INTERNATIONAL PERCEPTIONS OF THE UK MATERIALS RESEARCH BASE

EPSRC
Engineering and Physical Sciences Research Council

IOP Institute of Physics

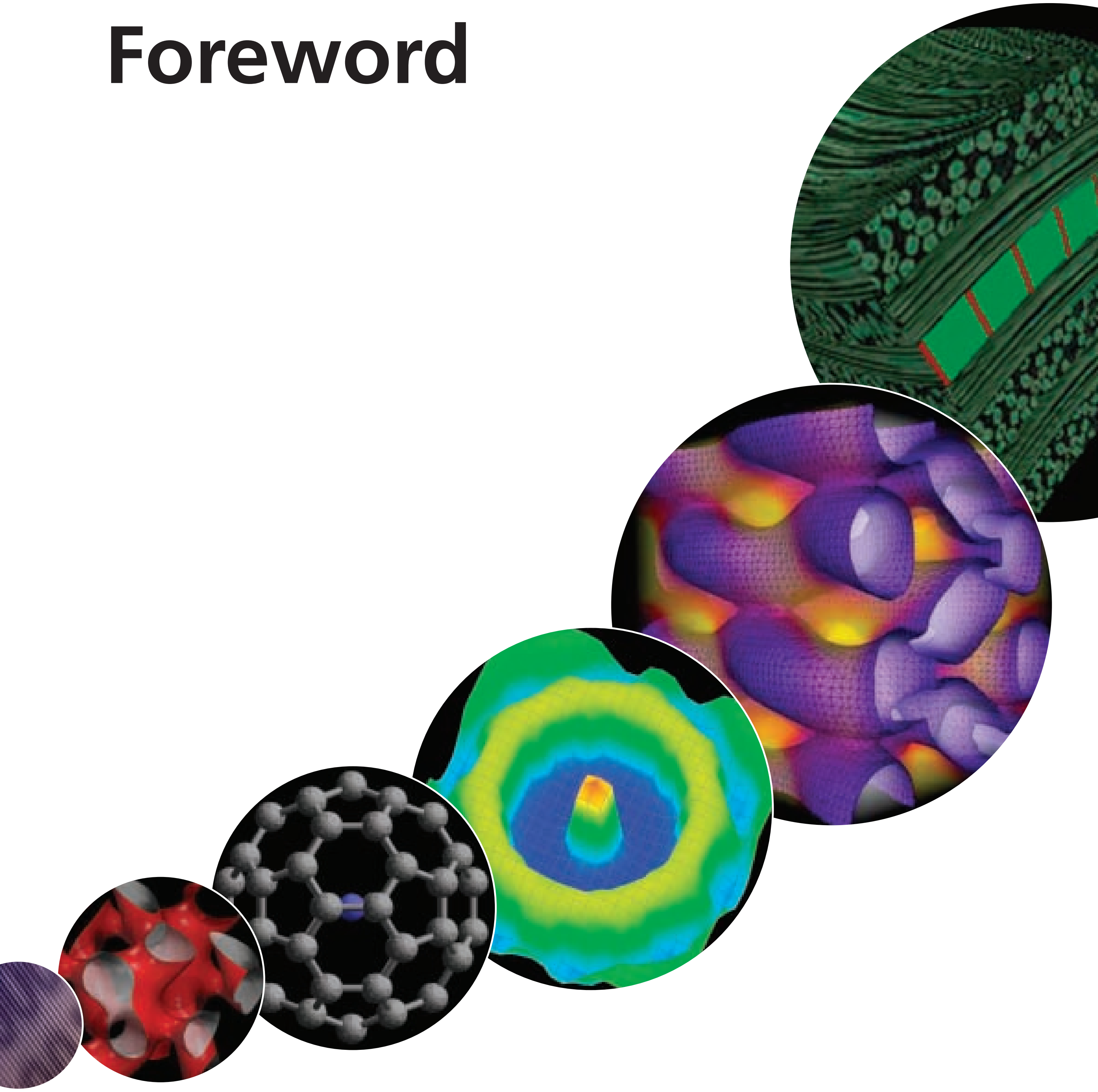
IOM3
The Institute of Materials, Minerals & Mining

Materials UK

The Royal Academy of Engineering

RSC | Advancing the Chemical Sciences

Foreword



This is an exciting time for the Engineering and Physical Sciences, when the UK seeks to extend both its economic and social impact and international reputation for cutting edge fundamental research. This is the second International Review of Materials and reflects the important contribution of this area to the UK. This contribution enables progress by bringing a fundamental knowledge and understanding of materials which drives advances in many areas. Materials research underpins a wide range of industries from electronics to construction, transport to healthcare; all are reliant on a fundamental understanding of the structure, properties and performance of existing materials and the development of new materials which enable technological advances.

The preparation for this review has been ongoing for over a year and we would like to thank our colleagues on the Steering Group, which included representation of the Institute of Materials, Minerals and Mining (IoM^3), the Institute of Physics (IoP), the Royal Society of Chemistry (RSC) and Materials UK. Specific thanks must go to EPSRC staff for their unwavering support and hard work which enabled the Panel to do its work so effectively.

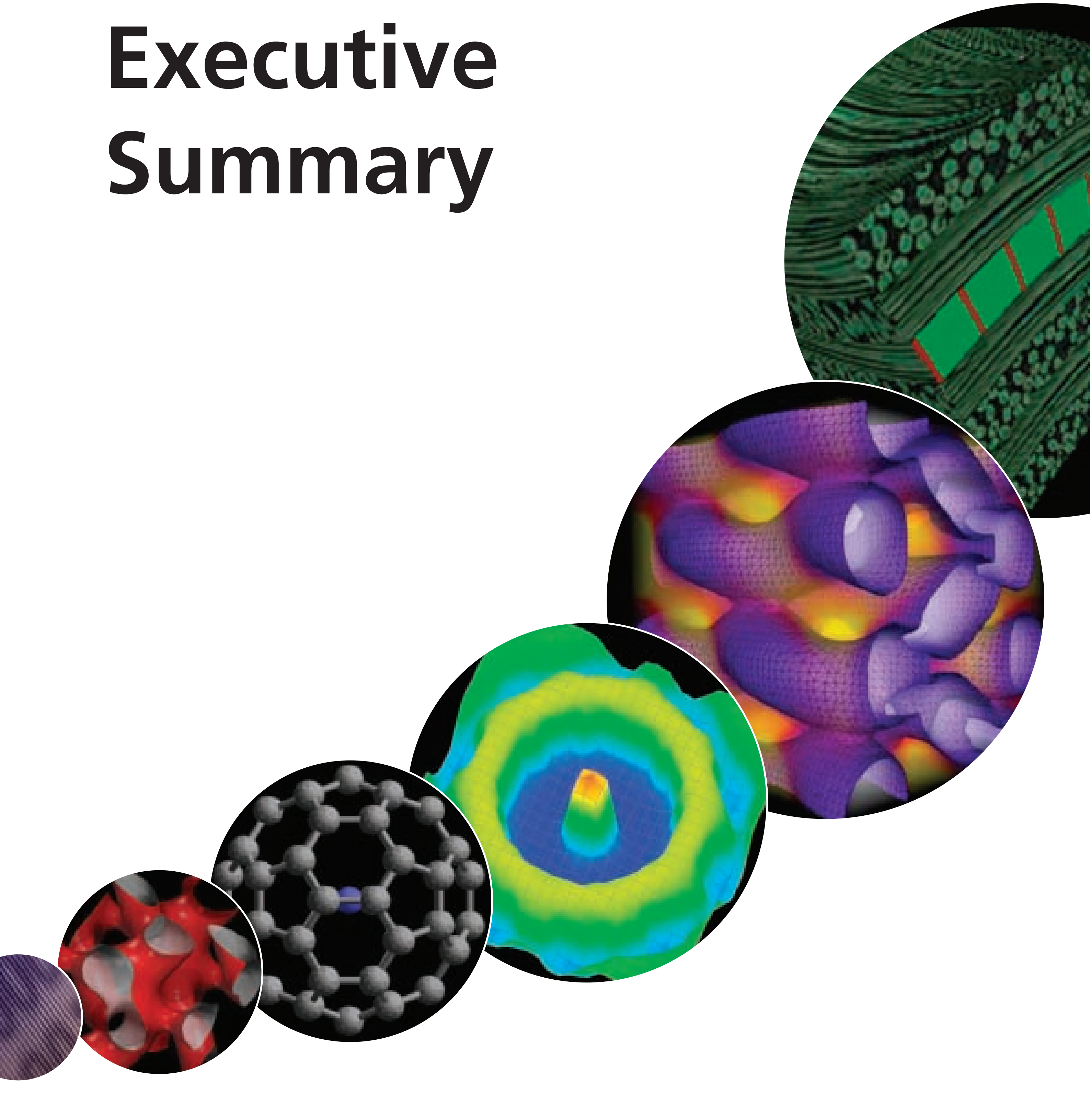
This report, the culmination of these activities, is entirely the work of the International Review Panel to whom we are very grateful – their expertise, teamwork, enthusiasm and capacity for sheer hard work impressed all those who came into contact with them. To Professor Jim Williams, Chairman of the International Review Panel, we are hugely indebted; his commitment and leadership were vital to both the review and the completion of this report.

Finally, we warmly thank all those in the UK academic research community, together with their collaborators in industry who are so vital to materials research, for rising to the challenges and opportunities that this review presented. We are especially grateful to those who coordinated and participated in each visit, often travelling some distance to meet the Panel. Due to the way in which the community worked so well together, the Panel interacted with a great many researchers and witnessed a wider range of exciting advances in the short time available to them than would have otherwise been possible.

We hope this report will stimulate further debate around the issues and recommendations highlighted and we genuinely welcome your feedback on any issues raised.

Professor David Delpy Chief Executive, EPSRC.	Dr Phil Ruffles, Steering Committee Chairman.

Executive Summary



The 2008 Materials International Review Panel has completed a week long review of materials research throughout the United Kingdom. This document presents the perceptions and recommendations of the review. The aim of this Panel is to provide long-term, strategic recommendations that will sustain and improve the excellent materials research that is occurring throughout the UK.

The Review took place during the week starting Sunday, 13th January 2008 and involved an international panel consisting of 14 scientists and engineers. The focus of the assessment was centred on but not limited to eight Framework Questions. These top level questions are common to the assessments that will be or have been performed by all the International Review Panels.

The general health of the UK materials research programme is good. The Panel was generally impressed with the calibre and intellectual strength of the young scientists and engineers they met. As in most other developed nations the UK industrial scene is changing and consequently the nature of employment is changing. The Panel heard more than once from the industrial representatives that the supply of classical materials engineers was inadequate. In part, this seems to be related to the reduction in the number of departments of materials science and engineering in the UK.

The Panel was briefed on a number of very high quality research efforts. These efforts varied considerably in their time-based "focal length". However, working on very hard application oriented research can be adventurous because the measures of success and failure are much clearer.

There are also a number of long-term threats to the current situation, one is the closeness of the university research to industrial interests. In the near term this is a major strength for UK companies but longer-term fundamental innovation must come from university research. This creates a paradox, which is best addressed by a balanced research portfolio, even if maintaining it is, from time to time, tantamount to appearing uncooperative where industry interests are concerned. The Panel witnessed some excellent examples of knowledge exchange between universities and industry. The nature of these exchanges was highly variable in its precise form. Established, large enterprises typically had well defined needs and expectations, whereas the nature of the university relationship with small and medium enterprises (SMEs) depended on the maturity of the company and its product. In some other countries, e.g. the US, issues associated with intellectual property (IP) rights are often barriers to industry/university cooperation. The Panel was pleasantly surprised to discover that this is seldom the case in the UK.

The field of materials is by definition a multidisciplinary activity. The early engagement of mechanics, multi-scale modelling and manufacturing experts in a research project typically allows earlier identification of issues that require solution before the results of the research can be implemented. Stimulating this approach through stipulations in the funding process can improve the willingness of researchers to structure their proposals as multidisciplinary efforts.

There are some excellent examples of international cooperation in materials research in the UK. However, many of these cooperative efforts are bottom up in nature. The success of more formal top down international cooperation, except for the EU programmes, is not as evident. In part this is because the counterpart agencies in the other countries are not well organised to facilitate these programmes either. In the case of emerging economies these programmes may not even exist. Even where there are programmes on both sides, the execution so far has been sorely lacking, leaving less than robust international programmes. Inter-institutional cooperation is more difficult than the equivalent intra-institutional programme. International cooperation is much harder still. A concerted effort to develop a broad international materials research programme will require a concerted effort and, most likely, the application of incentives.

During the Review it became apparent that university researchers are unaccustomed to thinking quantitatively about the impact of their research. Various recommendations are included in the report which could yield improvement.

The following recommendations are taken from a longer list that was developed by the Panel on the basis of the presentations and discussions during review. The complete list of recommendations is contained in the main body of the report. These major recommendations are not in any priority order but are grouped into several categories for convenience:

Industrial Interactions including Spin-outs and Knowledge Transfer

- A process to be developed to encourage UK industry to define and support new platform technology opportunities, especially disruptive ones that university researchers can address with early stage research.
- EPSRC is encouraged to publicise guidelines for intellectual property rights (IPR), especially as they are related to the delay of publications based on graduate student research.
- Where economic impact is a consideration for grant success, determine whether the research and development (R&D) supports existing UK industry or not. Where it does, seek industry support or involvement for determining grant success. Where it does not, ensure there is a systematic and strategic approach to creating a new company in the area of grant, including support for these new companies.
- Establish a fund for early stage start-up investments (e.g. Small Business Innovation Research Programme).

Talent Supply and Development

- Establish and track outcome related metrics of success of university research programmes in non-traditional areas such as the provision of high quality scientists and engineers to UK industry.
- Identify the best university outreach programmes and provide resources for their replication at other institutions.
- EPSRC should continue to articulate the importance of changing the UK government policy regarding foreign student related issues, in particular: visas, work permits, living expenses and fees.
- A core materials curriculum should be defined for all materials programmes. The effectiveness of this curriculum should be monitored over time and adjustments made as appropriate.
- The current academic leaders should be encouraged to recognise the importance of systematic leadership development to ensure the future of the materials field. Development should start from the early career stage. The necessary resources needed to support this activity must be applied.

Research Portfolio Balance and Efficiency of Use of Funds

- A mechanism for supporting idea driven research for synthesis and development of new materials, including the underlying fundamental science, should be developed. If such a mechanism is perceived to exist then a separate budgetary provision should be established to protect this activity.
- Define the long and short term objectives of the EPSRC research portfolio in terms that permit more direct comparison of outcomes and objectives.
- Establish a mechanism for sustaining large-scale, long-term funding of materials research laboratories including facilities. These facilities must have high utilisation rates to ensure a good return on investment. Proposed facilities should have clear plans to create such utilisation levels.
- Design a "UK materials leadership innovation initiative" to identify potential future leaders. Implement the initiative with appropriate instruments (fiscal, policy, etc.) and actions to achieve a desirable outcome.

Major Research Facilities

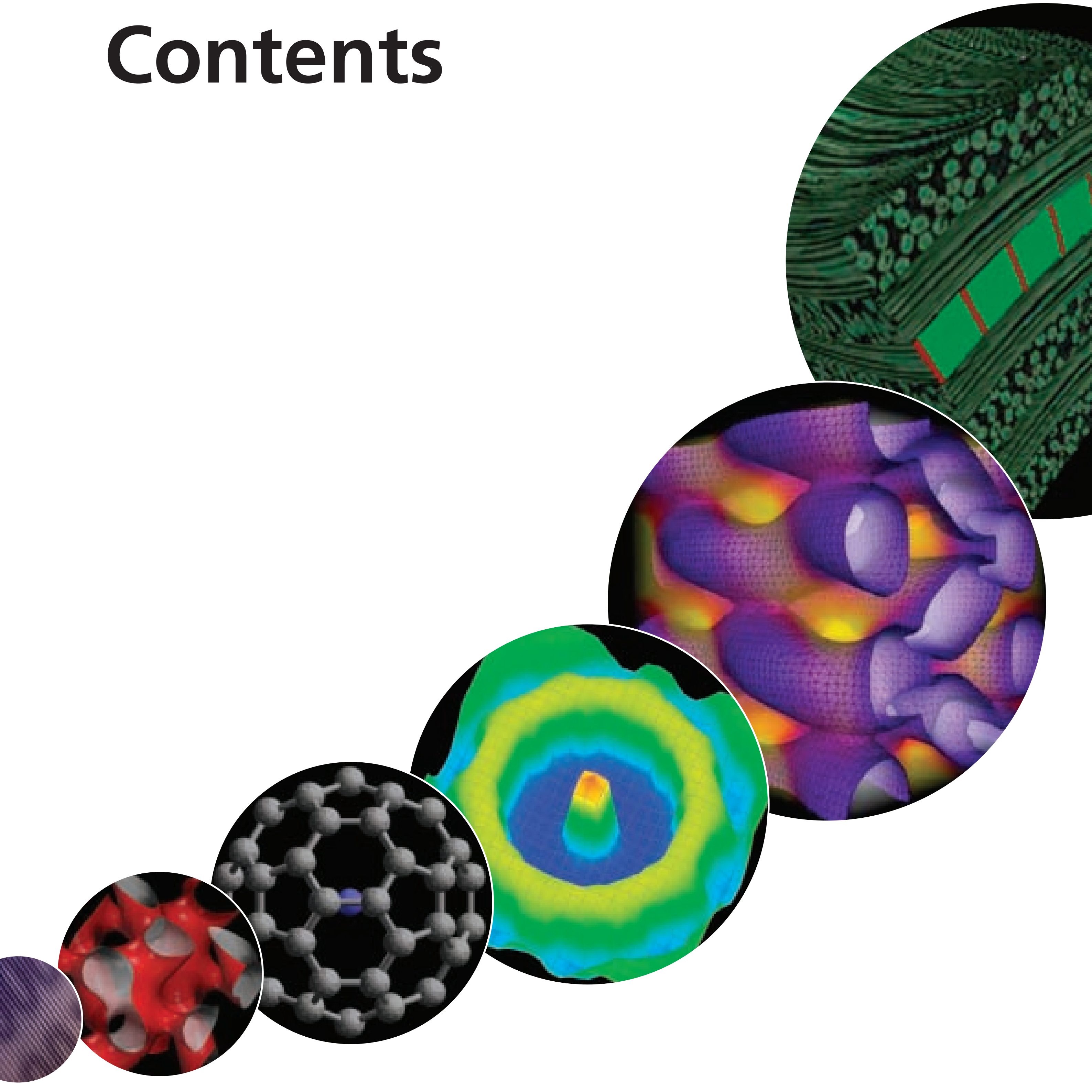
- Compile, maintain and publicise an inventory of facilities nationwide or at least regionally along with mechanisms for access and high utilisation levels.
- Create mechanisms/incentives to consolidate **major** materials preparation and characterisation

facilities in central laboratory space to serve the broad university materials community.

