skills Group.
215. Some academics commented that BRIC is over managed, and the provision and revision of Gantt charts, annual reports and meetings with the Programme Manager disrupts the normal process of research and could stifle creativity. The Panel was not persuaded that this was the case and noted that it is beneficial for academics to learn about industry approaches to project management.
216. BRIC was the first of several Research and Technology Clubs funded by BBSRC. Subsequently, BBSRC has launched the Diet and Health Research Industry Club (DRINC) and the Integrated Biorefining Technologies Initiative Research and Technology Club (IBTI Club), and is currently considering plans for two more Clubs in the areas of healthy ageing and crop improvement. BRIC has had a positive influence on the development of these other Clubs, which have modelled themselves on BRIC.

Comparison with responsive mode

217. BRIC is supporting a coordinated programme of industrially-relevant strategic research, which is addressing key bioprocessing challenges, aided by industry in setting the research agenda. BRIC is building capacity in the UK bioprocessing community, and additional BRIC activities including dissemination events, workshops, networking, and

²⁹ www.bioprocessuk-website.org

³⁰ www.ktnetworks.co.uk

contact with the Programme Manager and bioProcessUK are adding value to research grants. BRIC is providing important training to early-career researchers, promoting partnership links between academia and industry, providing opportunities for knowledge exchange, and raising awareness of end-user needs among academics and Research Councils. As a result, BRIC is substantially more than a portfolio of 25 individual research projects. The success of BRIC demonstrates the effectiveness of the Research and Technology Club model, and it is highly unlikely that similar progress could have been realised through responsive mode funding.

218. The provision of ring-fenced funding for bioprocessing has been necessary and effective; it is unlikely that a similar coordinated programme of bioprocessing research could have been supported through responsive mode. Although the quality of BRIC research is high, the number and variety of projects would probably be diluted if bioprocessing research were supported through responsive mode funding alone.
219. In the past, it has been very difficult for researchers to secure funding for bioprocessing research in responsive mode. There is a perception that BBSRC Research Committees favour basic research, and that proposals for industrially-relevant strategic or applied research are unlikely to be funded. The Panel welcomed the recent changes introduced by BBSRC to help to address this. In autumn 2008, BBSRC announced that it was restructuring its Research Committees³¹. An important driver for these changes was the need to deliver more inter-disciplinary and strategically focused science with greater impact in responsive mode. Under the new structure, a greater number of proposals for strategic and applied research are expected. In addition, from 2009 all applications will include statements about the impact of the research which will be assessed as part of the refereeing process.
220. While Research Councils' support for bioprocessing research through BRIC is very positive, it is very important to ensure research in this area is also funded through responsive mode. There are benefits from supporting researchers who are peripheral to BRIC, and further research in this area will generate knowledge that can subsequently be applied to industry.

³¹ www.bbsrc.ac.uk/organisation/structures/committees

CHAPTER 7: FUTURE DIRECTIONS AND CONCLUSIONS

Summary

- Research Councils should build on the success of BRIC by funding a successor scheme
- A BRIC successor scheme should develop another level of network to encourage greater participation from industry and academics from other disciplines
- Research Councils should publicise the success of BRIC to a wide audience