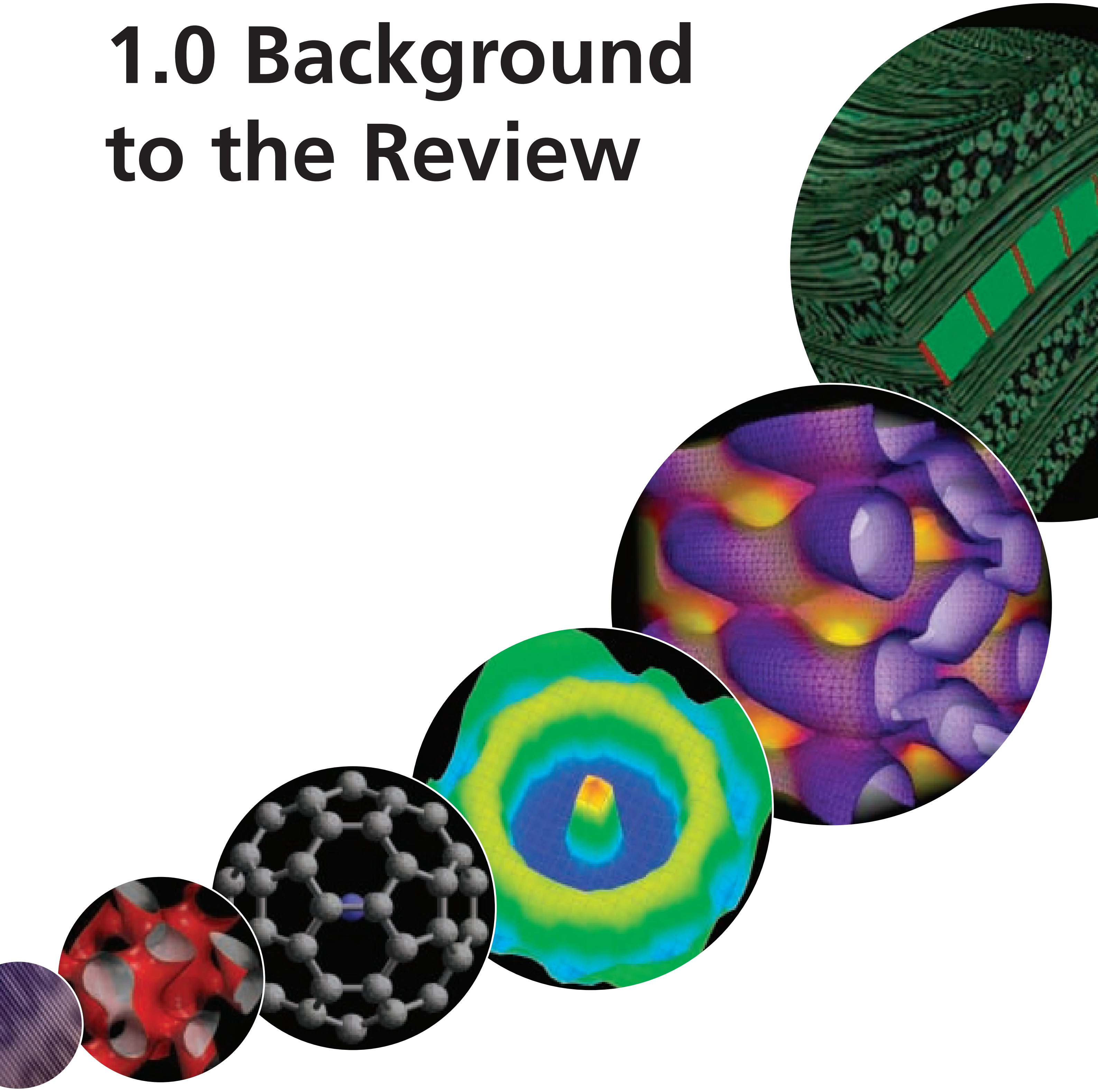
Framework Based Recommendations (not already mentioned)

- EPSRC should take the lead in establishing mechanisms for the exchange of personnel between universities and industry. There will be a number of inter-organisational issues to be resolved so it is recommended that a representative industry group be engaged early in the process.
- In several fields, ranging from more traditional to very high-tech fields, the concern was expressed regarding the funding level for core knowledge creation. EPSRC is encouraged to maintain the balance between this and research with potential applications in the long and shorter term.
- A quantitative review of the materials start-up activity in the UK over the last 25 years would be useful. The Panel was working off anecdotal evidence.
- We recommend a coordinated national effort to increase the awareness of materials as an attractive and fulfilling career option.
- We recommend that the UK community initiate its own benchmarking effort using the standard metrics (publications, citations, etc.) that are becoming applied rather generally world-wide. This can provide judicious feedback for assessing progress in rapidly exploding fields and also help assess declining fields where claims for significant EPSRC support are made. Such quantitative metrics may help alleviate anecdotal concerns that responsive mode review requires a critical community size for funding success.
- Beyond publications and citations, which can measure excellence in science, metrics that measure ‘innovation’ also need to be evolved, monitored and used for improvement of the overall inputs. Definition of the metrics used to measure innovation should involve a few progressive industrial partners.
- We recommend that innovation be included as a measure of success of EPSRC funding. As mentioned earlier, this will first require thoughtful creation of metrics to assess innovation.
- We recommend that the EPSRC materials programme re-affirm its unambiguous commitment to supporting world-level quality in all its programmes. This means no compromises in quality will be made in favour of providing near term assistance to industry.

Contents



1.0 Background to the Review



EPSRC holds regular international reviews to inform itself and other stakeholders (industrial bodies, learned societies, academia and government departments) about the quality and impact of the UK science base compared to the rest of the world and to highlight any gaps or missed opportunities. Each international review provides a broad perspective on the research activity in a particular discipline in the UK and is undertaken with the relevant learned institutions and other research councils as appropriate; it is a rolling programme in which the research base in each discipline is reviewed approximately every five years. Eleven reviews have been conducted since 1999.

The 2008 International Review of Materials is thus one in a series. The previous review in this subject area was the 2002 International Review of Materials, entitled, "Enabling the Future: A Perspective on UK Materials Research". The Review Panel was selected to reflect continuity from the last review and associated areas and following an extensive consultation exercise by the steering committee (chaired by Dr Phil Ruffles). Individuals were chosen for the breadth as well as the depth of their expertise.

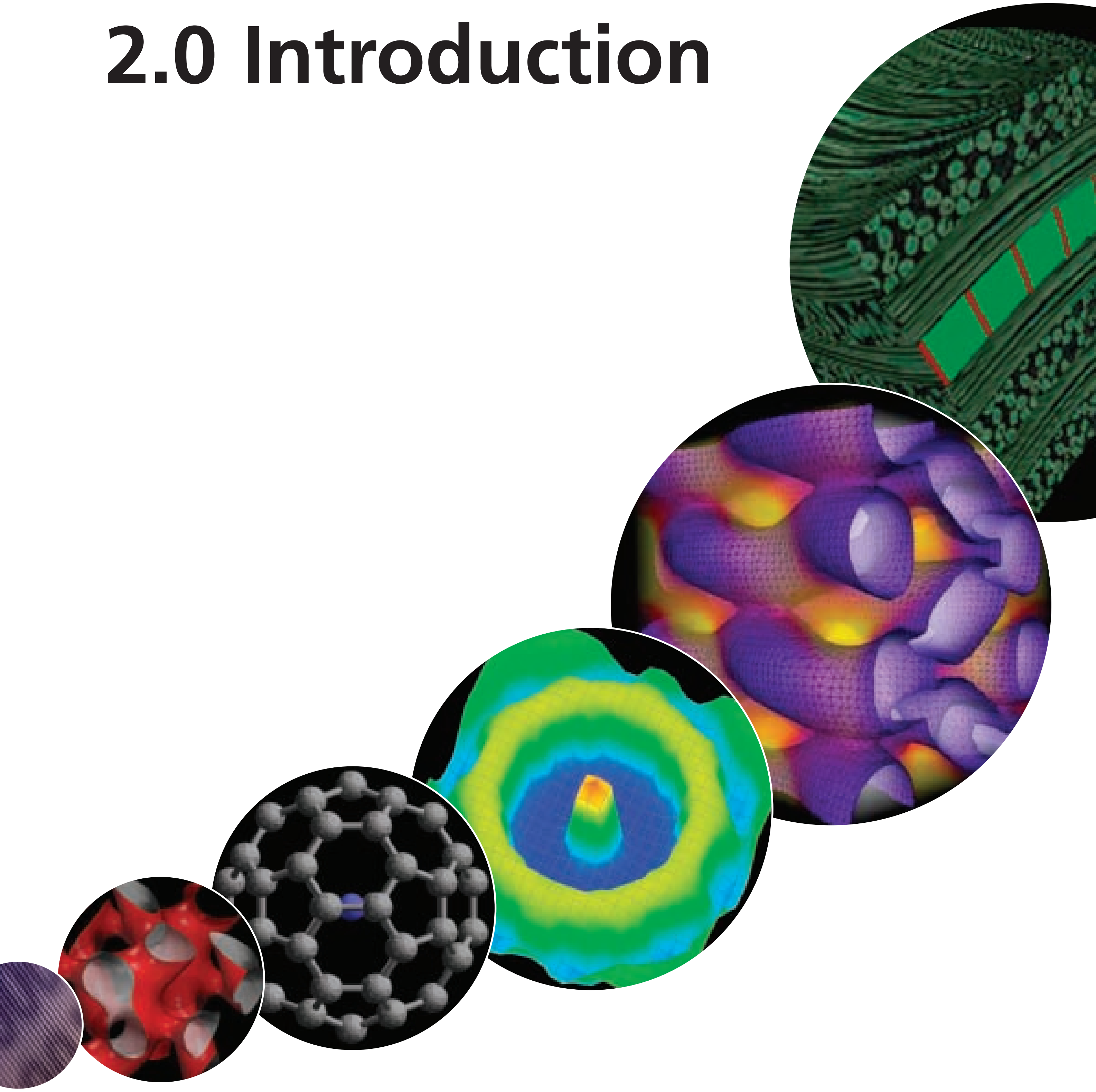
The role of the UK steering committee was to oversee the review and, as stakeholders, to act as a proxy for the community, representing views as appropriate. The steering committee advised the project management team on issues such as timing of the review, membership of the International Panel, including the chair, locations to be visited and the provision of evidence. During the review week itself, the steering committee met the Panel to introduce them to the UK context and also to hear and discuss their findings. Following the review week the steering committee's role changed to that of dissemination, helping to propagate the review findings and catalysing community development in response to the resultant action plan.

1.1 Terms of Reference

The terms of reference for the International Review were to:

- Assess and compare the quality of the UK research base in materials against the rest of the world and prepare relevant recommendations.
- Assess the impact of the research base activities in materials internationally, on other disciplines nationally, on wealth creation and on quality of life and prepare recommendations.

2.0 Introduction



During the week starting Sunday, 13th January 2008 an International Panel consisting of 14 scientists and engineers came together in Manchester, England for the purpose of assessing the quality and impact of academic materials research in the United Kingdom (UK). After an organisation meeting on Sunday, the Panel divided into sub-panels, each of which visited a separate set of venues during the ensuing Monday to Thursday.

The focus of the assessment was centred on but not limited to eight Framework Questions. These top level questions are common to the assessments that will be or have been performed by all the International Review Panels. In the case of the Materials Review, the steering committee modified a series of questions subsidiary to each of the top level Framework Questions. These questions, including the subsidiary questions, are found in Annex A. They are also repeated piecewise in the next section of this report that summarises the International Review of Materials (IRM) Panel's findings. Given the task at hand and the time available, a realistic assessment would have been very difficult without the commonality of inquiry that the questions provided. Many of these Framework Questions addressed issues that extended beyond the normal inquiry of quality and focus of research. Consequently, the scope of the Review was considerably broader. It also became clear as the week progressed that some of the issues identified by the steering committee and posed as subsidiary questions were not the types of issues that academics regularly ponder. In part, this accounts for the uneven responses that were provided at different venues and by different universities.

The Panel members, their home institution or company, their country of origin and their technical speciality are shown in Table 1 (overleaf). Brief biographies of the Panel members are found in Annex B.

During the ensuing four days the IRM Panel had the opportunity to visit 9 venues and meet with faculty and researchers from 25 institutions, including 22 universities and facilities such as those housed at the Rutherford Appleton Laboratory (RAL) or Daresbury Laboratories and Diamond. This was possible because several institutions often shared a venue. Without such sharing the extent of coverage of the institutions would have been considerably less. The details of the itinerary for the week including the venues and the universities present at each one are found in Annex C. In addition, individuals from companies involved with the universities as research collaborators were present at each venue. Given the nature of some of the framework questions, the presence of these private sector representatives proved invaluable.

As mentioned earlier, in order to accomplish such a broad coverage of these university research programmes in the course of four days, it was necessary to sub-divide the IRM Panel into sub-panels. Consequently there were two sub-panels on each of the days except for Tuesday, when there were three. Two Panel members who expected to participate in the review dropped out at the last minute due to (understandable) personal reasons. Nevertheless, this left the Panel a bit 'lean' when it was sub-divided into three sub-panels. The composition of the sub-panels for the various venues also can be found in Annex C.

Each university or group of universities was permitted by EPSRC to set the agenda for the day; however, the Framework Questions (Annex A) were provided in advance by EPSRC together with the request that these should be the centrepiece of the discussions. The responsiveness of the various institutions to this guidance was variable, but the Panel quickly learned to probe the presenters in order to get an adequate appreciation of the situation at each of the different universities.

Because the task of the Panel was to gather data related to the Framework Questions at each venue and to re-assemble this data into a broader picture, there will be no institutional attribution mentioned in this report. There was at least one EPSRC staff member present at each venue and they can provide attribution as deemed appropriate by EPSRC. It is hoped that, at a minimum, institutional "Best Practices" will be identified and propagated across the university community for the improvement of the overall UK programme. Many of the Best Practices are not materials specific and can be adopted by other disciplines as well. Conversely, there may be other disciplines that are leading the way in some of the areas covered by the Framework Questions and it is hoped that the results of other disciplinary reviews will enable transfer of these Best Practices to the materials research community as well.

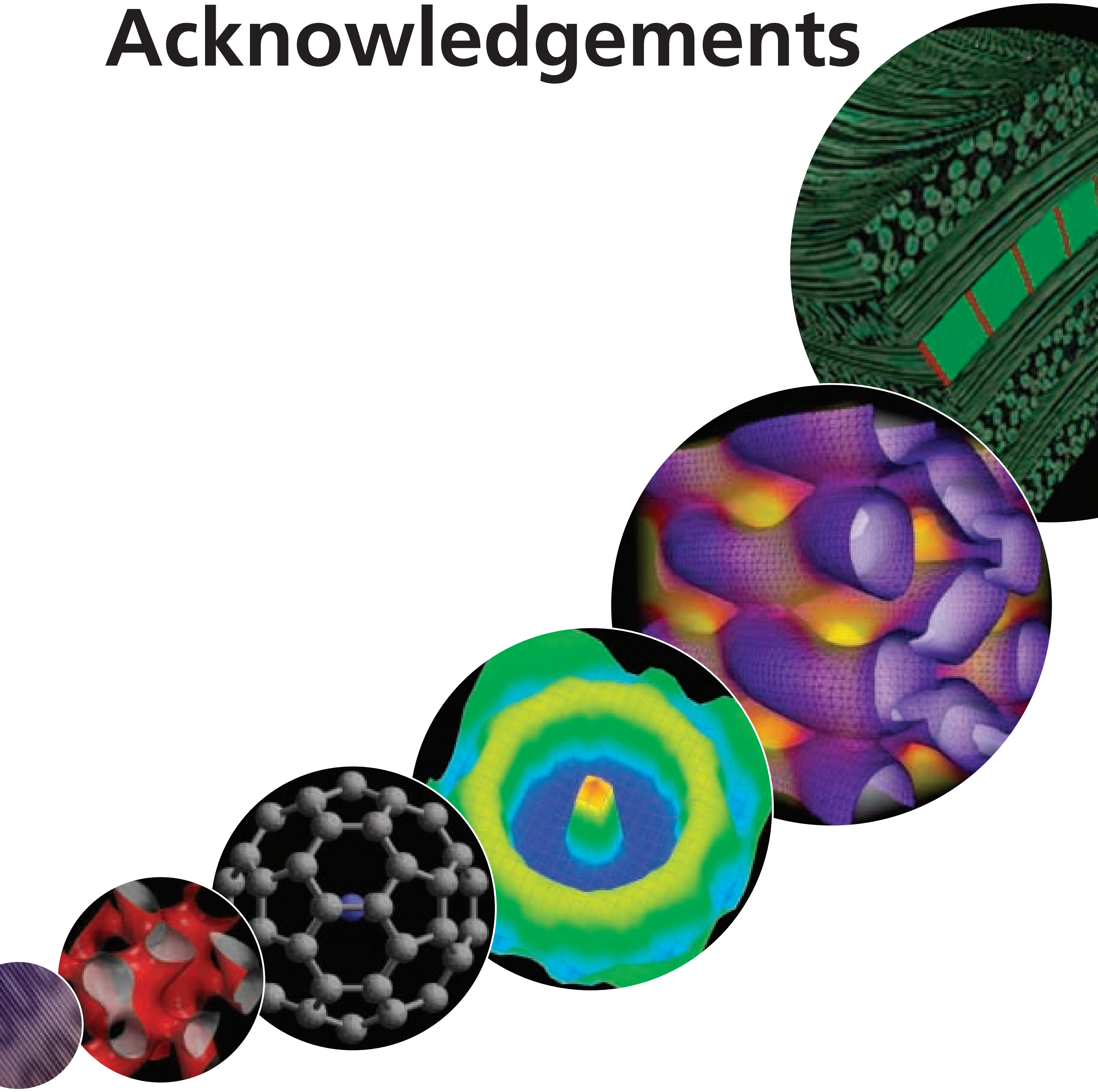
Table 1: Composition of International Review Team

Name	Institution	Expertise	Country
Professor Paulo de Freitas	INESC MN	Magnetic Materials	Portugal
Dr Alastair Glass	Ministry of Research and Innovation	Photonic Materials	Canada
Professor John Greedan	McMaster University	Magnetic Materials	Canada
Professor Robert Hull	Rensselaer Polytechnic Institute	Electronic Materials	USA
Professor Olli Ikkala	Helsinki University of Technology	Soft Materials	Finland
Professor David Larbalestier	Florida State University	Superconductivity	USA
Dr Ramesh Mashelkar	Indian National Science Academy	Polymers	India
Dr Ian Maxwell	Allen & Buckeridge	Photonics and Polymers	Australia
Professor Barry Muddle	Monash University	Metals and Alloys	Australia
Professor Manfred Rühle	Max Planck Institute for Metals Research	Ceramics and Inorganics	Germany
Dr Maxine Savitz	The Washington Advisory Group	Ceramics and Inorganics	USA
Professor Tim Swager	Massachusetts Institute of Technology	Photonic Materials	USA
Professor Gerhard Wegner	Max Planck Institute for Polymer Research	Polymers	Germany
Professor Jim Williams (Chair)	The Ohio State University	Metals and Alloys	USA

Materials International Review Panel and EPSRC Staff

Left to right:
Dr Ramesh Mashelkar, Professor David Larbalestier, Professor Paulo de Freitas, Professor Barry Muddle, Dr Maxine Savitz, Professor Gerhard Wegner, Dr John Wand (EPSRC), Professor Tim Swager, Anne Farrow (EPSRC), Dr Ian Maxwell, Professor Jim Williams (Panel Chair), Professor Manfred Rühle, Professor Olli Ikkala, Professor Robert Hull, Professor John Greedan, Dr Alastair Glass.

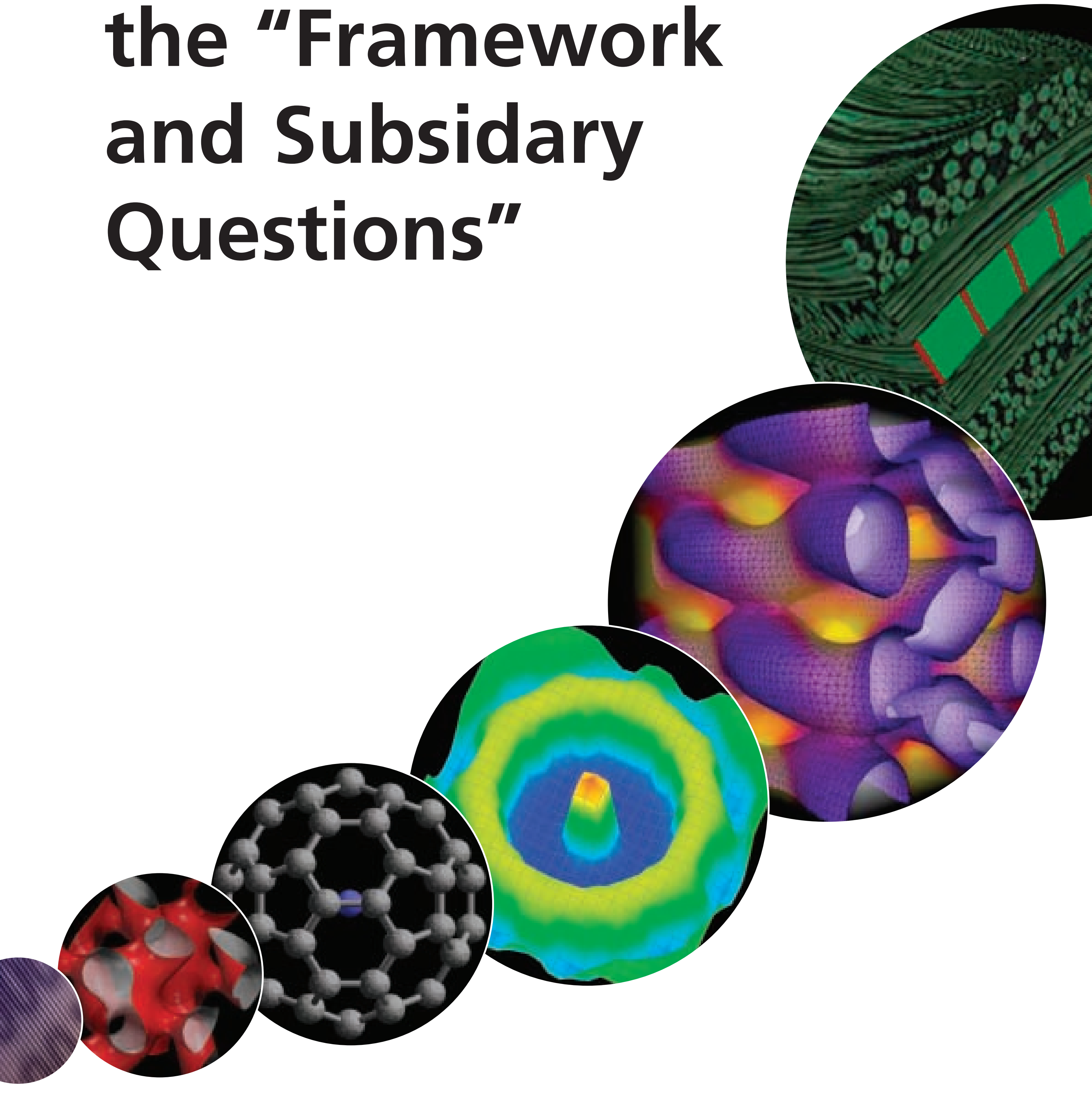
3.0 Acknowledgements



The Panel are grateful to the steering committee for their excellent preparatory work, which left the Panel able to appreciate a deeper interaction with members of the research community. Likewise, the members of EPSRC staff involved in managing the review, chaperoning members of the Panel, project managing and preparing for the review as well as rescuing luggage that had been forwarded to the wrong address by over zealous hotel staff were invaluable in ensuring that this major logistical challenge ran smoothly.

No review of this nature can take place without the enthusiastic and open participation of the researchers themselves. The Panel is deeply indebted to the academics and industrialists who freely gave their time to make the Panel's job an enjoyable and engaging one. Many researchers travelled to meet with the Panel and without their efforts, alongside those of local researchers and especially the coordinators of such visits the Panel's job would have been much harder and less effective. Parts of the review framework sought to examine the economic and social impact of the materials research base. Without the participation of key industrial researchers this would clearly have been impossible to do in a grounded manner. The Panel wishes to express their deep gratitude to all who were able to contribute to this important discussion.

4.0 Panel Responses to the “Framework and Subsidary Questions”



The following are the responses to the eight Framework Questions and the associated subsidiary questions. These responses have been prepared by sub-teams and reviewed by the entire Panel. The level of detail in each response varies depending on the amount of relevant information provided by the different universities at the various venues, both in their presentations and during follow-up question and answer sessions. It is the view of the Panel that these replies are representative of the situation and as complete as is realistic, given the time pressures experienced during the four days of data gathering. In some cases the information gathered does not map congruently onto the subsidiary questions in part because they have some overlap and are interconnected. As consequence, there are recommendations embedded in the responses to the Framework Questions where these pertain only to this particular question or sub-question. At the end, there are other more generic recommendations that relate to more than one question. Some recommendations are further emphasised at this point. All of the recommendations have been placed together in Annex E and are labelled as to which specific questions they relate to or are labelled with an 'O' meaning they are other recommendations.

4.A. To what extent is the UK materials community addressing key technological/societal challenges through engaging in new research opportunities?

> *4.A.1. What are the key technological/societal challenges and research directions in materials research? To what extent is the UK materials research community focused on these? Are there fields where UK activity does not match the potential significance of the area? Are there areas where the UK has particular strengths?*

The UK materials community is well aware of the key technological/societal challenges which are presently being discussed internationally and are the drivers of innovation and competitive actions world-wide. However, the UK scientific community responds to these challenges to a variable degree. This variation may reflect a rapidly changing situation in the UK's main industrial research directions and thrusts. The following is an account of topics which have been encountered in the course of the site visits. The sequence of entries does not necessarily reflect their importance in terms of economic or technological impact but rather the frequency by which these topics have been selectively mentioned as a key activity in the respective academic communities:

Energy

- Energy production is seen as the highest priority throughout. Intensive work on gas turbines, composites for harvesting of wind energy, research on solar energy harvesting/solar cells, novel light sources (energy saving) by OLEDs, sustainable energy production (increase of efficiency, reduction of losses), nuclear energy related issues are to be noted.
- Energy storage is considered to be a major challenge, resulting, for example, in considerable activity to improve the performance of Li-based batteries. This interest also has lead to a "revival" of electrochemistry as an integral part of materials research. There is also some good work on new or improved materials for more efficient hydrogen storage.

Communication

World class activity in research is found in materials for transport and processing of optical communication (optical fibres and fibre-optic devices), plastic electronics, ultra high-speed electronics, printing technologies for plastic electronics, optoelectronics.

Transportation and Traffic

The focus in UK-research seems to concentrate on development of composite materials for aerospace applications relevant to UK-industry and less so for automotive or ship building industries.

Public Infrastructure/Housing

Work to develop composite materials to build (or repair) buildings, roads, bridges etc. in conjunction with architecture and civil engineering is noteworthy.

Materials Safety and Recycling

Work on environmental issues in production, processing, recycling of materials as well as research aiming for sustainable materials applications including safety studies and life time predictions are of common concern but a lack of proposals has resulted in this area not receiving much funding.

Nanoscience

This is a research area which enjoys worldwide activity and draws much public interest. Relevant work in this category is found across all UK universities. However, there also is considerable effort that appears to be still searching for an application. This is reflected by activities in the UK aiming to find novel manufacturing processes for nanoscale materials as a prerequisite to real applications.

Security, Anti-terrorism research

Much of the current work to develop novel sensors draws credibility from the necessity to create proper protective devices against terrorist actions or criminal assaults. Good and relevant activity in this area is found in the UK materials research community.

Some fields can be identified where UK activity still does not match the potential significance of the area. Among these the following need mentioning:

Hydrogen-based economy is a subject of high interest, which triggers a wealth of materials research projects around the world. Scattered research activity is seen in some UK universities. However, a holistic view needs to be developed and implemented for the UK to gain leadership. This is an important domain, where the future direction of the national economy will be dependent on materials related issues. The whole chain needs to be addressed by the materials research community: efficient and sustainable production of hydrogen, storage and transport of hydrogen, the materials and safety base of distribution systems, fuel cells for stationary and mobile applications etc. Isolated work on particular aspects, even if brilliant, will not produce the necessary and highly important impact on technology development which, in turn, has the potential to sprout new industries.

Metallurgy is an area in which UK universities have traditionally enjoyed worldwide leadership however, it seems to be on the decline in many but not all institutions in the UK. While excellent research is continued in a few places, the industry does not seem to be able to find the necessary number of young and well trained experts from the UK materials research community to satisfy their recruitment needs. The reasons why metallurgical research does not meet with the interests of the academic research community and EPSRC priorities need to be identified and new research goals need to be articulated. Here, the help of EPSRC may be needed to formulate together with industry and academia new challenges which stimulate metallurgical research in a modern and internationally competitive manner.

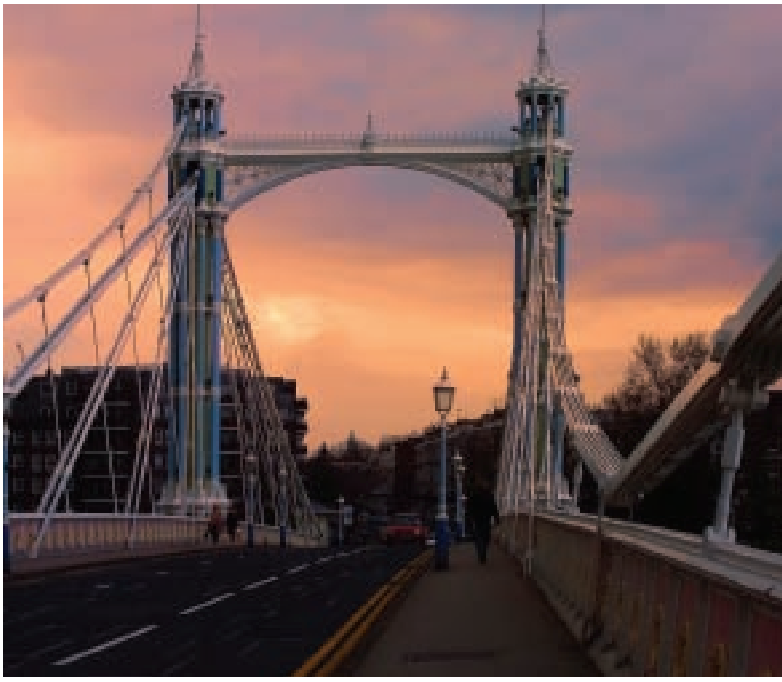
Research on polymers (or more generally on organic materials) has traditionally been a high academic standard in the UK. While innovation is supported by research in specialty polymers, for instance related to biomedical, pharmaceutical and optoelectronic applications, research on so-called commodity polymers for mass applications is on the decline. Yet such research brings important innovation to small and medium enterprises (SMEs) which traditionally focus on polymer processing and specialised applications, e.g. in packaging of solid and liquid goods, the building industry (thermal insulation, window frames etc.), the coatings industry and many more.

Materials as catalysts - heterogeneous catalysts and catalyst supports comprise another area where materials research and chemical engineering meet on a fertile ground. This is not exploited in the UK to a level comparable to other competing economies in overseas countries.

An evaluation of the economic growth factors with respect to innovations sprouting from the UK materials research community seems to be lacking but would be a necessary and welcome tool to implement research goals into the academic community. This includes perspectives on **transference of materials science based expertise to the developing countries.** Here, materials science needs to reconsider available materials and processing technologies with respect to economic costs amenable to the third world. To be clear, materials science is confronted with different tasks when solving problems which are widely experienced in the developing countries. In other words, "high tech" is not necessarily a solution considering lack of resources in these societies. "Low-tech" materials may solve problems when applied in an intelligent way. An example is prostheses.

Among the areas in which the UK shows particular strength the following needs to be mentioned:

Organic ("plastic") Electronics including the development of innovative methods of processing of the relevant materials for mass production of devices; similarly the development of glass fibre optics and related photonic devices defines an area in which the UK holds worldwide leadership. Many aspects of modelling and simulation of materials properties and performance are original to the UK research groups and are finding worldwide acceptance. The construction and implementation of major central research facilities which are in part supported by European partners give the UK materials science community a lead in structural research. Among these centres ISIS, Diamond and a further group of university based centres for specialised instrumentation (e.g. electron microscopy) play a special role and contribute visibly to the international competitiveness of the UK.



4.A.2. In terms of the defined remit of the EPSRC materials programme, are there any areas which are under-supported in relation to the situation overseas? If so, what are the reasons underlying this situation and how can the situation be remedied?

Metallurgy as a field, which was traditionally key to materials science departments, is clearly under-supported in the light of the demands of UK industry. The decline of traditional "iron and steel" industry in the UK may be one of the origins of the present situation. However, given that many challenges and opportunities do exist in industrial metals processing a new awareness of the importance of modern research in metallurgy and related fields (e.g. corrosion science) should be created. Otherwise the current trend seen in the UK industry, namely to hire the required experts with a metallurgy background from overseas thereby increasing the scientific gaps between UK universities and relevant UK industries would continue and become more pronounced.

The local facilities (centres) for high level competitive research making use of specialised and expensive instruments (e.g. centres of advanced NMR-spectroscopy, transmission electron microscopy, optical laser spectroscopy, clean-room facilities) are typically under supported in terms of funds and personnel for maintenance and repair. The lack of maintenance and skilled operation leads to rapid deterioration of initially outstanding facilities and shortens the life-time and viability of such capital investment. Even if such centres have not been originally funded by EPSRC they form the basis on which meaningful materials research activity can be developed.

While the participation of industry including SMEs and start-ups is well accepted among the UK materials science community, it remains unclear to what extent such links are coincidental or are the result of strategic actions by the universities. Forward looking strategies with the aim to develop particular strength in the region or across the whole of UK are not, in general, well enough developed or articulated.

4.A.3. Is the research community structured to deliver solutions to current and emerging technological/societal challenges? If not, what improvements could be implemented?

The relevant research community in the UK has a broad base and is quite strong. Consequently, this community is well-positioned to cope in a competitive manner with new challenges in the materials science area as they arise. Particular strength comes from the fact that it has links that extend into various other communities of academic and industrial research, namely civil engineering, physics, chemistry, biomedicine and life sciences. In other words, it is well embedded in a rich and highly structured research landscape within the UK. The funding mechanisms are well suited to fit to this situation. They offer sufficient and necessary freedom to adjust individual research projects to exploit interactions between the different fields. Participation of industry in this process is welcome and sufficient numbers of mechanisms are available to adjust the funding situation accordingly. This includes questions of IP-protection and knowledge transfer.

A problem exists in that the time-scale of most materials-related developments in industrial practice far exceed the duration of a single funding cycle. Mechanisms need to be found to enable materials developments to realise proper funding to permit success. One method of achieving this end is to develop a **road-map** that indicates the amounts and sources of funding to address questions such as materials safety and recycling, development of proper and efficient processing methods and other factors relevant to industrial commercialisation.

4.A.4. Are there a sufficient number of research leaders of international stature evident in the UK? If not, which areas are currently deficient?

The number of research leaders of international stature in the UK is certainly impressive considering the size of the scientific community. However, leadership is unevenly distributed both regarding age and specific expertise. While examples of aggressive recruitment of young talent can be identified in many places doubts remain whether this talent is properly **nurtured**. Such nurturing is necessary to ensure optimal conditions for their growth. In particular, a lack of **start-up funds** for young academics is common in UK universities. This situation is quite different from that found in other countries where universities and research organisations frequently compete for the same pool of talent. The lack of funds on this level of career development impedes rapid and independent growth of young talents to eventually achieve international leadership.

Looking across the areas covered by the present UK materials science community a stronger interaction with the engineering and process science community should be encouraged. There is insufficient concentration on novel and innovative methods of materials processing, neglect of issues relating to surface modification and thin-layer technology and lack of input into micro-/ nano-electronic engineering, just to mention a few. These issues clearly point to a lack of highly visible research leaders which, in turn, may be a consequence of a blind spot of the research community.

4.B. To what extent is the materials research base contributing to other disciplines and multidisciplinary research?

4.B.1. What evidence is there that there is sufficient research involving investigators from a *broad range of traditional disciplines including chemistry, physics and engineering as well as materials scientists?*

The Panel noticed a great diversity in methods for enhancing interdisciplinary research, dependent primarily on the local situation, i.e. university culture, history of materials-centred activity, etc. At least four models were identified:

- An existing materials science department (there are only around 6 remaining in the UK). In some cases these were all encompassing, including staff from other disciplines, with appointments in the materials department, in essence a stand-alone effort.
- An existing materials science department with outreach to other departments, chemistry, physics, engineering, etc. involving institutes with a thematic focus, as well as pair-wise interactions with other departments.
- No existing materials science department but multidisciplinary institutes, often based around a theme, that are performing research but do not have affiliated teaching faculty. The most effective of these involved co-location of the involved staff or at least central location of common facilities.
- No existing materials department nor research institute but pair-wise research interactions between research groups.

It is our view that interdisciplinary research is wide-spread and viable in many places in the UK. This appears to be spurred on in part by increasing involvement in investigations of complex systems and processes which require interdisciplinary teams. Nonetheless, in many university environments, the interdisciplinary activation barrier is still high. Even when examples of success can be found, these successes often require exceptional efforts to sustain them. This is similar to the lessons learned during the early day of the Materials Research Labs (MRLs) in the US. One issue which arose in many discussions concerned the attribution of "credit" for cross-departmental grant proposals. It was widely perceived that the principal investigator and his/her department aquired all or most of said credit to the disadvantage of co-applicants and departments. This matter

assumes importance only because it affects the outcome of RAE scores. This could be viewed as an unintended consequence of the RAE. This is clearly a problem on both the intra-university and inter-university levels and the Panel perceived this as a barrier to multi-disciplinary research efforts. While EPSRC staff maintained that credit attribution for the research it supported was in fact distributed in a fair and proportional manner, the opposite perception certainly exists within the community. The actual EPSRC and Funding Council (in the case of the Research Assessment Exercise) policy should be more widely publicised.

4.B.2. Are there appropriate levels of knowledge exchange between the materials community and other disciplines? What are the main barriers to effective knowledge and information flow and how can they be overcome?

Within individual universities, the co-location of involved faculty and students and the establishment of central facilities not connected with a specific department or individual, has proved to be very effective in enabling multidisciplinary research. As well, the large international facilities (ISIS/DIAMOND) play a strong role here as they are inherently multi-user and multi-disciplinary. Nonetheless, much remains to be improved. The national inventory of materials science hardware is neither well known nor widely disseminated. In many cases, this even applies at the intra-departmental level! Young researchers, PhD and postdoctoral level, are the group most adversely affected. University structure, traditionally based along disciplinary lines, is the problem here. Creative efforts to surmount the barriers are needed. It is noted that incentives such as subsidies from the central administration that recognise the value of achieving economy of scale have been helpful at institutions in other countries.

4.B.3. What evidence is there to demonstrate the influence that the EPSRC programme has had in encouraging multidisciplinary research?

There is abundant evidence that EPSRC programmes have enhanced multidisciplinary research nationwide. The practice of funding research proposals involving different departments within a university or even between or among more than a single university has been effective. This impression was formed from responses to direct questions from the Panel as well as from the actual numbers of clearly multidisciplinary programmes which were presented during the visits. As mentioned above, the increasing importance of programmes addressing complex systems, which often feature industrial involvement, also drives multidisciplinarity.

4.C. What is the level of knowledge exchange between the research base and industry that is of benefit to both sides?

The knowledge exchange between academia and industry varies greatly between different fields. In some fields, the closeness and extent of industrial collaboration was very impressive when using international standards as the basis for comparison. This was evident in university connections with some sectors of large scale industry, but also industrial participation in university research centres exploring new fields. The close contact is a considerable national strength, but in the worst scenarios, adverse changes in the industry may also adversely affect the university activities. Such a close collaboration seems to be driven by many factors. We were told that the collaboration with UK universities is "easy" compared to other international experiences. In several cases the national industry specifically searched for university partners geographically close to their own industrial activities. This promotes close information exchange between the industry and university in the form of consultancy, addressing challenging industrial development problems, promoting access to sophisticated facilities and training in their use. In some cases the industrial R&D seems to have declined but, in contrast, in other cases the large scale industry is currently forming research centres at universities. Funding for these centres appears to come from many sources and the collaboration is beneficial for the universities. The competitiveness of UK academia is appreciated also internationally, e.g. recently a multinational materials manufacturer selected a UK university as its research partner to develop global expertise. We found that the interactions range from long-term pre-competitive to short term applied development.

4.C.1. What is the flow of trained people between industry and the research base and vice versa? Is this sufficient and how does it compare with international norms?

There was limited evidence presented regarding the exchange of faculty and technical staff from companies. In other countries there are reasonably successful examples of ways to accomplish this interchange. Included are separate faculty "tracks" for high calibre individuals who have spent most of their time in an industrial setting. The individuals have backgrounds that are complementary to the traditional academic experience, yet are not viewed as comparable by most academics. Provision of a separate career track provides a means of appointing such individuals. To enhance appreciation of the industrial "culture", incentives for academics to spend some of their sabbatical leave at companies have been shown to work elsewhere (e.g. the NSF GOALI Programme in the US). Finally, formalising provisions for industrial researchers to spend shorter (6 months) periods at a university for exchanges of ideas and, perhaps, a degree of self reinvention can be very productive. Such activities are occurring now but are largely accomplished on an ad hoc basis.

Recommendations:
C1: EPSRC should take the lead in establishing mechanisms for the exchange of personnel between universities and industry. There will be a number of inter-organisational issues to be resolved, so it is recommended that a representative industry group be engaged early in the process.

4.C.2. How robust are the relationships between UK academia and industry both nationally and internationally and how can these be improved?

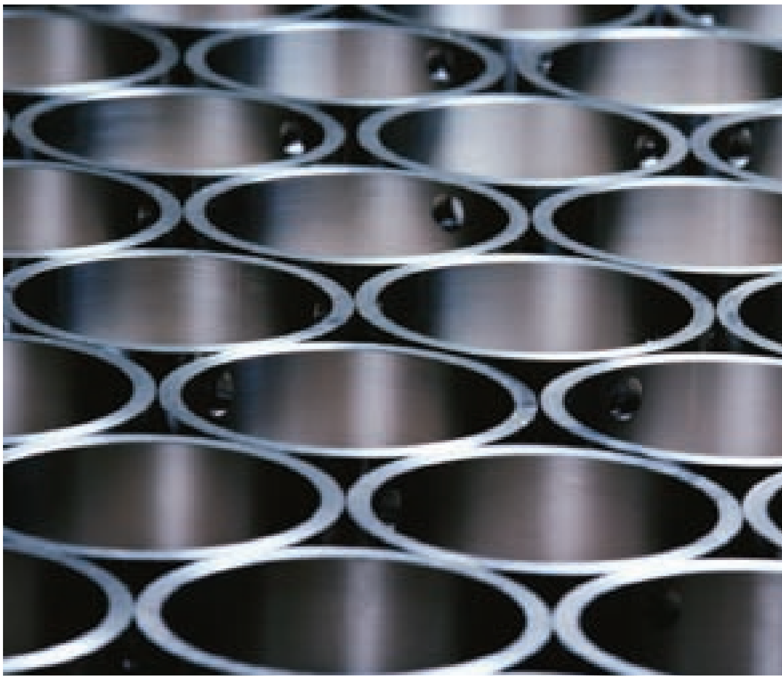
In emerging fields, where the industry more depends on SMEs, spin-offs and start-up companies, the situation is often fragmented and more science-driven. The university connections are often made using the university research centres. This is also the situation globally. But, for example, even in fields related to soft matter and nanotechnologies, a concern was expressed that, in competition with the "trendy" research titles, it is challenging to acquire funding to develop the core materials science understanding of immediate interest to industry.