Future Research Council support for bioprocessing research

221. BRIC has been very successful in reenergising the UK bioprocessing community. It has expanded a relatively small field, bringing new academics and postdoctoral researchers into the community, and it has broadened the appeal of bioprocessing research, attracting researchers from other disciplines. BRIC is also an excellent vehicle for promoting academia-industry interactions. However, so far, the community developed by BRIC is relatively small, involving 25 research projects and 18 industry members. The community is vibrant and highly valued by its members, but it is also fragile; there is a high risk that, without further ring-fenced funding for bioprocessing research, the community may dissipate and opportunities for impact may be lost.
222. Research Councils should build on the success of BRIC by funding a successor scheme. This should encourage continuity through follow-on funding opportunities, but also seek to broaden the community even further by involving more academics from other disciplines and an increased number of UK companies. Any future scheme will need to develop another level of networking to achieve this goal.
223. There are many academics whose work could contribute to the BRIC research agenda, but who would not currently consider themselves to be part of the bioprocessing field. BRIC should promote its activities more widely to ensure researchers are made aware of the opportunities available. BRIC should approach other professional organisations to attract these scientists including, for example, the International Society for Pharmaceutical Engineering, the Joint Pharmaceutical Analysis Group or the Protein Society. BRIC should also organise its own presentations to a wider academic audience to raise awareness and demonstrate its achievements. The perceived changes in the funding climate among academics are likely to encourage attendance at such events. In addition, BRIC grantholders should speak with colleagues in their own institutions about how their colleagues' work could contribute to the bioprocessing research agenda.
224. BRIC should also seek to promote further links with the industrial bioprocessing community. There are many more companies with an interest in bioprocessing than are currently involved in BRIC. In the future, BRIC should seek to widen industry participation, and particular consideration should be given to attracting more small and medium-sized enterprises (SMEs). Increased participation by SMEs would be beneficial for both BRIC and the companies themselves. BRIC should also ensure SMEs are adequately represented on the SG; SMEs suffer from a general lack of representation, despite making up a substantial proportion of the UK biotechnology industry.

225. BRIC should make particular efforts to attract SMEs in the field of regenerative medicine. This may be challenging as SMEs which are commercialising stem cell or tissue engineering science are often at an early stage of development and may be more interested in research which contributes to the development of individual products; BRIC's remit is to fund research that addresses generic issues which will benefit the whole bioprocessing sector. However, SMEs in the regenerative medicine field would benefit from interacting with academics and with one another within BRIC. It was noted that these SMEs would not participate in BRIC until related projects had been funded. This should no longer be an issue, as BRIC is now funding four projects investigating the growth of stem and tissue cells *in vitro*.
226. BRIC membership fees could be a barrier to entry to companies, particularly small start-up companies with very limited discretionary funds. The sliding scale of membership fees is welcome and helps to ensure companies of all sizes are able to participate. However, the current economic climate may create difficulties for BRIC in the future, as it may be harder for industry members to justify their investment in BRIC especially as it is not tied to a specific research project.
227. BRIC enables companies to gain exposure to a large amount of science for a relatively small investment, and is an excellent example of how academia and industry can work more closely together for mutual benefit. BRIC's achievements should be publicised to a wide audience, including government, relevant industry, and other academics. In particular, the Department for Business, Innovation and Skills should be made aware of the success of the Research and Technology Clubs in delivering the Research Councils' 'Excellence with Impact' agenda.

Summary of findings and recommendations

228. BRIC is a very successful scheme and is making very good progress towards meeting its objectives. BRIC is supporting high-quality, industrially-relevant research in a strategically important area, and this research has the potential to deliver significant impact. The Panel was unanimous in its view that BRIC has had an extremely positive effect in reinvigorating bioprocessing research in the UK and that mechanisms must be found to maintain this momentum.
229. There were some areas within BRIC where the Panel identified potential gaps and weaknesses, and addressing these will help BRIC to be even more effective in the future. The following text summarises the issues and recommendations raised throughout the report.

Standard of research

- A very small number of grants were less successful than expected
- The primary issues affecting grant performance were staffing difficulties or over-ambitious objectives
- Long-term objectives were most likely to show delayed progress

Strategic relevance and potential for future impact

- DSP projects are more likely to deliver short-term impact than USP projects
- Some USP projects are using model proteins that are not representative of those used in industry

Publications

- Institutions place too much emphasis on publications in high impact-factor journals as a measure of research excellence

Intellectual property

- It is essential that intellectual property developed by BRIC grantholders is protected
- There must be more explicit consideration of IP protection within BRIC
- BRIC should provide RAs with IP awareness training

Research Assistants' training and skills development

- There is scope to improve transferable skills training for postdoctoral RAs (e.g. project management, communication skills, design of experiments, six sigma, lean sigma, quality by design)
- Long-term industry placements should form part of BRIC's training strategy
- The training provided through BRIC is unlikely to meet the overall demand for skilled individuals with bioprocessing experience in industry and academia