Recommendations:
C2: EPSRC is encouraged to support grand scientific and technical challenges that are jointly defined by the academic and industrial communities.

C3: To better engage industry and academic communities the EPSRC research portfolio should be presented in a format that reflects both near and long-term strategic objectives. Proposal solicitations also would benefit from such clarity.

C4: EPSRC must establish and maintain a very close partnership with the Technology Strategy Board (TSB) to ensure very smooth hand-off of research to development.

4.C.3. To what extent does the materials community take advantage of EPSRC schemes to enable this knowledge exchange? Is there more that could be done to encourage knowledge transfer?



EPSRC has been encouraging the transfer of knowledge generated by its programmes. The learning curve for both sides can be steep and the process time consuming. We found the EngD scheme is an efficient way to promote the interface between the industry and universities, therefore further development is strongly encouraged. However there is a perception among regular faculty members that the EngD is not recognised as a "real degree" in some circles. This is unfortunate and engagement of potential employers in discussions could help clarify this point.

Intellectual property (IP) in general seems not to be a large issue even if some variations were observed. Delays of publication and even theses up to 18 months until patents are secured can be an issue in some cases. In some areas there was no culture of patenting. EPSRC has already provided IP guidelines which can be found at: *http://www.epsrc.ac.uk/Business/Guidance/CollaborationAgreements.htm*. Unfortunately, these are not broadly recognised.

Recommendations:
C5: EPSRC is encouraged to broadly publicise their guidelines for the handling of IPR, especially as this relates to delay of publications.

C6: In several fields ranging from more traditional to very high-tech fields, the concern was expressed regarding the funding level for core knowledge creation. EPSRC is encouraged to maintain the balance between this and research with potential applications in the long and shorter term.

4.C.4. What is the scale of industrial R&D in materials nationally and internationally and what is the trend? What are the implications for the UK materials research community and to what extent is it well-positioned to respond? Is there any way that its position could be improved?

With the demise of long-term research in corporate research laboratories, there is a need to fill the gap between the research activities and products. Spin-offs fill some of these gaps. Mechanisms need to be explored to capture the value of the research. Some industrial firms make good use of spin-offs to gain access to the IPR.

Recommendation:
C7: Establish a fund for early stage commercialisation investments (e.g. Small Business Innovation Research Programme (SBIR)). The EPSRC "Follow-on-Fund" addresses this issue but doesn't seem to be well recognised.

4.D. To what extent is the UK materials research activity focused to benefit the UK economy and global competitiveness?

Historically the UK has been at the forefront of both the development and manufacture of new materials, and also the sale of products enabled by new materials. From the advent of the industrial revolution up until World War II the UK was a primary global source of both innovation and new manufacturing technologies in the area of materials.

However, the economic context in which the International Panel addressed this question has changed significantly since the pinnacle of UK manufacturing early in the 20th century. Anecdotally, it is understood that traditional manufacturing technologies are contributing proportionally less to the UK economy than they did previously. The context of the transition is the maturation of many of the materials industries (e.g. metals, building and construction materials, etc) and the concomitant reduction in gross margins of the products in these industries, which has led to a drift of the manufacturing to lower cost economies, particularly in Asia.

This transition of manufacturing to lower cost economies has had two unexpected and probably unwanted outcomes. First, it has meant that the UK has had a reduced industrial base that can define, innovate and exploit new materials opportunities; and, secondly, the UK academic sector in materials has had less input from industry both in terms of defining opportunities and exploiting outcomes.

The issue can be clearly defined as a lack of "critical mass"; without a large and diverse industrial base to drive innovation, the residual pockets of materials excellence in academia appear to have become increasingly isolated and less effective at creating an impact on the UK economy (at least this is what was argued to the International Panel by many academics).

But not all areas of materials are in unattractive low margin industries; key high technology industries such as the defence industries, security, the energy sector and the medical sector are all high margin and growth industries. However, the growth of these sectors in the UK does in fact rely on a thriving academic materials base to supply qualified students, support for product development and the source for potential new technology platforms to replace ageing platforms. The risk to the UK economy is that without a thriving academic base, the longer-term outcome will be that UK materials companies or their UK customers will become less globally competitive, and the UK will have to import more or all of its material products, whether they be old low margin products, or the newer high margin products.

Addressing the question as to whether the UK desires low or high margin materials industries, or both, is outside the scope of this Panel. However, we note that physical goods still make up a large fraction of all human activities, and that materials incorporated in physical goods are undergoing continual renewal and improvements, especially in the context of increasing consumption, continually lowering costs, the influence of global warming related policies and limited resources. Whilst the argument for maintaining specialist high margin materials industries is easy to make, it could also be argued that these high margin industries can only thrive and grow where there is a large base of lower margin materials industries to help create the overall environment for materials focus and excellence. It should also be remembered that low margins tend to be off-set with high volumes, and hence high overall revenues (and more importantly high impact on national deficits if these products have to be imported).

4.D.1. What are the major innovations in the materials area, current and emerging, which are benefiting the UK? Which of these include a significant contribution from UK research?

The International Panel identified areas of particular strength in materials science and technology in UK universities, specifically with regard to the following companies and sectors:

- Rolls-Royce –high technology structural materials.
- Corus – added value to steel products.
- Semico, MEMS and Optoelectronics – potential start-up opportunities that are not systematically exploited to create long-term economic benefit to the UK but lots of niche defence benefits.
- Fuel cells – no economic activity.
- Scientific instrumentation – strong innovation but less commercial activity.
- Soft matter – almost exclusively focused on Bio applications except for Unilever and some areas of excellence in soft electronics.
- Functional materials (magnetics and superconductors) – good research base looking for industrial applications.

The exploitation of academic capability or inventions from UK universities falls roughly into three areas:

- The first is where the technology development is being advocated and partially sponsored by UK industry, and a key example is Rolls-Royce which actively promotes activities which help keep it at the forefront of the aerospace engine sector.
- The second is where the technology development is being sponsored by non-UK corporations. We saw examples of this in the rubber, display and semiconductor industries.
- The third is where there is no industry to exploit the capability or inventions in the UK (or elsewhere) and the intention (if articulated) is for new companies, probably funded by venture capital, to be developed in the UK or elsewhere to take up these innovations.

Clearly the greatest contributions to the UK economy, with the lowest risk, are achieved where current UK corporations advocate and partially sponsor the research. Alternatively they can be actively involved in collaboration with the academics, which will aid the adoption by these companies of any inventions made at those universities. The collaboration will also help shape the direction of research, such that key problems identified by the industry partners are solved by academics.

Successful arguments supporting programmes where the UK taxpayers sponsor research in UK universities that is exploited by companies outside the UK are few, but include creating meaningful international collaborations with best of breed international companies, which may eventually lead to the essential acquisition by the UK of key know-how and capabilities. This could in turn lead to foreign corporations setting up UK operations (which has happened), or even new start-ups in the UK that are focused on these areas.

In the materials space there is evidence of significant activity in the UK of the creation of new companies through the collaboration of both angel- and venture-backed start-ups with UK universities. There also are direct spinouts from universities. However, in many cases the start-ups have failed to mature into stand-alone UK corporations, and have instead been sold off to foreign interests. Even so, in many cases at least the benefit of the R&D realised by these companies has remained in the UK.

Recommendation
D1: A quantitative review of the materials start-up activity in the UK over the last 25 years would be useful. The Panel was working off anecdotal evidence.

4.D.2. How successful has the UK materials community (academic and industrial) been at innovation? What are the barriers to successful innovation in materials in the UK and how can these be overcome?

In the traditional venture capital sectors of software, semiconductor design and internet, the time-to-market for a new company is relatively short, and essentially no investment beyond salaries and computers is required. Hence, these types of start-ups have been favoured by venture capital. In the biosciences the path to revenue is much longer, but venture capital has still been able to invest in this sector due to the willingness of the biosciences corporations to acquire pre-revenue companies. No such willingness exists (systematically) in the materials space.

In fact, a start-up in the materials sector must often do some or all of the following:

- Design and prove a new material.
- Modify or design a new manufacturing process to make the new material.
- Design a new product or modify an existing product to accept the new material.
- Modify or design a new manufacturing/assembly process for the new product that incorporates the new material.

This heavy reliance of physical technology often takes at least 5 years and sometimes more than 10 years to get from concept to product revenues. In the absence of a corporate sector that is keen to systematically support start-ups in the materials space (by acquiring pre-revenue companies or investing directly with long-term intent), success from venture activities in the materials space will remain sporadic. The answer is probably further government intervention to create a scheme to support the prolonged pilot stage for the development and application of new materials – this is probably a gap that may have once been filled by the more applied government labs.

Recommendation:
D2: There is certainly scope for further investigation into the success or otherwise of materials start-ups in the UK and an assessment of what, if any, government strategies could be created to help foster more success from these activities.

In general the Panel saw many universities where it appeared academics were working on areas with high degrees of novelty, and some projects that had led to new inventions. However, except for a few pockets of excellence, we saw little evidence of a strong connection between the choice of inventive activity and economic outcome for the UK. This could be due to the lack of a strategic structure in which the academics can measure their proposed projects, or it could be due to an academic culture that does not really want too much interference from industry or government strategic input that infringes on academic freedom. There was also the suggestion that measures of academic merit, such as publication counting and citation indices, were corralling academics into specific clusters of research activity (in order to ensure sufficient impact to achieve grant funding); the issue the Panel identified is that these cluster areas do not necessarily match with areas which would have the maximum economic impact on the UK.

Recommendations:

D3: The Panel believes these factors need to be systematically studied with quantitative data in order to understand how research funding processes could be more aligned with UK economic goals.

D4: Overall, the Panel believes that recommendations as to how the UK university system in materials could best serve the UK economy are best made in the context of an overall strategy for the future direction of the UK materials sector. Once such a strategy was in place it would be easier to determine how funding for the university sector could best serve these strategic goals.

4.E. To what extent is the UK able to attract talented young scientists and engineers into materials research? Is there evidence that they are being nurtured and supported at every stage of their career?

The future of materials research in the UK depends critically upon its students, postdoctoral associates/fellows, and young faculty members. The Panel met with groups of these young scientists at each of the venues they visited, and found many to be of the very highest calibre. Nevertheless, there were some areas of concern, as described in the following.

> *4.E.1. Are the numbers of graduates (at first and higher degree level) sufficient to maintain the UK research base in this area? Is there sufficient demand from undergraduates to become engaged in materials research? How does this compare with the experience in other countries?*

The availability of talented individuals to fill each stage of the academic pipeline is a major issue in the UK, as it is in most developed nations. Undergraduate

enrolment in UK materials departments is declining. This is a challenge also in the USA, for example, where many materials departments struggle to maintain undergraduate programmes that are viable in numbers. However, it is even more notable in the UK, where the number of conventional materials departments has declined so significantly in recent years.

Inevitably, given both the paucity of materials undergraduates and the interdisciplinary nature of the materials field, postgraduate materials researchers will have received their undergraduate training in a range of disciplines and indeed perform their PhD work in a broad set of departments. This interdisciplinarity in training and research is an enormous strength of the materials field. However, the Panel finds an area of considerable concern arising from the declining number (currently about six) of formal materials departments in the UK. The Panel found that there is increasing evidence for a lack of available training/classes in the key core concepts of materials science. To a limited degree this can be an issue even within formal materials science departments, given the current trend for broadening of materials curricula. However, the major issue arises at institutions where there is no formal materials department, and students are housed in a range of disciplines. This constitutes the majority of PhDs in the field of UK materials research. While the interdisciplinary training inherent to this configuration can be superb, the Panel is concerned that some of these PhD students may have little or no exposure to classes that cover the core concepts and methods of materials researchers. The Panel believes that if the postgraduate degree is described as being in the field of materials research, the student should have a strong knowledge of the core tools and concepts that comprise materials science and engineering. The apparent lack of such knowledge is already generating concern among industrial employers, several of whom lamented to the Panel that they could not find sufficient UK students who they found to be adequately trained in materials science. The Panel is thus concerned that a generation of PhD materials students may in large numbers lack the necessary underlying fundamental knowledge of materials science, with serious potential consequences for the future of the UK materials enterprise. The Panel also encourages the development of more extensive research opportunities for undergraduate students.

Recommendations:

E1: The Panel recommends a coordinated national effort to increase the awareness of materials as an attractive and fulfilling career option.

E2: The UK should review the situation with respect to foreign students: visas, work permits, living expenses and fees, in order to fulfil the needs of industry for sufficient numbers of high quality students.

4.E.2. How effective are public engagement activities aimed at attracting school age students into materials?

A critical issue here is the lack of awareness of materials science and engineering as a discipline among students as they enter the undergraduate population. The Panel applauds efforts by some universities to develop the awareness of secondary school students of materials research, and this is clearly an immediate and effective approach to increasing undergraduate interest in materials. Nevertheless, this activity is very uneven across UK universities, and it does not appear to be well coordinated between institutions. Another activity noted with approval was efforts to incorporate elements of materials science into A-level curricula.

There exists a real concern that there is not sufficient physical metallurgical knowledge as the number of materials departments within universities has been reduced. This brings a considerable mismatch between the industrial needs and education, as industries that use structural metals are having difficulty in finding and employing sufficient numbers of highly qualified personnel with core materials science expertise. To attract more students, the most effective university outreach programmes should be identified and used as best practices for other institutions. Traditional materials science could be presented as an exciting and inspiring field, for example by showing how it is a key contributor to solutions of contemporary problems such as energy, climate change and national security.

Recommendations:

E3: In order to attract a sufficient amount of high quality students, the best university outreach programmes should be used as a nation-wide model. The Panel recommends a coordinated national effort in outreach built on Best Practices adopted from the most successful programmes already in existence at some universities.

E4: The Panel recommends that a core set of knowledge be defined for materials science, and that any student funded within the materials remit be demonstrated to have been formally trained in this knowledge by the time of their thesis defence.

4.E.3. Are there areas of weakness - is the UK producing a steady-stream of researchers in the required areas and/or are there areas that should be declining to reflect changes in the research climate?

The Panel found the best of the PhD students they met to be superbly motivated, knowledgeable and enthusiastic about their work. They are clearly competitive with any comparable group in the world. The broader distribution of students the Panel met, however, did not always demonstrate such mastery of their field, and often appeared unsure of the context and significance of their work. In some of the multidisciplinary materials centres, the impression of the Panel was that some students lacked a strong sense of community or academic identity. The Panel believes that recommendation E4 could help address this issue. Another crucial factor restricting the talent pool at the postgraduate level is the current UK policy on the citizenship of students that are eligible for UK Research Council funding, currently restricted to UK citizens (or those completing undergraduate studies in the UK) and limited opportunities for EU citizens. Access to the full global talent pool for postgraduate students would be a major impetus to UK materials science and engineering.

The development of students with experience and skills operating the most advanced equipment is another important underpinning of the future health of UK materials research. While some EPSRC-funded major facilities provide full hands-on access to students, others do not. This will inhibit the development of future leadership in these techniques. The Panel urges EPSRC to ensure that all facilities they fund include extensive hands on experience for students. The Panel also felt there was merit in the suggestion made by some students to form national student networks among those working in similar fields.

Several universities visited by the Panel described formal programmes for skills set development for their PhDs, combining compulsory and optional elements. These appeared to be well thought through, although most were relatively recent and in the process of refinement. In general, the students appeared to appreciate these efforts and found them worthwhile, although they found some of the compulsory courses rather repetitive and basic.

Recommendation:
E5: To effectively compete on the global stage, the Panel strongly recommends a systematic review of the factors and limiting processes that are preventing access to the full global talent pool. Included should be issues such as the granting of visas and work permits.

4.E.4. How does the career structure for materials researchers in the UK compare internationally?

The Panel also met with multiple groups of postdoctoral students. Again, the most talented of this group were competitive with the very best in the world. There seemed to be considerable uncertainty among many of the broader group, however, as to the pathways to permanent academic positions, and as to the strategies for best positioning themselves for this transition. There was also widespread concern about the paucity of available academic positions. Further, many postdoctoral associates had been through a set of short term (one to two year), often rather unrelated, contract positions, and felt they were not developing the coherent body of experience and expertise necessary for career progression. Many also felt that career development advice was lacking. On the positive side, the great majority of postdoctoral associates reported that they had considerable research freedom within the boundaries of their project definition, and that they were mentored effectively by their immediate supervisors. It is also clear that the fellowship mechanisms established by EPSRC, Royal Society and other organisations are very successful programmes. They provide a highly effective mechanism for retaining and recruiting the most talented young scientists, and are an effective "fast track" to an academic position. However, some suggestions for improvement were heard by the Panel. These include more ability to apply for competitive grants while on fellowship, and better defined mechanisms for transition from a fellowship to a permanent position. Nevertheless, the various fellowship programmes are highly successful retention and advancement mechanisms for talented young scientists. Finally, with respect to recruitment of postdoctoral associates from within the UK and from abroad, uneven success was reported even at the most eminent institutions. Salary was sometimes identified as a barrier to recruitment.

Recommendation:
E6: The Panel recommends that EPSRC work with universities to develop "best practices" for hiring, mentoring and career development of postdoctoral associates. Included should be a means of creating greater research independence at earlier stages of their research careers. For example, creating mechanisms for pursuing original research avenues that are more independent of senior faculty such as more direct access to equipment or seed grants.

4.E.5. To what extent is the UK able to attract overseas materials scientists and engineers to the UK? Is there evidence of ongoing engagement either through retention within the UK research community or through international linkages?

The Panel was greatly impressed by the quality of the young faculty members it met. There was compelling evidence that the UK system was effective in developing the most talented young scientists and engineers for these positions. Most, but by no means all, of these young faculty members had progressed to their positions through fellowships. As a group, they were energetic, enthusiastic, articulate and highly talented. They were also generally very positive about their experience. They were excited about their research opportunities, and generally positive about the portfolio of programmes that could fund their activities. The EPSRC First Grant mechanism was particularly praised. One potential area for improvement was the perceived lack of mechanisms for setting up a new experimental laboratory. Young faculty found they had to piece this together from a number of funding sources, but at least felt that the challenges were surmountable. The announcement by one visited institution that they intended to provide new faculty with "internationally competitive" start-up funds would be an additional factor here. In general, the Panel heard that start-up funds provided by most institutions were relatively modest by international standards. The young faculty also reported generally positive experiences with informal and formal mentoring programmes, although it seems that some institutions could still improve in this area. Overall, however, the Panel felt that the quality of the young faculty and the programmes they were developing were fully competitive on the international stage.

4.F. To what extent are UK researchers engaged in "best with best" science-driven international interactions?

Accelerating globalisation of the knowledge economy ensures that research in science and engineering is increasingly an international enterprise. Materials research is no exception. Effective international engagement, both through high-level science-driven research collaborations, and through involvement with and investment in major international research programmes and facilities, is crucial to the UK materials research effort, if it is to sustain an internationally-competitive position and an influential leadership role. It is pleasing to note that the EPSRC materials programme is well aligned with the international research strategy of RCUK to meet these broad objectives.

4.F.1. What is the nature and extent of engagement between the UK and Europe, USA, China and India respectively?

The UK research community demonstrates evidence of very significant participation in research programmes defined by the European Union (EU) across the full spectrum of research activities defined by EPSRC materials sub-programmes. Such engagement is invariably at a high level that is ensured by the intense competition for funding from EU Framework Programmes, and is seen as a point of distinction by all groups. It is arguable that European interaction should be seen as a template for broader international engagement in so far as it has led to the following:

- an increased profile for UK materials research and increased opportunities for the UK community to influence the European research agenda.
- a very substantial contribution of EU funds to UK-based research teams and centres.
- employment of young academic/research staff with international backgrounds, specifically from EU member states, that has significantly broadened the UK human capital base in materials research.
- increased opportunities for international experience and employment for UK research graduates.

Despite these positive signs, facilitation and strengthening of European engagement must continue to be encouraged as a matter of priority.

A particular feature of such engagement is the increasing focus of major collaborative research programmes involving large-scale research facilities, both in the UK and Europe. These programmes have seen not only significant and well-justified UK investment in major European facilities, but equally substantial EU contributions to large-scale facilities (e.g. ISIS) critical to the UK research base. Facilitation of access to such facilities is seen to be a highly effective means of promoting high-level international research collaboration.

UK interaction with the USA in materials research reflects both common and complementary interests and capabilities, and is founded upon a sound base of mutual respect and a record of successful collaboration. Based on the number and value of research projects bearing evidence of UK-USA linkage, this interaction is seen to be strong and healthy. The Materials World Network initiative, led by the US National Science Foundation, currently provides highly commendable direct support of typically £1.5 - 2.0M per annum for USA-UK collaboration. However, it is arguable that the linkage is still largely founded on collaboration through projects that are independently funded in the respective countries. When compared to European programmes mentioned earlier, it is significantly constrained by limited mutual funding for

genuinely cooperative research activities. The competition for limited funding ensures that existing collaborations are of the highest calibre. However, because the competition is for a finite set of resources, there are numerous worthy opportunities to further strengthen linkages that go unfunded. A more substantial investment in an expanded range of programmes directed to common strategic priorities is clearly warranted. There is also perceived to be a mismatch in the potential project scope for key funding agencies, most notably EPSRC and the National Science Foundation (NSF) in the USA. Providing better coordination and greater clarity on mutually agreed research objectives, expected outcomes and common programme guidelines would be a valuable evolutionary programme development step by these agencies.

There are encouraging signs that the materials research community in the UK is showing renewed interest in increased interaction with India, and there is some evidence of recognition of rapidly emerging opportunities in China. Both countries are, however, still largely considered as a resource base for research students and, to a lesser degree, research staff. There is currently limited evidence of science-driven research engagement with the better quality, research-intensive universities and institutes in India and China. Equally, there appears to be only limited UK recognition of the research opportunities with major industrial enterprises in these developing countries. Consequently, materials-related industries seek to fast-track technological development.

There is emerging evidence that UK institutions, research agencies and professional bodies are beginning to recognise, promote and facilitate engagement in India and China. Initiatives of the recently-established UK-India Science Innovation Council, embracing not just science but also innovation, represent a timely example, with funding at a scale that is an order of magnitude higher than just five years ago. However, there appears a lack of widespread recognition within the UK materials research community of the scope of the engagement of other developed countries with these emerging economic powers, and the level and attendant benefit derived from the genuinely bilateral cooperation involved in that engagement. There are risks to the competitive position of the UK research community if a more collaborative form of interaction with Indian and Chinese institutions is not embraced and, as addressed elsewhere, more efficient protocols are not developed for engaging research staff and students from these regions.

There is a history of successful materials research interactions between the UK and Japan at the level of individual researchers and projects. There is also evidence of this engagement beginning to extend selectively to larger-scale programmes initiated within Japan. The current involvement of UK researchers in two materials-intensive World Premier International (WPI) Research Centres launched under the auspices of the Japan Society for the Promotion of Science (JSPS) is a recent example. However, the current level of bilateral engagement is low, compared with Europe and the USA, and is only likely to expand significantly in the near-term with pro-active strategic policy initiatives and investment from UK agencies.

4.F.2. How effective is the engagement between the UK and the rest of the world? Are there particular issues for the materials research area? What could be done to improve international interactions?

Beyond Europe and the four countries (USA, Japan, India and China) designated for emphasis under the RCUK International Research Strategy, international engagement is widespread but, by most measures, limited in scale and largely restricted to interaction at the level of individual researchers and projects. Provided that such interactions engage ‘best with best’, they will continue to deliver significant value to the UK materials research effort, most notably through exchange/acquisition of high quality research staff and students.

From an international perspective, the five leading research universities, in terms of cumulative EPSRC materials programme funding, continue to be seen as benchmark institutions in the UK across a broad range of materials research activities. Other institutions are recognised for world-class capability in specific research fields, either as a result of a strategic institutional decision to focus activity or as a result of the emergence of outstanding research leadership. All institutions in the top twenty attracting EPSRC materials programme funding overtly recognise a need for institutional focus and specialisation, and efforts to define world-class centres of excellence are to be encouraged if UK materials research is to maintain the desired international profile.

Collectively, the special capabilities and focused materials research activities, that distinguish UK institutions as preferred international research partners and destinations for research and staff of the highest quality, are arguably less frequently to be found. UK capabilities in materials research are increasingly matched internationally, both in breadth and depth, by institutions in countries of traditional strength (e.g. USA, Europe and Japan) and emerging capability (e.g. Singapore and Hong Kong). Increasing international competition places a priority on the development by UK institutions and research agencies of new proactive models for outreach in international engagement and collaboration to sustain the UK profile.

Since 2002, among those grants funded by the EPSRC materials programme involving international collaborations, only ~6% involved participation from the Asia-Pacific region. This is not commensurate with the growth in quality and quantity of materials research during the past decade. Research activities within the increasingly powerful emerging economies of this region must be understood and a strategy to connect with them should be promptly developed. In terms of total research output (numbers of publications) in materials science, the Asia Pacific region now leads Europe and the USA, and in the case of the USA the margin is by more than 2:1. While other measures of quality and influence may not currently reflect a similar shift in balance, it is likely that the next decade will see substantial advances in both the quality and impact of materials research from the region.

Effective strategies for improving international engagement will be specific to individual countries and the maturity of existing relationships. Such is the level and sophistication of current UK interactions with the USA and Japan, for example, that significant improvements are most likely to be achieved in the near term by targeted mutual investment in major joint research programmes. In the case of developing countries, such as India and China, significant progress might be made in promoting international partnerships through initial investment in the following:

- targeted international scholarships and fellowships for exchange of research students and staff between key institutions, and/or
- small grants to support networks, specifically for student exchange.

The best value from such investment will likely result from targeted commitment to a small number of institutions of the highest quality.

4.G. What is the impact on a global scale of the UK materials research community both in terms of research quality and the profile of researchers?

4.G.1. Is the UK the international leader in materials research? In which areas? What contributes to the UK strength and what are the recommendations for continued strength?

The Panel is concerned that specific answers to this question cannot be assured without extensive benchmarking data which the Panel did not have. Nevertheless, given what we were presented with during the week and amplifying this with our own knowledge of the UK programme, we were particularly impressed with the quality of the work in the following areas: organic semiconductors, high temperature fuel cell materials, physical metallurgy, especially structural materials, near and net-shape metal forming for aerospace applications, superconducting materials, battery polymer materials, spintronics, quantum computing systems, electron microscopy, optical fibre devices, large user facilities, carbon fibre composites and high speed GaAs electronics. At the root of this success lie talented people who are globally recognised as leaders on the world scene; a pooling of resources and people focused on key problems; and critical mass to carry out forefront work which achieves world-wide recognition and impact. As has been mentioned elsewhere, the quantity of the effort sometimes does not match the demand for graduates in some areas. Physical metallurgy and structural materials are just two examples.

Recommendations:

G1: We recommend that the UK community initiate its own benchmarking effort using the standard metrics (publications, citations, etc) that are becoming applied rather generally world-wide. This can provide judicious feedback for assessing progress in rapidly exploding fields and also help assess declining fields where claims for significant EPSRC support are made. Such quantitative metrics may help alleviate anecdotal concerns that responsive mode review requires a critical community size for funding success.

G2: Beyond publications and citations, which can measure excellence in science, metrics that measure 'innovation' also need to be evolved, monitored, and used for improvement of the overall inputs. Definition of the metrics used to measure innovation should involve a few progressive industrial partners.

G3: We recommend that the EPSRC materials programme re-affirm its unambiguous commitment to supporting world-level quality in all its programmes. This means no compromises in quality will be made in favour of providing near term assistance to industry.

4.G.2. What are the opportunities/threats for the future?

A widely felt concern was conflict between the desire of the UK Government to use research to stimulate wealth creation and the long-term trend of a declining large-industry UK manufacturing base, while not yet having the desired, thriving small and medium enterprise (SME) base needed to fill the gap. Like all mature industrial economies, one can point to the rapid growth of manufacturing and innovation in Asia as a threat to the local application of bright UK ideas, even if they do initially transition to a local SME.

Another threat is concern over with the number and quality of students coming into materials at both the undergraduate and graduate levels. An important related concern was that materials as a subject has broadened and deepened without the core undergraduate discipline of materials reflecting this in a suitable manner. This uncertainty has certainly contributed to the disappearance of traditional departments. One unfortunate result of the demise of traditional departments is that many students entering materials departments at the graduate level often lack certain elements of core knowledge of concepts most commonly found in a materials curriculum, e.g. phase diagrams, solid state phase transformations, chemical thermodynamics and reaction kinetics and mechanical behaviour. These topics are seldom covered to the appropriate depth in the curricula of other disciplines

A further concern is over the balance between short-term research that might be very relevant to industrial needs replacing longer-term, more speculative research.

Recommendations:

G4: To encourage better academic-SME interactions, we encourage greater opportunities for SME-Academic partnerships that can help bridge the gap from idea to manufacture. An example of this is the SBIR programme in the US, which is funded by a 5% set-aside from all federal R&D budgets. The goal is to make it easier for academic enthusiasm to make it to industrial practice.

G5: We heard some good examples of how UK academics had developed new curricular materials for secondary school use and how this had produced both more and stronger applicants to university undergraduate materials programmes. We applaud this initiative and encourage its expansion, perhaps using this initiative as a means of rethinking what the core materials curriculum and department focus should be.

4.G.3. In which areas is the UK weak and what are the recommendations for improvement?

As mentioned in the above discussion of the strong areas of UK science, we are also constrained by the metrics and time to make it clear that we cannot be authoritative in defining weak areas either. Having made this caveat, we felt a broad concern about the need to expand multidisciplinary approaches so as to form genuine collaborations that could address grand challenges such as a National Energy Initiative or Health & Wellbeing. This is the time to exploit existing strengths in the elements that anchor such initiatives, which could also be used to build strong international partnerships and relationships. We also find that the search for new functional materials seems low, and that, like much of North America, there is a low capacity for producing single crystals of new materials. We found that fundamental exploratory science without expectation of immediate outcomes was uneven, as was the translation of these into industrial outcomes.

Recommendations:
G6: We recommend that innovation be included as a measure of success of EPSRC funding. As mentioned earlier, this will first require thoughtful creation of metrics to assess innovation. (See recommendation G2).

4.H. What evidence is there to support the existence of a creative and adventurous research base and portfolio?

The UK has excelled in development of novel processing and analytical science (instrumentation). Examples are photonics, processing of conventional composites, flexible electronics, imaging/diffraction/ spectroscopy, and instrument development. In these areas they are internationally competitive and innovative. The Responsive Mode funding and grand challenge programmes are credited with allowing researchers to propose new adventurous research programmes, with the consensus opinion that this type of funding is most competitive. Longer PhD programmes, which have increased from three to four years, have also assisted faculty in undertaking more speculative research projects that may take longer periods of time to yield publishable results. A culture that continues to encourage faculty and students to take on increasingly bold directions in their research will be important to sustain a competitive presence in a knowledge based economy, and which can extract maximum value from the intellectual resources of the UK.

4.H.1. Is the current balance between high-risk/high-return research and "safe research" appropriate?

In spite of these considerable strengths, the development of new compositions of matter/new materials with disruptive potential for economic and technological impact to the UK research enterprise was judged to be less impressive. This aspect is important given the current emphasis of EPSRC on facilitating innovations that will enhance the future economy of the UK. In developed nations where high fixed costs are not conducive to sustaining production of commodity materials, there is an ever-increasing industrial focus on high value specialty functional materials that deliver larger profit margins. Competition in these areas requires more rapid transition of technology from invention to the market place and constant innovation. As such, increased innovation in new functional materials should be encouraged by EPSRC.

The opportunity for the UK to excel in the development of novel functional materials is considerable and can leverage the excellent talent in modelling and analysis. Indeed, a central challenge posed by modern materials is the difficulty of properly determining their structures and properties. Achieving success in the area of functional materials is also complicated by the need to often create integrated systems. Exploration of new materials, the study of their properties, and creation of integrated devices will be best served by collaborative studies. The field of inorganic materials chemistry is strong in the UK; however the same cannot be said for organic materials, where the UK is not generally competitive with its European peers, with the exception for a few outstanding, but small, individual contributor efforts. The larger exception to this assessment is the activity in organic electronics, which is aided in part by strong international collaborations. In the area of polymer chemistry, the UK lags considerably behind peer nations in both the design of new polymers and development of novel synthetic methods.

Historically the UK has been strong in supramolecular organic chemistry and there is a natural extension of these concepts to materials. In this area there are pockets of excellence, however the magnitude of the effort is limited. Liquid crystal research is an area that must be considered a historic strength of the UK and increased focus on leveraging this talent for unconventional applications is recommended.

Given that organic materials are needed in much greater diversity and represent the majority of emerging functional materials markets, it is important to place greater emphasis on organic materials/macromolecular chemistry. These efforts will benefit from the expertise in device integration, processing, theory, and analytical studies. Materials with novel electronic, magnetic, mechanical, interfacial, and optical properties will underpin these innovations. In the solid-state electronics area, the UK must adapt to the lack of a large-scale international semiconductor industry. The existing national and regional growth facilities and the demonstrated excellence in characterisation have the potential to facilitate the development of advanced and ultra fast semiconductor heterostructures, carbon nanotube based electronic devices, magnetic materials for new types of spintronic devices, and to continue exploring novel low dimensional functional materials. Nanomaterials will continue to have prominence in new materials development and longer-range views in some cases are needed to properly capitalise on the unfolding opportunities. For example, although there is considerable emphasis on the formation of classical composites, nanocomposites are underrepresented. The situation is exactly the opposite in most other developed countries and, as a result, the UK needs to be careful to not over emphasise near term research goals relevant to local industry at the expense of long-term opportunities for innovation.

4.H.2. What are the barriers to more "adventurous research" and how can they be overcome?

More adventurous research will often require longer-term planning on the part of EPSRC. There is concern that projects that do not mature in a 3-5 year time horizon will not be provided for in the future with responsive funding that emphasises new adventures. Researchers will benefit from larger and longer-term grants, wherein they feel comfortable applying part of their resources toward more speculative research.

Grand challenges are potentially an important vehicle to encourage adventurous projects with possible high economic return. There is a concern among a number of Panel members and researchers that excessive EPSRC top-down direction of research restricts innovation, some of which is traceable to the influence of industry. As a result, an "open" category of grand challenge grants should be encouraged.

In its best form, adventurous research will lead to seminal discoveries that can define a researcher's career and can define mid-career and younger researchers as international leaders. The UK academic demographics appear as a pyramid structure wherein the vast majority of the best-known world-class researchers are in the later stages of their careers. Mechanisms that encourage higher risk projects for younger scientists without impinging on their career progression are recommended in the hope that new generations of scientists can emerge on the world stage and drive future science and engineering innovations. Creating the expectation that some "adventurous research" should be part of PhD research could be a low-risk way to accomplish or at least start overcoming the fear of failure.

4. I. Other Observations

In addition to the responses to the Framework Questions included in the previous section, there were several observations that were common enough between venues that the Panel felt they should be included in the report. These are contained in this section.

4.I.1. Faculty diversity

One issue that concerned the Panel was the lack of diversity of the faculty groups they met. Given that these groups were generally presented as the leadership of the institutions they visited, the lack of gender diversity in particular was very troubling. While EPSRC statistics show that 11% of grants in the materials remit are awarded to women (a statistic that in itself gives rise to concern), the faculty leadership groups we met with were even more overwhelmingly male. With only a few exceptions, virtually all presentations were made by men, and a typical scenario was for there to be just one or two female faculty members in the room among a few dozen male faculty members. While recognising that under-representation of women in science and engineering is a global problem, the Panel was troubled that the participation of women among these leadership groups was a good deal below even the low numbers for female faculty generally in the UK. On a more positive note, the diversity of graduate students, postdoctoral associates and young faculty members seemed to be consistent with international trends. The Panel strongly believes however that there is an urgent need to improve diversity among groups designated as faculty leadership.

In most developed countries ethnic diversity is a far greater issue than gender. It is also country specific. The Panel did not feel qualified to address this issue in the UK.

4.I.2. Major Research Facilities

Materials Science and Engineering has a significant experimental component and the nature of the experiments is becoming much more sophisticated as new measurement and analytical capabilities emerge. While the power of these new capabilities is vitally important, the cost of acquiring and maintaining the facilities necessary to perform these measurements also is escalating rapidly. In fact, the ongoing support of these new facilities is more onerous than the acquisition cost. This was a recurring theme at several of the venues. This item is meant to call attention to this point and to encourage some innovative thinking on the part of EPSRC and the universities to overcome this barrier. EPSRC has started an activity in this area, but its recognition needs to be improved.

4.I.3. Awareness of the Importance of Research Impact

The whole notion of the impact of the research being conducted was not common among the academics that spoke to the Panel. This is despite the matter being explicitly addressed in Framework Question G. It would be very useful for EPSRC to develop guidelines for determining impact so this assessment can be done uniformly. Having measures of impact could also be quite helpful during budget discussions, especially when budgets are tight.

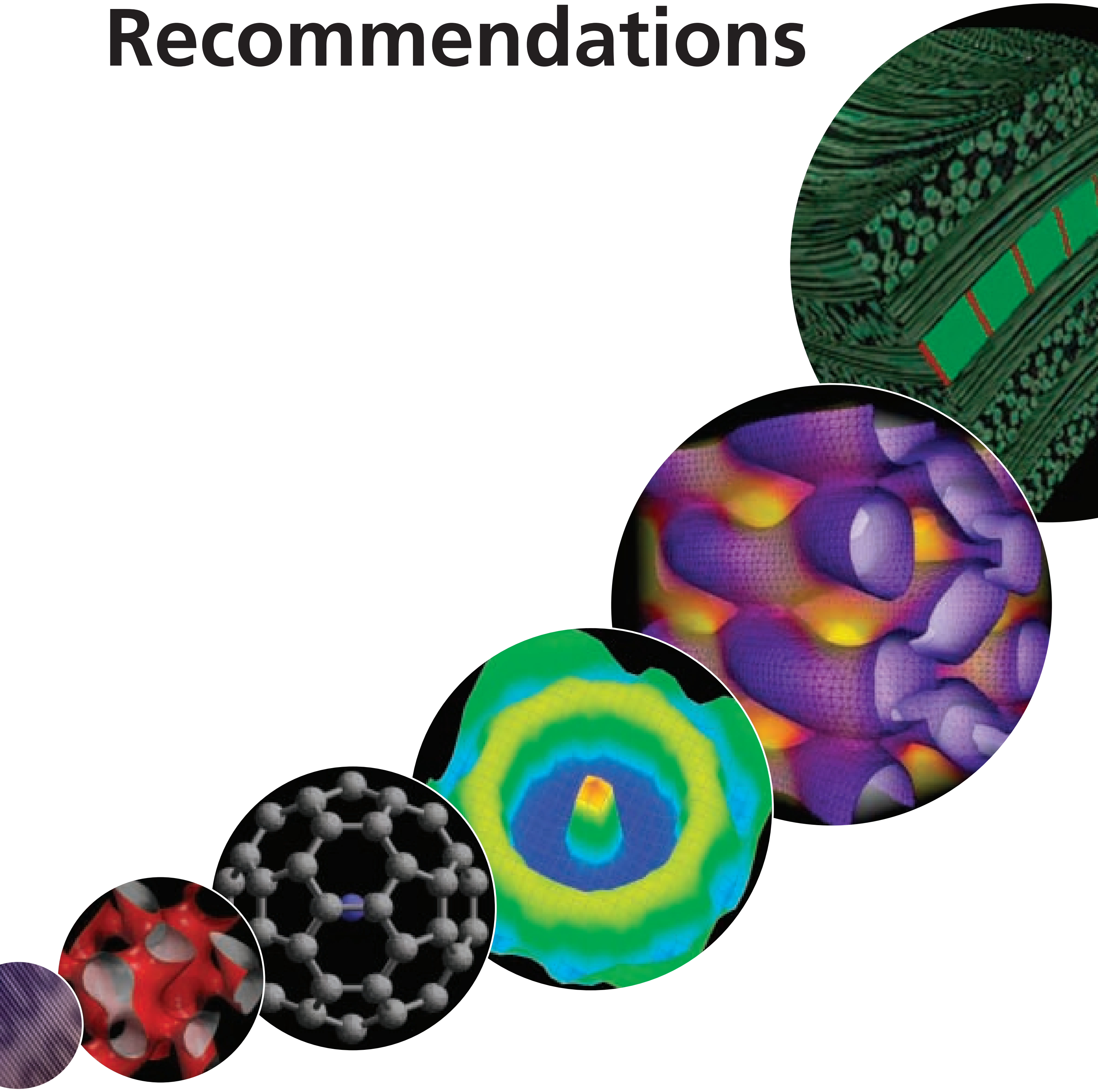
4.I.4. Benchmarking Research Programmes

The Panel encourages development of a process to benchmark the UK materials research programme. Initiation of this effort should begin with the participating countries agreeing on the metrics to be assessed. Ideally, all or many of the key elements of an effective research culture should be included. For example, the following might be included: people, funding, facilities, research output and outcomes. This effort should be far more inclusive than the impact assessment mentioned earlier. This is an area where international cooperation and exchange of data would be meaningful, helpful and make the process less burdensome for all involved. A set of metrics that draw on the Framework Questions could be a good start.