Postgraduate training opportunities within BRIC

- Postgraduate training is formally outside BRIC's remit and this is potentially a serious weakness with the scheme
- BBSRC's Targeted Priority Studentships in bioprocessing are focused in a small number of institutions and are not building capacity more widely
- Research Councils should consider funding studentships that are directly aligned to BRIC grants
- There is a need for Masters training in bioprocessing

Career development opportunities for early-career researchers

- There must be funding opportunities available to enable the highest calibre early-career scientists to establish independent bioprocessing research groups
- Research Councils should ensure their fellowship schemes recognise all types of excellent research – basic, strategic and applied

Developing partnership links between academia and industry

- It is more difficult for researchers who are new to the bioprocessing field to establish academia-industry links; BRIC should focus its support on these groups when promoting partnerships

Knowledge exchange

- The majority of annual reports describe plans for knowledge exchange rather than specific examples of where it has taken place
- As BRIC matures, there will be a need to improve the level of knowledge exchange and the SG should monitor progress in this area
- Industry can be guarded about providing industrially-relevant materials to BRIC researchers

BRIC dissemination events

- The closed nature of dissemination events may reinforce a perception that BRIC is exclusive
- There is scope for BRIC to organise additional open events to showcase its achievements to a wider audience

Balance and coverage of the portfolio

- There are some gaps in the coverage of the BRIC scientific remit (e.g. whole process modelling)
- There are a few examples in the BRIC portfolio where there is overlap between funded projects

Application and administration procedures

- The research community expressed some concerns about the application processes (e.g. transparency, the involvement of industry, the provision of feedback)
- Some aspects of the application process should be made more explicit to the community (e.g. weighting of assessment criteria, the role of IMs, procedures for dealing with conflicts of interests)

Future Research Council support for bioprocessing research

- BRIC has had an extremely positive effect in reinvigorating bioprocessing research in the UK and mechanisms must be found to maintain this momentum
- Research Councils should build on the success of BRIC by funding a successor scheme
- A future scheme should encourage continuity through follow-on funding opportunities but should also seek to broaden the bioprocessing community even further
- A future scheme should attract more academics from other disciplines whose work can contribute to addressing bioprocessing research challenges
- A future scheme should widen industry participation and should encourage more involvement from SMEs, especially those in the regenerative medicine sector
- A future scheme should pursue areas that have not received funding in BRIC and, if necessary, conduct specific activities to attract or commission high-quality cross-disciplinary proposals

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APPENDIX 1

PANEL MEMBERSHIP

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APPENDIX 2

TERMS OF REFERENCE

1. The task of the Review Panel is to carry out an independent evaluation of the Bioprocessing Research Industry Club (BRIC) covering the three years since its inception. The Panel is asked to review the achievements of BRIC to date and to consider BRIC's potential for future impact as research projects develop.
2. Specifically, the Panel is asked to review the information presented and to:
 - a. take an overview of the evidence from annual reports and surveys to assess the quality and international standing of the science supported by BRIC
 - b. comment on the extent to which BRIC is supporting research relevant to the UK bioprocessing industry, including the bioscience that underpins bioprocessing and improved tools for bioprocessing
 - c. assess the effectiveness of BRIC in promoting interactions between academia and industry
 - d. assess the effectiveness of BRIC in promoting knowledge and skills transfer between the science and engineering base and industry
 - e. comment on the extent to which BRIC is building capacity in UK bioprocessing research through the provision of relevant training for post-doctoral researchers and by encouraging academics to conduct industrially-relevant bioprocessing research
 - f. in the context of priorities for UK bioprocessing, assess the balance and coverage of the BRIC portfolio, identifying strengths and weaknesses
 - g. comment on the BRIC application, assessment and administration procedures
 - h. comment on the potential long-term economic and social impacts of BRIC-funded research and identify ways to ensure that, as BRIC matures, these impacts are maximised
 - i. make recommendations to the Research Councils on ways to build on successes and ways to address identified gaps and issues.

APPENDIX 3

LOGIC CHART FOR BIOPROCESSING RESEARCH INDUSTRY CLUB EVALUATION