4.I.5. Other Funding Sources and Programmes

The universities and EPSRC should work together to make the most out of funding initiatives from other UK government agencies. For example, there was a recent materials call from the Energy Programme which resulted in £12M in funded projects. The response to this call was proposals requesting a total of £36M. A coordinated approach to funding the best proposals would benefit the UK research programme in this critical area. Similar cooperation between EPSRC and other agencies responsible for strategic national thrusts could have a beneficial effect on the total UK materials research budget.

5.0 Overall Recommendations



The following recommendations have been developed by the Panel on the basis of the presentations and discussions during the review. These have been grouped into several categories for convenience, but these categories are sometimes cross-cutting with regard to the Framework Questions. Where recommendations pertain to a single question, these are included with the responses to the individual Framework Questions and subsidiary questions. These recommendations are not in any order of importance or priority.

5.1 Industrial Interactions including Spin-outs and Knowledge Transfer

O1: A process to encourage UK industry to define and support new platform technology opportunities be developed, especially disruptive ones that university researchers can address with early stage research.

O2 (reinforces C5): EPSRC is encouraged to publicise guidelines for IPR, especially as they are related to the delay of publications based on graduate student research.

O3: Where economic impact is a consideration for grant success, determine whether the R&D supports existing UK industry or not. Where it does, seek industry support or involvement for determining grant success. Where it does not, ensure there is a systematic and strategic approach to creating a new company in the area of grant, including support for these new companies.

O4 (reinforces C4): EPSRC should establish a more effective partnership with the TSB to ensure very smooth hand-offs of research to development.

O5: Industry stakeholders and the academic community should be engaged to clarify the research portfolio in a manner that reflects the near and long-term strategic objectives.

O6 (reinforces C7 and G4): Establish a fund for early stage start-up investments (i.e. SBIR).

5.2 Talent Supply and Development

O7: Establish and track outcome related metrics of success of university research programmes in non-traditional areas such as the provision of high quality scientists and engineers to UK industry.

O8 (reinforces E3): Identify the best university outreach programmes and provide resources for their replication at other institutions.

O9 (reinforces E2): EPSRC should continue to articulate the importance of changing the UK government policy regarding foreign student related issues, in particular: visas, work permits, living expenses and fees.

- One means of accomplishing this is to develop and publicise the results of a study that describes the benefit of doing this and the cost of not doing it.

O10 (reinforces E4): A core materials curriculum should be defined for all materials programmes. The effectiveness of this curriculum should be monitored over time and adjustments made as appropriate.

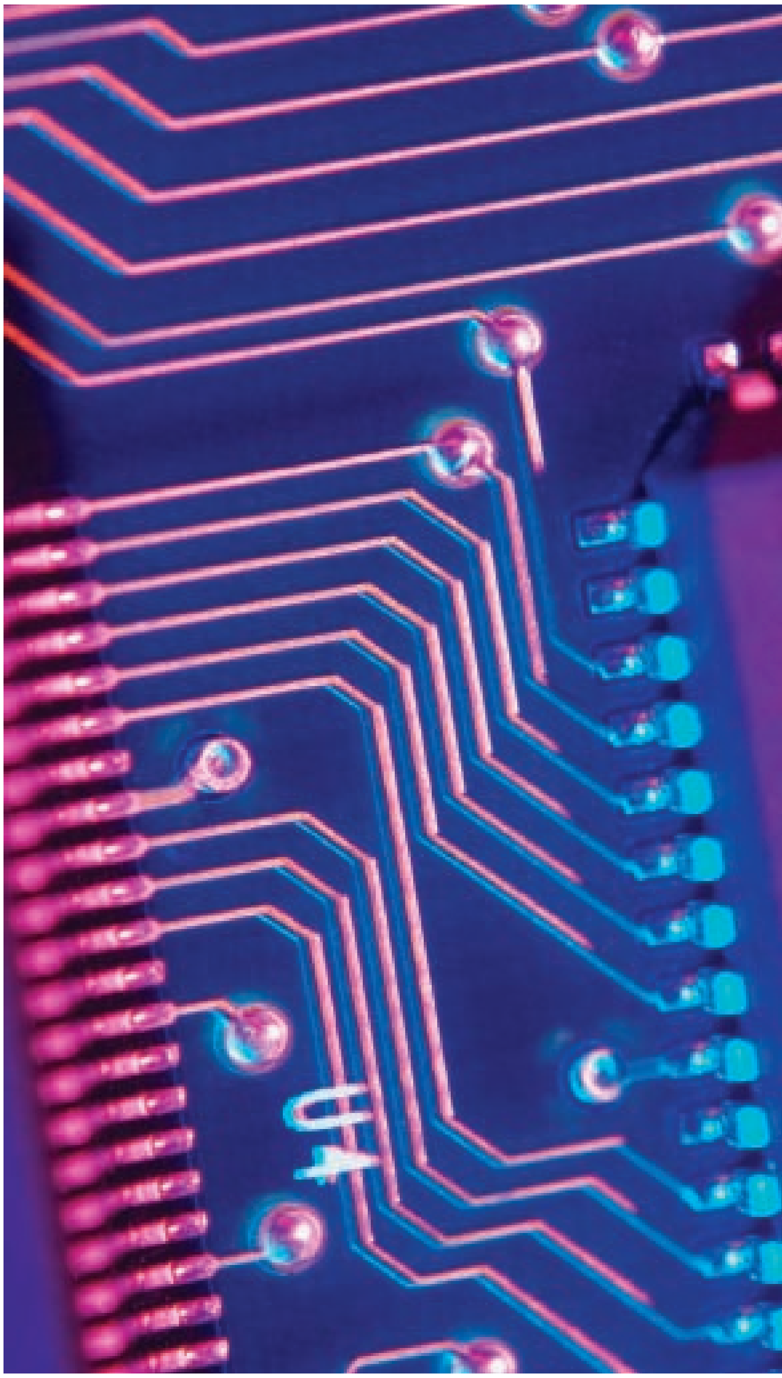
5.3 Research Portfolio Balance and Efficiency of Use of Funds

O11: In addition to conventional sub-programme based classification, define deliverables, which will meet the national goals (for instance, in the areas of energy, security, health and ageing society, etc.) and support fully integrated interdisciplinary programmes.

O12: EPSRC should establish a new high risk-high return project category that utilises longer-term funding and large unrestricted awards to mid-career (45 years or younger) academics.

O13: A mechanism for supporting idea driven research for synthesis and development of new materials, including the underlying fundamental science should be developed. If such a mechanism is perceived to exist. Then a separate budgetary provision should be established to protect this activity.

O14 (reinforces C3): Define the long and short term objectives of the EPSRC research portfolio in terms that permit more direct comparison of outcomes and objectives.



O15: Increase the flexibility of the funding cycle duration in universities to make them commensurate with the long innovation cycle needed to increase the success rate of commercial applications. Communicate this clearly to the research community to avoid the perception of a fixed cycle.

O16: Establish a mechanism for sustaining large-scale, long-term funding of materials research laboratories including facilities. These facilities must have high utilisation rates to ensure a good return on investment. Proposed facilities should have clear plans to create such utilisation levels.

O17: Design a "UK materials leadership innovation initiative", to identify potential future leaders. Implement the initiative with appropriate instruments (fiscal, policy, etc.) and actions to achieve a desirable outcome.

O18 (reinforces C2): EPSRC should support grand scientific and technical challenges that are jointly defined by the academic and industrial communities.

5.4 Major Research Facilities

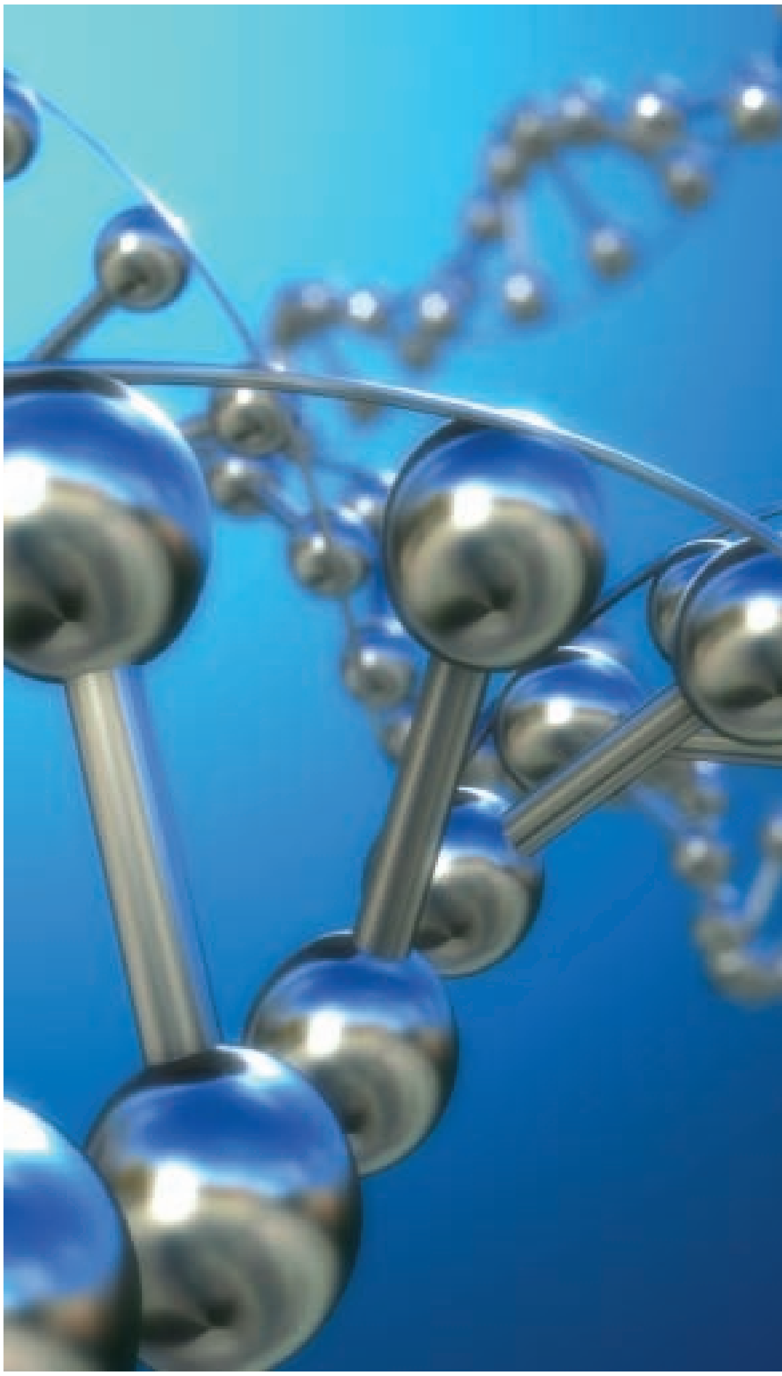
O19: Compile, maintain and publicise an inventory of facilities nationwide or at least regionally along with mechanisms for access and high utilisation levels.

O20: Create mechanisms/incentives to consolidate **major** materials preparation and characterisation facilities in central laboratory space to serve the broad university materials community.

- This may require some renovation and modification of existing space and the addition of support personnel. A separate mechanism for supporting these facilities will probably be required.

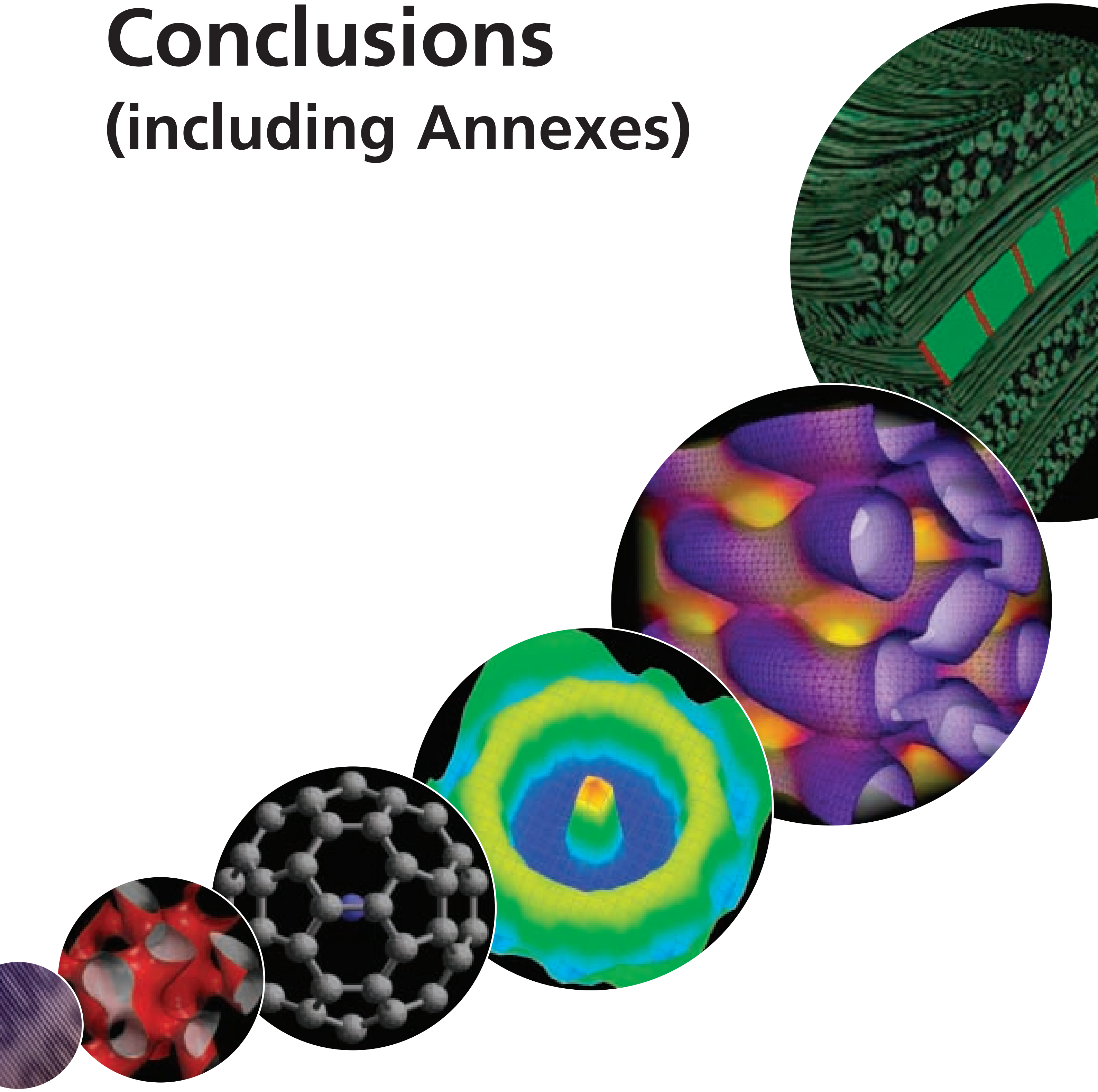
5.5 Miscellaneous

O21: The current academic leaders should be encouraged to recognise the importance of systematic leadership development to ensure the future of the materials field. Development should start from the early career stage. The necessary resources needed to support this activity must be applied.



O22: Encourage, measure and reward greater inter-departmental, national, international and multi-disciplinary work.

6.0 Summary and Conclusions
(including Annexes)



The Panel agreed that the review process was both interesting and useful. The breadth of enquiry outlined by the Framework Questions and the numbers of discrete programmes that were reviewed made the task daunting, particularly in the time allowed. The following conclusions are derived from the information that was provided to the Panel by the universities, EPSRC and was gathered from the discussions held throughout the week. These conclusions are drawn from a fairly high elevation vantage point and are intended to be responsive to the eight Framework Questions. Accordingly, the Panel offers the following conclusions:

1. The general health of the UK materials research programme is good. However, there are a number of impediments that can pose long-term threats to the current situation. One is the closeness of the university research to industrial interests. In the near term this is a major strength for UK companies. In the longer-term, with the companies engaged in the global economy, there is a declining ability of the companies to innovate. The source of fundamental innovation must, therefore, be university research. This creates a paradox, which is best addressed by a university research portfolio that is balanced. EPSRC must consistently strive for such a balance even if maintaining it is, from time to time, tantamount to appearing uncooperative where industry interests are concerned.

2. The field of materials is by definition a multidisciplinary activity. The early engagement of mechanics, multi-scale modelling and manufacturing experts in a research project typically allows earlier identification of issues that require solution before the results of the research can be implemented. Stimulating this approach through stipulations in the funding process can improve the willingness of researchers to structure their proposals as multidisciplinary efforts.

3. The Panel witnessed some excellent examples of knowledge exchange between universities and industry. The nature of these exchanges was highly variable in its precise form. Established, large enterprises typically had well defined needs and expectations, whereas the nature of the university relationship with SMEs depended on the maturity of the company and its product. In some other countries, e.g. the US, issues associated with IP rights are often barriers to industry/university cooperation. The Panel was pleasantly surprised to discover that this is seldom the case in the UK.

4. As discussed in 1 opposite, the UK materials research activity is, in some cases, too focused on shorter-term economic outcomes. It is appropriate for some university research to be focused on near term economic benefit, but universities are tremendous sources of long-term innovation, and this role cannot be compromised.

5. The Panel was generally impressed with the calibre and intellectual strength of the young scientists and engineers they met. However, there are some questions about the distribution of backgrounds of these young people as the availability of permanent jobs is concerned. The UK industrial scene is changing, just as it is in most other developed nations. Consequently, the employment opportunity spectrum is also changing. The Panel heard more than once from the industrial representatives that the supply of classical materials engineers was inadequate. In part, this seems to be related to the reduction in the number of formal departments of materials science and engineering in the UK.

6. There are some excellent examples of international cooperation in materials research in the UK. However, many of these cooperative efforts are bottom up in nature. The success of more formal top down international cooperation, except for the EU programmes, is not as evident. In part this is because the counterpart agencies in the other countries are not well organised to facilitate these programmes either. In the case of emerging economies these programmes may not even exist. Even where there are programmes on both sides, the execution so far has been sorely lacking, leaving less than robust international programmes. Inter-institutional cooperation is more difficult than the equivalent intra-institutional programme. International cooperation is much harder still. A

concerted effort to develop a broad international materials research programme will require a concerted effort and, most likely, the application of incentives.

7. As mentioned earlier in this report, university researchers are unaccustomed to thinking quantitatively about the impact of their research. Addressing the question of impact was generally the most difficult and least satisfactory aspect of most of the exchanges with university researchers. Some recommendations are included elsewhere in this report which, if implemented, should help improve this situation.

8. The Panel was briefed on a number of very high quality research efforts. These efforts varied considerably in their time-based "focal length". However, working on very hard application orientated research can be adventurous because the measures of success and failure are much clearer. Many of the Panel members were a bit mystified about the term "safe research" (see Framework Question H, sub-question (i)) and some even wondered aloud if this term could not be construed as an oxymoron. Research is always about risk taking, no matter whether the risk involves failure to meet a certain set of expectations or failure to create truly new, significant knowledge or understanding of a problem. To be clear, if the outcome of the effort can be anticipated, it is highly questionable whether this effort should be called research.

A. To what extent is the UK materials community addressing key technological/societal challenges through engaging in new research opportunities?

i) What are the key technological/societal challenges and research directions in materials research? To what extent is the UK materials research community focused on these? Are there fields where UK activity does not match the potential significance of the area? Are there areas where the UK has particular strengths?

ii) In terms of the defined remit of the EPSRC materials programme, are there any areas which are under-supported in relation to the situation overseas? If so, what are the reasons underlying this situation and how can the situation be remedied?

iii) Is the research community structured to deliver solutions to current and emerging technological/societal challenges? If not, what improvements could be implemented?

iv) Are there a sufficient number of research leaders of international stature evident in the UK? If not, which areas are currently deficient?

B. To what extent is the materials research base contributing to other disciplines and multidisciplinary research?

i) What evidence is there that there is sufficient research involving investigators from a broad range of traditional disciplines including chemistry, physics and engineering as well as materials scientists?

ii) Are there appropriate levels of knowledge exchange between the materials community and other disciplines? What are the main barriers to effective knowledge and information flow and how can they be overcome?

iii) What evidence is there to demonstrate the influence that the EPSRC programme has had in encouraging multidisciplinary research?

C. What is the level of knowledge exchange between the research base and industry that is of benefit to both sides?

i) What is the flow of trained people between industry and the research base and vice versa? Is this sufficient and how does it compare with international norms?

ii) How robust are the relationships between UK academia and industry both nationally and internationally and how can these be improved?

iii) To what extent does the materials community take advantage of EPSRC schemes to enable this knowledge exchange? Is there more that could be done to encourage knowledge transfer?

iv) What is the scale of industrial R&D in materials nationally and internationally and what is the trend? What are the implications for the UK materials research community and to what extent is it well-positioned to respond? Is there any way that its position could be improved?

D. To what extent is the UK materials research activity focussed to benefit the UK economy and global competitiveness?

i) What are the major innovations in the materials area, current and emerging, which are benefiting the UK? Which of these include a significant contribution from UK research?

ii) How successful has the UK materials community (academic and industrial) been at innovation? What are the barriers to successful innovation in materials in the UK and how can these be overcome?

E. To what extent is the UK able to attract talented young scientists and engineers into materials research? Is there evidence that they are being nurtured and supported at every stage of their career?

i) Are the numbers of graduates (at first and higher degree level) sufficient to maintain the UK research base in this area? Is there sufficient demand from undergraduates to become engaged in materials research? How does this compare with the experience in other countries?

ii) How effective are public engagement activities aimed at attracting school age students into materials?

iii) Are there areas of weakness - is the UK producing a steady-stream of researchers in the required areas and/or are there areas that should be declining to reflect changes in the research climate?

iv) How does the career structure for materials researchers in the UK compare internationally?

v) To what extent is the UK able to attract overseas materials scientists and engineers to the UK? Is there evidence of ongoing engagement either through retention within the UK research community or through international linkages?

F. To what extent are UK researchers engaged in "best with best" science-driven international interactions?

i) What is the nature and extent of engagement between the UK and Europe, USA, China and India respectively?

ii) How effective is the engagement between the UK and the rest of the world? Are there particular issues for the materials research area? What could be done to improve international interactions?

G. What is the impact on a global scale of the UK materials research community both in terms of research quality and the profile of researchers?

i) Is the UK the international leader in materials research? In which areas? What contributes to the UK strength and what are the recommendations for continued strength?

ii) What are the opportunities/threats for the future?

iii) In which areas is the UK weak and what are the recommendations for improvement?

H. What evidence is there to support the existence of a creative and adventurous research base and portfolio?

i) Is the current balance between high-risk/high-return research and "safe research" appropriate?

ii) What are the barriers to more "adventurous research" and how can they be overcome?

PROFESSOR JIM WILLIAMS (CHAIR)

Professor Jim Williams is Professor of Materials Science and Engineering and Honda Chair at The Ohio State University (OSU). From July 2001 until June 2004 he was Dean of Engineering and Honda Chair also at OSU. Until March 1999 he was General Manager, Materials and Process Engineering Department, GE Aircraft Engines. He is a member of the National Academy of Engineering, a Fellow of TMS/AIME and a Fellow of ASM International. He is the recipient of the 1992 ASM Gold Medal, the 1993 TMS/AIME Leadership Award, the 2002 TMS/AIME Application to Practice Award, the International Titanium Association 2003 Achievement Award and was inducted into the GE Aircraft Engines Propulsion Hall of Fame in 2003. He was Chairman of the National Materials Advisory Board from 1989 - 1995. He was a member of The Oversight Committee of the Division of Engineering and Physical Sciences of the National Research Council from 2000 - 2005. He was a member of the MST Division Review Committee from 1993 - 1999 and the ESA Division Review Committee at Los Alamos National Laboratory from 2000 - 2006. He served on The US Air Force Scientific Advisory Board from 1994 - 2000. Prior to joining GE in 1988 he spent 13 years at Carnegie Mellon University as Professor (‘75 - ‘80), President of Mellon Institute (‘80 - ‘83) and Dean of Engineering (‘83 - ‘88). Before joining Carnegie Mellon he held research and engineering positions with Rockwell (1968 - 1975) and Boeing (1961 - 1968). He has consulted extensively for government and industry. He has published more than 200 papers based on his research. His professional interests include structure-property relations of high strength materials, the performance of materials in extreme environments (temperature, stress and strain rate), materials processing, technology policy, particularly as it pertains to materials and the management of high technology organisations. In much of his work he has specialised in titanium alloys. In 2003 he and Professor Lütjering completed a book entitled “Titanium”, published by Springer-Verlag. A second edition is scheduled for release in spring 2007.

Jim received his BS, MS and PhD degrees, in Metallurgical Engineering, from the University of Washington, the latter in 1968.

PROFESSOR PAULO JORGE DE FREITAS

Professor Paulo Jorge Peixeiro de Freitas is the Director of INESC Microsystems and Nanotechnologies and is responsible for the magnetic recording technology research group. His current research interests include GMR heads for ultra high density recording, spin-dependent tunnelling junctions, non-volatile memories, magnetic multi layers and thin films, micromagnetism, transport phenomena, GMR sensors, bioelectronics and biosensors.

Paulo received his PhD in Solid State Physics from Carnegie Mellon University in 1986. His thesis topic involved the study of magnetoresistance in CoFe thin films. Between 1986 - 1987, he was a post-doctoral fellow at IBM, Yorktown Heights where he worked on magnetic thin films and high TC superconductors. Since 1990, he has been at the Instituto Superior Tecnico, where he is a Full Professor in the Physics Department.

DR ALASTAIR GLASS

Dr Alastair Glass became Deputy Minister of Research and Innovation in Ontario, Canada in February 2006. Previously, Dr Glass played a pivotal role in building research and development programmes in Ireland as the first Director of Information and Communication Sciences at Science Foundation Ireland, and in helping build effective partnerships between industry, government and academia. He remains the Chairman of the Tyndall National Institute in Cork.

Dr Glass has held senior leadership positions at Bell Laboratories, and he has been a frequent advisor to government agencies and academic institutions, an invited speaker at international conferences and a published author and leader in technical societies.

Dr Glass has a BSc (Special) from University College London and a PhD in physics from the University of British Columbia.

PROFESSOR JOHN GREEDAN

Professor John Greedan is the Professor of Solid State Inorganic and Materials Chemistry and a member of the Brockhouse Institute of Materials Research. He received a BA from Bucknell University and a PhD from Tufts University. He is the Vice President of the Canadian Institute for Neutron Scattering and a member of the Canadian Institute of Chemistry and the Materials Research Society. Professor Greedan is the Editor of Chemistry of Materials (1999 - present) and is on the editorial board of the Journal of Solid State Chemistry. He was an Invited Speaker at the 10th European Solid State Chemistry Conference, Sheffield, September, 2005 "The Anatomy of the Mott Transition in $Nd_{1-x}TiO_3$" and at the 1st International Symposium on Structure Property Relationships in Solid State Materials, Bordeaux, June, 2006, "The Design and Characterisation of Low Dimensional and Geometrically Frustrated Magnetic Materials".

PROFESSOR ROBERT HULL

Professor Robert Hull spent ten years at AT&T Laboratories in the Physics Research Division, and joined the faculty of the Materials Science and Engineering Department at the University of Virginia, where he is the Charles Henderson Professor of Engineering. His recent research focuses upon nanoscale assembly, fabrication and characterisation using focused ion and electron beams, with particular emphasis on epitaxial semiconductor structures. He has published well over 200 journal and conference papers, edited several books and proceedings in the fields of semiconductor materials and devices, given over seventy keynote and invited talks at national and international conferences, and presented over one hundred additional seminars at universities and government and industrial laboratories. He is a member of multiple editorial and advisory boards, a Fellow of the American Physical Society, a Member of the European Academy of Sciences, and has served as the president of the Materials Research Society. Within the University of Virginia, he is Director of the National Science Foundation Centre on "Nanoscopic Materials Design" and is Director of the University's Institute for Nanoscale and Quantum Engineering, Science and Technology (NanoQuest). Recently he chaired a workshop and edited a report for the National Nano-technology Initiative defining new directions in the field of Nanomaterials for the next decade and beyond.

Professor Hull received a PhD in Materials Science from Oxford University in 1983.

PROFESSOR OLLI IKKALA

Professor Olli Ikkala is an Academy Professor of the Academy of Finland and Professor of Polymer Physics and Molecular Nanostructures at the Helsinki University of Technology, Finland. He received a PhD degree in 1983 from Helsinki University of Technology on the first observation of superfluid ^{3}Helium vortices. After a period in chemical industry eg. developing industrial applications of electrically conducting polymers (Neste Corporation in collaboration with Uniax Corp, California), he returned to academia to establish Laboratory of Molecular Materials at the Helsinki University of Technology in 1994. He currently runs the interdisciplinary laboratory jointly with Professor Janne Ruokolainen.

Professor Ikkala´s research interest is in applications of self-assembled hierarchies of polymers and polypeptides for functional materials properties, such as porosity, and electrical and optical activities. Recently the work has expanded towards cellulose nanofibers. He has more than 140 peer reviewed articles, 3 book chapters, and he has more than 10 patents and applications. He received the Emanuel Merck Award in 2002.

He has had also several other duties: he is in the Board of Reviewing Editors of Science, he has been the president of the Finnish Physical Society, he has been in the advisory board for European Commission, 6PthP Framework programme (Thematic topic Priority 3 Nanotechnology), and in several other boards of national and international funding organisations and evaluation committees.

PROFESSOR DAVID LARBALESTIER

Professor David Larbalestier and the Applied Superconductivity Centre moved from the University of Wisconsin to Florida State University in October 2006, where he is now Francis Eppes Professor and Chief Materials Scientist at the National High Magnetic Field Laboratory. Prior to the move he was Professor in the Department of Materials Science and Engineering and in the Department of Physics at the University of Wisconsin in Madison, where he held both the L. V. Shubnikov Chair and the Grainger Chair of Superconductivity. He has been active in superconductivity since his PhD for which his thesis work gained the Matthey Prize of the Department of Metallurgy at Imperial College. After two years in Switzerland, he returned to England in 1972 to the Superconducting Magnet Research Group of the Rutherford Laboratory, working for four years on the development of multifilamentary Nb_3Sn conductors and magnets in work on the first filamentary Nb_3Sn NMR magnet, for which he shared a 1978 IR-100 award with an Oxford Instrument Company team. He joined the University of Wisconsin in 1976, becoming Associate Chairman of his Department in 1981, a post held until 1991 when he became director of the Applied Superconductivity Centre. His group made the definitive studies of the materials science and processing of the most widely used superconductor, Niobium Titanium, an achievement recognised by the 1991 IEEE Particle Accelerator Conference Award and by election to Fellowship of the American Physical Society.

Professor Larbalestier has been very active in promoting collaborations uniting industry, national laboratory and other university groups, exerting a leadership role in both the Low Temperature and High Temperature Materials Superconductor Communities, achievements recognised by prizes of the IEEE (1991 and 2000) and the Council for Chemical Research (2000) for his work and that of his collaborators on $(Bi,Pb)_2Sr_2Ca_2Cu_3O_x$. He has served on many review panels of the National Science Foundation and the Department of Energy, was a member of the 1987 National Academy of Sciences Panel on High Temperature Superconductivity, and led the 1996 World Technology Evaluation Centre Panel on Energy Applications of Superconductors sponsored by DOE and NSF. He was a member of the 2004 - 2005 NRC panel (COHMAG) assessing the status and future of high magnetic field science and technology. His more than 70 former students, post-doctoral workers and visiting scientists are widely dispersed in the superconductivity community in the US, Europe and Asia. He has published more than 300 refereed papers and been invited to give more than 200 seminars and presentations at scientific meetings. During 2000 he was Visiting Professor at the University of Geneva and Visiting EPSRC Fellow at the Imperial College of the University of London. He was elected to the National Academy of Engineering in 2003 and is also a fellow of the American Physical Society and of the Institute of Physics (UK).

DR RAMESH MASHELKAR

Dr Ramesh Mashelkar is presently the President of Indian National Science Academy (INSA) and President of Global Research Alliance, a network of publicly funded R&D institutes from Asia-Pacific, Europe and USA with over 60,000 scientists.

Prior to this Dr Mashelkar served as the Director General of Council of Scientific and Industrial Research (CSIR), with thirty-eight laboratories and about 20,000 employees for over eleven years.

Dr Mashelkar has played a critical role in shaping India's S&T policies in post-liberalised India, has served on the Scientific Advisory Council to the Prime Minister and also on the Scientific Advisory Committee to the Cabinet and is the recipient of over 40 awards and medals. Previous to this role, as one of India's foremost chemical engineers, Dr Mashelkar has made seminal and path-breaking contributions in polymer science and engineering and in the engineering analysis of non-Newtonian fluids. As Director of the National Chemical Laboratory during 1989 - 1995, he took the laboratory to great heights and converted it to one of the finest international chemical laboratories consistently performing to its true potential.

As former Director General of the CSIR, a chain of thirty eight laboratories and 20,000 employees, Dr Mashelkar had played the crusading role in transforming these national laboratories into strong and self-confident institutions of innovation and creativity, commited to generating national wealth and social good.

Dr Mashelkar has received extensive international recognition and is a Fellow of the Royal Society (UK), a Foreign Associate of the National Academy of Science (USA), a Foreign Fellow of the US National Academy of Engineering, a Fellow of the Royal Academy of Engineering (UK) and a Fellow of the World Academy of Art and Science (USA). Twenty-six universities have honoured him with honorary doctorates, including the Universities of London, Salford, Pretoria, Wisconsin and Delhi.

DR IAN MAXWELL

Since 2000 Dr Ian Maxwell has focused on founding and operating high-tech start-ups, including RPO (optical waveguides for cell phone touch-screens), WRiota (silicon lithography and memory), Cylite (optical data link for cell phones), Enikos (content ingestion & distribution software), and Viva Blu (AOP water treatment technology). In addition, since 2003 Ian has been a Venture Partner at Allen & Buckeridge Venture Capital.

Previously, Ian was VP, Business Development Manager at Redfern Photonics – a corporate incubator/Venture Capital group focused on photonic technologies. Prior to joining Redfern Photonics, Ian was Director, R&D at James Hardie Corporation (the world's leading supplier of fibre-cement building products), where he was responsible for all corporate R&D. Before that Ian had various roles at Memtec Ltd (a membrane and filtration start-up that was eventually listed on the NYSE and sold for US$600m), in R&D, marketing, manufacturing operations and eventually, as International R&D Manager.

He has been a Senior Lecturer at the University of Technology, Eindhoven, and was the founding CEO of the University of Sydney Polymer Centre (now Key Centre for Polymer Colloids). He also worked for DuPont Australia in the development and marketing of water treatment chemicals for the mining industry.

Ian has a BSc (Hons, 1st Class) and PhD in Physical Chemistry from the University of Sydney. He has attended business studies at Harvard, IMD and the Australia Graduate School of Management.

Ian has been the recipient of the Rennie Medal of the Royal Australian Chemical Institute, and also the Rennie-Corday Morgan Exchange Medal, jointly awarded by the Royal Society of Chemistry (UK) and the Royal Australian Chemical Institute.

PROFESSOR BARRY MUDDLE

Professor Barry Muddle is currently the Research Director, ARC Centre of Excellence for Design in Light Metals. Previously Barry was the Director, National Key Centre for Advanced Materials Technology (CAMT).

Barry's current research interests include crystallography of solid state phase transformations, the structure of interfaces in nanostructured materials, modelling of the evolution of nanostructure and the microstructure of advanced ceramics and high strength aluminium alloys. He gained his BSc and PhD from the University of New South Wales. He has been a visiting scientist at BHP Research - Melbourne Laboratories, CSIRO Material Science and Technology, Melbourne and a visiting scholar at the Department of Material Science and Engineering, University of Virginia.

Barry has served on the board of governors of Acta Materialia Inc., and has been awarded the Centenary Medal, Commonwealth of Australia, an honorary Professorship at Wuhan University of Technology, an Adrian Ashton Lecture, Inst. of Materials Engineering Australia, a Fulbright Senior Award (U of Virginia) Australia-American Educational Foundation, and the Silver Medal from Institute of Materials Engineering, Australia. Barry is a Fellow of the Australian Institute of Physics (AIP) and the Australian Academy of Technological Sciences and Engineering. He is also a Member, and previous National President of the Inst. of Materials Engineering Australasia (IMEA) (Mater.Soc. of IEAust) and a member of the Institute of Materials (UK) (MIM), CEng, the Minerals, Metals and Mater. Soc. (TMS-AIME), Materials Research Society (MRS), The Australian Society for Electron Microscopy, ASM International (ASM) and the Australasian Ceramic Society.

PROFESSOR MANFRED RÜHLE

Professor Manfred Rühle received his PhD in Physics from the University of Stuttgart. He joined the Max-Planck-Institut für Metallforschung in Stuttgart as a scientific staff member before moving to Argonne National laboratory, IL as a visiting scientist from 1970 to 1971. In 1985 he joined the Materials Department of the University California at Santa Barbara, CA. Since 1989 he has been a Scientific Member and Director at the Max-Planck-Institut für Metallforschung in Stuttgart. The focus of Professor Rühle's research is the investigation of the structure, comparison and bonding at internal interfaces in metals, ceramics as well as metal/ceramic composites.

DR MAXINE SAVITZ

Dr Maxine Savitz is Director of the Washington Advisory Group, and advises on research and development management, energy and environmental policy, materials development, production and utilisation, and technology transfer. Her areas of expertise also include energy efficiency R&D and products in the transportation, industry and buildings sectors, aerospace technology and integration of R&D between laboratories and business units.

Dr Savitz is the former Deputy Assistant Secretary for Conservation, U.S. Department of Energy. She received the Outstanding Service Medal from the Department of Energy in 1981. Prior to her DOE service, she was programme manager for Research Applied to National Needs at the National Science Foundation. Following her government service, Dr Savitz served in executive positions in the private sector, including: President of Lighting Research Institute, assistant to the vice president for engineering at The Garrett Corporation, and General Manager of AlliedSignal Ceramic Components. She recently retired from the position of General Manager for Technology Partnerships at Honeywell.

Dr Savitz is a member of the National Academy of Engineering and the American Association for the Advancement of Science. She was appointed to the National Science Board in 1998 - 2004. She is a member of the Science Advisory Board for Sandia National Laboratories, the Department of Energy's Laboratory Operations Board, and advisory bodies for Oak Ridge National Laboratory and Pacific Northwest National Laboratory. Dr Savitz also serves on the board of directors of the Electric Power Research Institute (EPRI) and the American Council for an Energy Efficient Economy.

Dr Savitz received a BA in Chemistry from Bryn Mawr College and a PhD in Organic Chemistry from the Massachusetts Institute of Technology.

PROFESSOR TIM SWAGER

Professor Timothy Swager is the John D. MacArthur Professor of Chemistry and the Head of the Department of Chemistry at the Massachusetts Institute of Technology (MIT). A native of Montana, he received chemistry degrees from Montana State University (BS) and the California Institute of Technology (PhD). After a postdoctoral appointment at MIT, he joined the University of Pennsylvania and rose to the rank of Professor before moving back to MIT in July of 1996. He has published over 200 peer reviewed papers, 70 proceedings, and 5 book chapters and serves on multiple editorial and scientific advisory boards. Professor Swager's research interests are in design, synthesis, and study of organic-based electronic, sensory, and liquid crystalline materials. In the field of liquid crystals he developed new molecular designs and fundamental mechanisms for increasing/controlling order in liquid crystals. Tim's research in electronic polymers has focused on new conceptual approaches to amplification in sensory materials. Materials and methods from the Swager laboratory are the enabling technology for explosive detectors deployed by the US Military. These methods have been extended to the detection of chemical weapons, toxic industrial chemicals and biological molecules. He has also developed new receptors, conducting polymers, low dielectric constant materials, polymer actuators and probes for medical diagnostics.

PROFESSOR GERHARD WEGNER

Professor Gerhard Wegner joined the Max Planck Society in 1983 as one of the founders of the present Max Planck Institute for Polymer Research. He holds a doctoral degree in chemistry from the University of Mainz (1965). In 1966-69 he worked as a research staff chemist at Yale University, Conn., USA. Returning to the University of Mainz, he joined the group of Professor E W Fischer in the Institute of Physical Chemistry. His habilitation in physical chemistry (1970) concentrated on solid-state polymerization of diacetylenes and showed how macroscopic single crystals of polyconjugated macromolecules can be made. From 1974 to 1984 he had the chair in Macromolecular Chemistry at the University of Freiburg (Germany). He was a visiting professor at Poona, India (1974), Amherst, Mass., USA (1979), Tucson, AZ, USA (1986), Milan, Italy (1987), Leuven/Louvain, Belgium (1988), Midland, Mich., and Storrs, Conn., USA (1990), Helsinki, Finland (1991), Pisa, Italy (1992), Université de Montreal, Canada (1992), Cornell University (Baker Lecture-ship) (1994), University of Akron, Ohio, USA (1995).

Professor Wegner received the Otto Bayer Award in 1984, the Philip-Morris-Technologie-Preis in 1989, the Hermann Staudinger Medal of the German Chemical Society in 1990, the Rolf Sammet Lectureship (1997), the ACS Award in Polymer Chemistry (1998), the Award of the Society of Polymer Science Japan (1998), the Xerox-Lectureship, Halifax Canada (1998), the Butler-Lectureship, Gainesville, Florida (1999), the Solomon Lectureship, Sydney Australia 2005. He received Honorary Doctorates from the University of Massachusetts at Lowell, USA (2000), the University of Erlangen, Germany (2004) and the Technical University of Lodz, Poland (2005), University of Patras (2007). He is also Honorary Professor at Nankai University, Tianjin, China and Honorary Member of the Topchiev Institute of the RAS, Moscow, Russia.

Gerhard served as the chairman of the Chemistry-Physics-Technology section of the Max Planck Society from 1991 to 1994 and was Vice President of the Max Planck Society from 1996 to 2002 and he is presently Vice-President of the Adademie der Wissenschaften und der Literatur, Mainz since 2005. Professor Wegner is also the founder and chairman of the current International Max-Planck-Research School for Polymer Science (IMPRS-PMS) and serves as its chairman as well as for the Early Stage Training (EST) - Marie-Curie-Action at MPI-P.

Saturday 12 Jan	**Arrived in UK**	Whole Panel	**Focus**

Sunday 13 Jan	**Arrived Manchester**	Whole Panel	
	Afternoon welcome/briefing session		Getting to know you, scope and purpose of review and the UK research funding environment; meet with Materials Strategic Advisory Team (SAT)

Monday 14 Jan	**Manchester**	J Williams M Rühle O Ikkala P de Freitas A Glass G Wegner R Mashelkar	Metals, Polymers, Ceramics Photonics Electronic Materials, Encourage KT examples
	Leeds/Sheffield inc. Durham and Sheffield III-V	B Muddle M Savitz R Hull J Greedan T Swager D Larbalestier I Maxwell	Polymers, Metals, Photonics (Sheffield and Durham), Biomaterials Magnetics, KT, Ceramics (Structural and Functional), Spintronics (Leeds and Durham), Electronic Materials (Sheffield), Superconductivity (Durham)
Monday evening	**Discussion/reflection**	Whole Panel	Lessons learnt and initial thoughts

Tuesday 15 Jan	**Liverpool/Daresbury (SuperSTEM, NCESS) inc. Belfast**	J Williams I Maxwell M Savitz R Hull	Ceramics, Electronic Materials, Polymers
	Birmingham inc. Swansea, Nottingham, Rolls-Royce	O Ikkala P de Freitas B Muddle D Larbalestier	EngDoc-Metals (Birmingham and Swansea), Superconductivity, Polymers (Nottingham), Spintronics and Electronics (Nottingham)
	Bristol inc. Bath and Southampton	M Rühle A Glass G Wegner J Greedan T Swager R Mashelkar	Composites, Metals, Photonics (Southampton) Polymers-colloids, Magnetic Materials,

Wednesday 16 Jan	**Oxford/ISIS/Diamond**	M Rühle O Ikkala A Glass G Wegner B Muddle J Greedan T Swager D Larbalestier R Mashelkar	Metals, Microscopy Modelling Centre, Ceramics, Photonics, Electronics, Oxford Centre for Advanced Materials and Composites (OCAMAC)
	Edinburgh inc. Glasgow, St. Andrews, Strathclyde	J Williams P de Freitas I Maxwell M Savitz R Hull	Photonics (St Andrews and Strathclyde) Polymers/composites (Strathclyde) Magnetics and Electronics (Glasgow)
Wednesday evening	**Travel and discussion/reflection**	Whole Panel	

Thursday 17 Jan	**Imperial inc. UCL, QMUL and Surrey**	O Ikkala A Glass R Mashelkar B Muddle M Savitz J Greedan	All/most subjects. KT, Ceramics (Structural and Functional) (Imperial, UCL Queen Mary and Surrey), Metals (Imperial), Photonics (Imperial, UCL and Surrey) Polymers (Surrey, Imperial, Queen Mary) Electronics (Surrey, Imperial and Southampton) and Felix (Surrey) Magnetics (Imperial)
	Cambridge	J Williams M Rühle P de Freitas G Wegner I Maxwell R Hull T Swager D Larbalestier	Superconductivity, Functional Ceramics, Electronic Materials, Metals, Photonics, Polymers
Thursday evening	**Travel**	Whole Panel	

Friday 18 Jan	**Redhill - agreed main findings, drafted report, agreed future actions and presented to steering committee**	Whole Panel	

Saturday 19 Jan	**Leave UK**		

A range of supporting evidence and information was provided to the Review Panel both before and during the review. This included:

- A background data document prepared by EPSRC.
- An overview of science and innovation in the UK.
- The 2002 International Review of Materials and subsequent action plan.
- An explanation of the RAE.
- A summary of the evidence submitted as part of the open consultation.
- Visits to universities supplemented by data and briefs (a list is provided below).
- Key industrial partners were present at each visit and briefs were provided by Rolls-Royce and the National Physical Laboratory.

The following Universities were visited during the review week:

- Leeds including representatives from Durham, Sheffield and Sheffield III-V centre.
- Manchester.
- Birmingham, including representatives from Nottingham and Swansea.
- Bristol, including representatives from Bath and Southampton.
- Liverpool including representatives from MEIS, NCESS, SRS and QUB.
- Edinburgh including representatives from St Andrews, Glasgow and Strathclyde.
- Oxford, including representatives from CLF, ISIS and DIAMOND.
- Cambridge.
- Imperial College including representatives from UCL, QMUL, Surrey and FELIX.

The following submitted evidence in response to the open consultation:

Grantholders:

- Professor S Armes, University of Sheffield
- Professor R Jones, University of Exeter
- Professor S Bull, Newcastle University
- Professor R Pethrick, University of Strathclyde
- Professor P Chalker, University of Liverpool
- Professor P McMillan, University College London
- Dr D Worsley, University of Wales Swansea
- Professor S Spearing, University of Southampton (including comments from Terence G. Langdon, Materials Research Group)
- Professor U Martin, Queen Mary, University of London
- Dr A Hector, University of Southampton
- Professor P de Groot, University of Southampton
- Professor Sir J Ball, University of Oxford
- Professor R Young, University of Manchester
- Professor J Wood, Imperial College London
- Professor A Long, University of Nottingham
- Professor D Payne, University of Southampton
- Professor C Hall, University of Edinburgh
- Professor K Edge, Pro-Vice-Chancellor (Research) & Professor D Almond, Director, Materials Research Centre, University of Bath
- Dr G Walker, Queen's University Belfast
- Professor A Greer, University of Cambridge
- Professor M Smith, University of Warwick
- Professor S Beaumont OBE, University of Glasgow
- Mr T Newsom, Queen's University Belfast
- Dr S Gray, University of Bristol
- Professor M Edirisinghe, University College London
- Professor W Barnes, University of Exeter
- Professor P Reed, University of Southampton
- Professor A Kent, University of Nottingham
- Professor J Binner, University of Loughborough
- Professor A Hutchinson, Oxford Brookes University
- Chemistry, Physics & Engineering Departments, University of Durham (late submission)
- Professor C Imrie, University of Aberdeen (late submission)

International experts:

- Professor P Smith – ETH Zürich.
- Professor J Hirsch – Hydro Aluminium Deutschland GmbH, R&D Bonn.

Stakeholders:

- Mark Morrison, Institute of Nanotechnology
- Dr S Garwood, Materials & Structures National Advisory Council
- Dr D Brown, Institute of Chemical Engineers
- Professor M Gibbs, IEEE Magnetics Society
- Mr J Dorken, British Rubber and Polyurethane Products Association
- Dr B Rickinson, Institute of Materials, Minerals & Mining
- Andy Leather, Society of British Aerospace Companies (SBAC)
- Dr P Bleasdale, Nexia Solutions Ltd
- Neil Glover, Rolls-Royce
- Professor M Bache, University of Wales Swansea
- Dr M Sambrook, Royal Society of Chemistry
- Professor Sir C Llewellyn Smith, UKAEA Fusion
- Kamal Hossain, National Physical Laboratory
- Richard Pitman, Department for Business, Enterprise and Regulatory Reform (BERR)
- Alastair Wilson, Photonics KTN
- Professor N Harrison, Science and Technology Facilities Council, Daresbury Laboratory
- Dr. Alan Hooper/Dr. Robert Quarshie, Technology Strategy Board/ Materials KTN/Materials UK (late submission)

Others:

- Dr F Rahman, University of Glasgow
- Dr B Beake, Micro Materials Ltd
- Professor D Jiles, Wolfson Centre for Magnetics, Cardiff University
- Professor K Evans, University of Exeter
- Tony Jones, Corus Group

Note: recommendations which arise within the Framework sections and are then emphasised in the Overall section are reported only once here.

O1: A process to be developed to encourage UK industry to define and support new platform technology opportunities, especially disruptive ones that university researchers can address with early stage research.

O2 (incorporating C5): EPSRC is encouraged to suggest guidelines for IPR, especially as they are related to the delay of publications based on graduate student research.

O3: Where economic impact is a consideration for grant success, determine whether the R&D supports existing UK industry or not. Where it does, seek industry support or involvement for determining grant success. Where it does not, ensure there is a systematic and strategic approach to creating a new company in the area of grant, including support for these new companies.

O4 (incorporating C4): EPSRC should establish a more effective partnership with the TSB to ensure very smooth hand-offs of research to development.

O5: Industry stakeholders and the academic community should be engaged to clarify the research portfolio in a manner that reflects the near and long-term strategic objectives.

O6 (incorporating C7 and G4): Establish a fund for early stage start-up investments (i.e. SBIR).

O7: Establish and track outcome related metrics of success of university research programmes in non-traditional areas such as the provision of high quality scientists and engineers to UK industry.

O8 (incorporating E3): Identify the best university outreach programmes and provide resources for their replication at other institutions to attract a sufficient amount of high quality students.

O9 (incorporating E2): EPSRC should continue to articulate the importance of changing the UK government policy regarding foreign student related issues, in particular: visas, work permits, living expenses and fees.

O10 (incorporating E4): A core materials curriculum should be defined for all materials programmes. The effectiveness of this curriculum should be monitored over time and adjustments made as appropriate.

O11: In addition to conventional sub-programme based classification, define deliverables, which will meet the national goals (for instance, in the areas of energy, security, health, and ageing society, etc.) and support fully integrated interdisciplinary programmes.

O12: EPSRC should establish a new high risk-high return project category that utilises longer-term funding and large unrestricted awards to mid-career (45 years or younger) academics.

O13: A mechanism for supporting idea driven research for synthesis and development of new materials, including the underlying fundamental science should be developed. If such a mechanism is perceived to exist then a separate budgetary provision should be established to protect this activity.

O14 (incorporating C3): Define the long and short term objectives of the EPSRC research portfolio in terms that permit more direct comparison of outcomes and objectives.

O15: Increase the flexibility of the funding cycle duration in universities to make them commensurate with the long innovation cycle needed to increase the success rate of commercial application. Communicate this clearly to the research community to avoid the misperception of a fixed cycle.

O16: Establish a mechanism for sustaining large-scale, long-term funding of materials research laboratories including facilities. These facilities must have high utilisation rates to ensure a good return on investment. Proposed facilities should have clear plans to create such utilisation levels.

O17: Design a "UK materials leadership innovation initiative", to identify potential future leaders. Implement the initiative with appropriate instruments (fiscal, policy, etc.) and actions to achieve a desirable outcome.

O18 (incorporating C2): EPSRC should support grand scientific and technical challenges that are jointly defined by the academic and industrial communities.

O19: Compile, maintain and publicise an inventory of facilities nationwide or at least regionally along with mechanisms for access and high utilisation levels.

O20: Create mechanisms/incentives to consolidate **major** materials preparation and characterisation facilities in central laboratory space to serve the broad university materials community.

O21: The current academic leaders should be encouraged to recognise the importance of systematic leadership development to ensure the future of the materials field. Development should start from the early career stage. The necessary resources needed support this activity must be applied.

O22: Encourage, measure and reward greater inter-departmental, national, international and multi-disciplinary work.

C1: EPSRC should take the lead in establishing mechanisms for the exchange of personnel between universities and industry. There will be a number of inter-organisational issues to be resolved, so it is recommended that a representative industry group be engaged early in the process.

C6: In several fields ranging from more traditional to very high-tech fields, the concern was expressed regarding the funding level for core knowledge creation. EPSRC is encouraged to maintain the balance between this and research with potential applications in the long and shorter term.

D1: A quantitative review of the materials start-up activity in the UK over the last 25 years would be useful. The Panel was working off anecdotal evidence.

D2: There is certainly scope for further investigation into the success or otherwise of materials start-ups in the UK and an assessment of what, if any, government strategies could be created to help foster more success from these activities.

D3: The Panel believes these factors need to be systematically studied with quantitative data in order to understand how research funding processes could be more aligned with UK economic goals.

D4: Overall, the Panel believes that recommendations as to how the UK university system in materials could best serve the UK economy are best made in the context of an overall strategy for the future direction of the UK materials sector. Once such a strategy was in place it would be easier to determine how funding for the university sector could best serve these strategic goals.

E1: The Panel recommends a coordinated national effort to increase the awareness of materials as an attractive and fulfilling career option.

E5: To effectively compete on the global stage, the Panel strongly recommends a systematic review of the factors and limiting processes that are preventing access to the full global talent pool. Included should be issues such as the granting of visas and work permits.

E6: The Panel recommends that EPSRC work with universities to develop "best practices" for hiring, mentoring and career development of postdoctoral associates. Included should be a means of creating greater research independence at earlier stages of their research careers. For example, creating mechanisms for pursuing original research avenues that are more independent of senior faculty such as more direct access to equipment or seed grants.

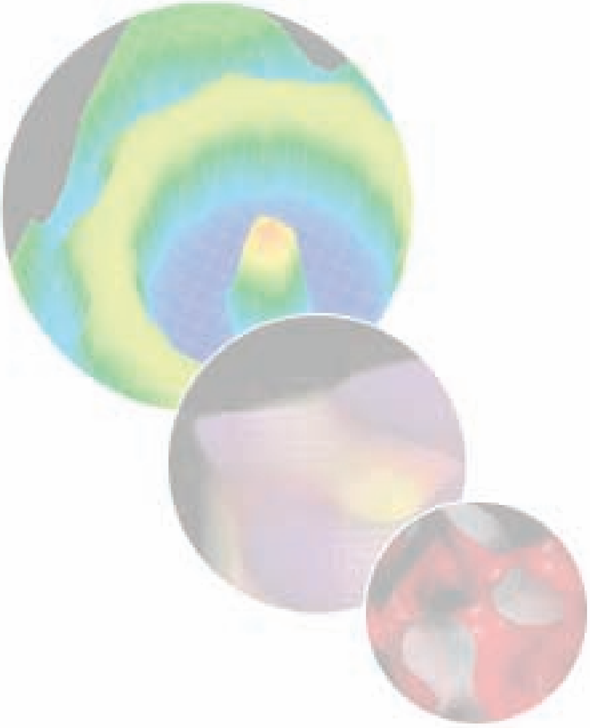
G1: We recommend that the UK community initiate its own benchmarking effort using the standard metrics (publications, citations, etc) that are becoming applied rather generally world-wide. This can provide judicious feedback for assessing progress in rapidly exploding fields and also help assess declining fields where claims for significant EPSRC support are made. Such quantitative metrics may help alleviate anecdotal concerns that responsive mode review requires a critical community size for funding success.

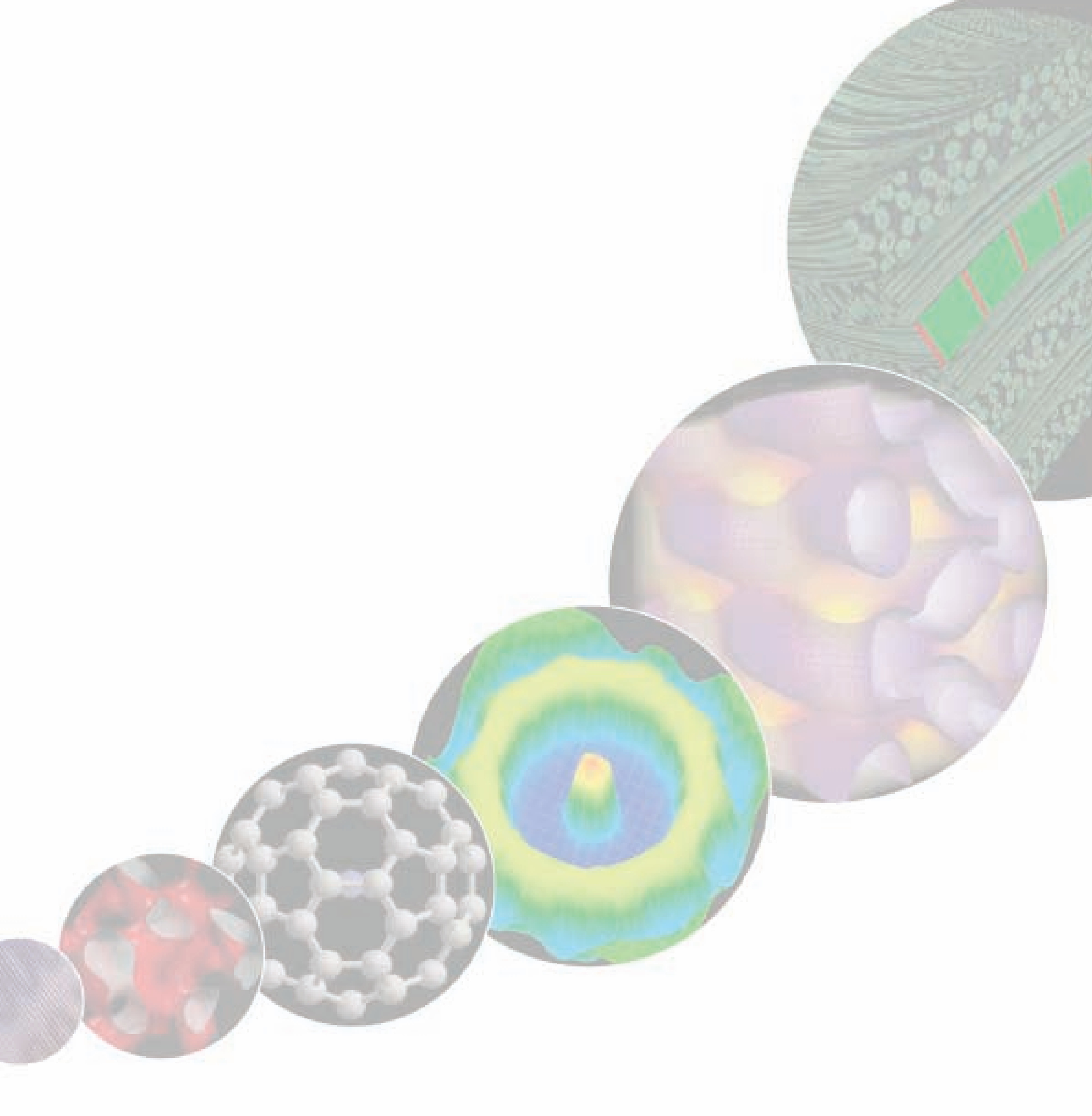
G2: Beyond publications and citations, which can measure excellence in science, metrics that measure 'innovation' also need to be evolved, monitored and used for improvement of the overall inputs. Definition of the metrics used to measure innovation should involve a few progressive industrial partners.

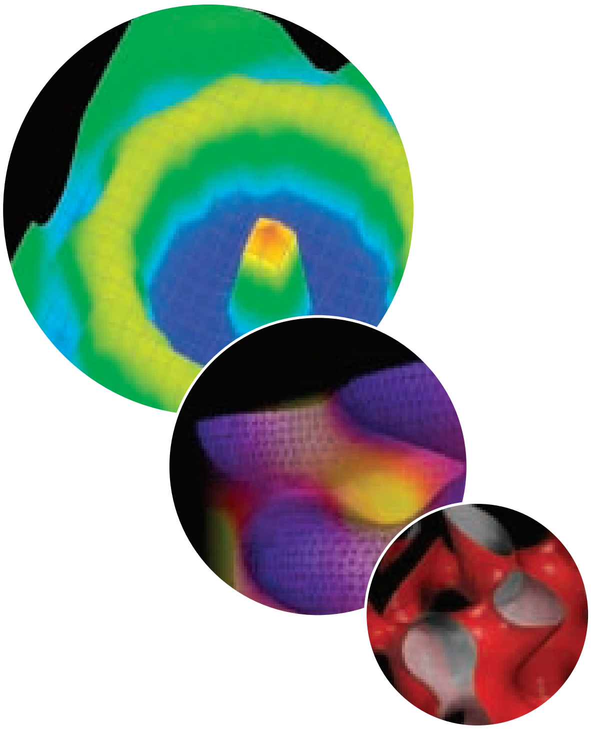
G3: We recommend that the EPSRC materials programme re-affirm its unambiguous commitment to supporting world-level quality in all its programmes. This means no compromises in quality will be made in favour of providing near term assistance to industry.

G5: We heard some good examples of how UK academics had developed new curricular materials for secondary school use and how this had produced both more and stronger applicants to university undergraduate materials programmes. We applaud this initiative and encourage its expansion, perhaps using this initiative as a means of rethinking what the core materials curriculum and department focus should be.

G6: We recommend that innovation be included as a measure of success of EPSRC funding. As mentioned earlier, this will first require thoughtful creation of metrics to assess innovation (see recommendation G2).







EPSRC

Engineering and Physical Sciences
Research Council

Polaris House
North Star Avenue
Swindon
SN2 1ET