Progressing UK Energy Research for a Coherent Structure with Impact

This is a challenging time for science, when the UK seeks to extend both its economic and social impact and international reputation for cutting edge fundamental research. This is the first RCUK Review of Energy and reflects the important contribution of this area to the UK. This contribution enables progress by bringing a fundamental knowledge and understanding of energy which drives advances in many areas. Energy research is the key to achieving an affordable low carbon energy system whilst conserving our natural resources, the environment and our quality of life. Energy Research will be indispensable in attacking the challenges of climate change and accelerating the deployment of affordable green energy technologies that decarbonise our energy supply and increase energy efficiency in buildings, industry and transport sectors.

The preparation for this review has been ongoing for over a year and we would like to thank our colleagues on the Steering Committee, which included representation of the Royal Academy of Engineering, National Grid and E.ON. We also thank our colleagues from the Biotechnology and Biological Sciences Research Council (BBSRC), Economic and Social Research Council (ESRC), the Natural Environment Research Council (NERC) and the Science and Technology Facilities Council (STFC) who also supported and helped to guide the review. Specific thanks must go to the 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, team work, enthusiasm and capacity for sheer hard work impressed all those who came into contact with them. To Dr Carsten Hein Westergaard, Chair 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.

We also warmly thank all those in the academic research community, together with their collaborators in industry who are so vital to the health of UK Energy 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 findings and recommendations highlighted and we genuinely welcome your feedback on any issues raised. Comments should be sent to the Energy International Review team at EnergyReview@rcuk.ac.uk

Professor David Delpy
Chief Executive, EPSRC

Professor Sue Ion
Steering Committee Chair
Executive Summary

In this review we have considered the energy R&D undertaken in the UK, largely through the funding by the RCUK. This exercise is most timely given that the UK government has recently established ambitious targets for emissions reduction by 2020 and 2050. The RCUK energy research portfolio could play a significant role in achieving these goals.

Our terms of reference required us to consider four key aspects, the impact both nationally and internationally, the quality of the R&D, the skills base both now and into the future and finally, the value added by organising and funding research through specific programmes.

One can synthesise all of these aspects into one overarching question:

Is the energy research funded by the UK government through the RCUK energy programme delivering impact in the UK and worldwide?

The answer is undoubtedly that in many aspects, good value is being delivered. In the long-term however, especially in terms of impact, there are significant concerns, particularly around structure relating deployment from research through demonstrations, as these are covered in many different bodies.

Turning specifically to the four key terms of reference, we note:

On impact: On the whole, the academic community is very well regarded on the international scene for its excellence. However, in terms of impact on economic benefit, industry development and quality of life, we have concerns that much more can be done.

On quality: There are many examples of impressive excellence, especially where there has been sustained focus. Again, we recommend improvements.

The skills base: There is a good pipeline of doctoral students and post doctoral research associates. The availability of long-term career paths thereafter is less than clear.

Targeted programmes: These are necessary and have produced impressive results e.g. from programmes such as SUPERGEN. There are significant issues, in particular the communication of the balance between open ended discovery and targeted strategic programmes and there is a distinct lack of transparency of process.

Our review focused upon two distinct elements; first the structure of, and mechanisms for, the funding of research and second the quality of the research itself.

With respect to the structure of research funding there are clear strengths. SUPERGEN and BSBEC as models are commendable as are the centres for doctoral training. The latter, however, are also a concern if they lead to the elimination of studentships associated with specific projects in a budget constrained environment.

There are, however, fundamental weaknesses that therefore give rise to significant concerns. The weaknesses arise because of a lack of a sustained long-term coherent energy research programme across the different funding bodies, competition between the funding bodies, a lack of transparency particularly as perceived by the researchers and poorly executed or non-existent mechanisms for moving technologies from the research stages to early demonstration, application and deployment (TRL3 to TRL4 and beyond).

Across almost all areas reviewed by us we found interesting, leading edge and world class research. The excellent international reputation of UK research is deservedly earned. This is not to say that all of the research was of a uniform high standard. This might reflect the robustness of the review process or the emerging position of UK researchers in particular areas.
Interdisciplinary research deserves a special mention. There is evident commitment from the universities to encourage interdisciplinary research. However, identifying the opportunities requires more attention.

**Recommendations**

The Panel therefore recommends:

- A fully integrated “roadmap” for UK research targets be completed and maintained to allow all to know and understand what is considered essential to meet society’s needs.

- A single, well defined, cross-Councils’ energy research budget with coordinated deployment mechanisms be created to provide a common vision and strategy to the research community and to avoid conflicting priorities. Such a coordinated approach should also enhance the linking of RCUK funds to wider resources.

- The allocation process for strategic programmes needs to be more transparent and anchored to clear plans to ensure better research community involvement and acceptance as well as a better targeting of deliverables. At the same time, the current level of support for open ended programmes is seen as appropriate.

- Many application areas are best served by interdisciplinary R&D. There needs to be increased efforts to identify opportunities, provide funding and then promote, recognise and reward interdisciplinary R&D.

- Postdoctoral graduates are a critical element of the UK’s human capital. To ensure long-term engagement in the UK, there needs to be more attention and resources directed to career paths both in industry and academia. It should be recognised that international careers and experiences are beneficial.

- Meeting climate change targets of necessity requires reduction in energy demand across the board. R&D on demand reduction needs a higher profile in the R&D portfolio and may warrant a dedicated programme.

**Concluding comments**

Energy and emissions are increasingly important to the UK and internationally. The scene is changing rapidly and the connections between an R&D portfolio and its impact on achieving emission reductions is complex. The connection includes many factors including metrics for impact, government policies on mandating certain paths, a price on carbon and other factors. 2050 may seem a long way off but achieving change requires focus and traction.

Regular review of the impact of the R&D effort should be undertaken. From time to time it will be necessary to look at the portfolio and particularly the balance between directed programmes and work targeting breakthroughs. Equally the extent to which the UK should invest in its own R&D or co-invest internationally and with industry needs periodic evaluation.
# Table of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ABB</td>
<td>Asea Brown Boveri</td>
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<tr>
<td>AHRC</td>
<td>Arts and Humanities Research Council</td>
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<tr>
<td>BBSRC</td>
<td>Biotechnology and Biological Sciences Research Council</td>
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<tr>
<td>BERR</td>
<td>Department for Business, Enterprise and Regulatory Reform (merged with DIUS in 2009 to form BIS)</td>
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<tr>
<td>BIS</td>
<td>Department for Business, Innovation and Skills (established 2009) - formerly DIUS and BERR</td>
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<tr>
<td>BSBEC</td>
<td>BBSRC Sustainable Bio-Energy Centre</td>
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<tr>
<td>CCFE</td>
<td>Culham Centre for Fusion Energy</td>
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<tr>
<td>CCLRC</td>
<td>Council for the Central Laboratory of the Research Councils (merged with PPARC to become STFC)</td>
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<tr>
<td>CDT</td>
<td>Centre for Doctoral Training</td>
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<tr>
<td>CIF</td>
<td>Capital Investment Framework</td>
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<tr>
<td>Co-I</td>
<td>Co-investigator</td>
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<tr>
<td>CSA</td>
<td>Chief Scientific Adviser</td>
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<td>CSR</td>
<td>Comprehensive Spending Review</td>
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<td>DECC</td>
<td>Department of Energy and Climate Change</td>
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<tr>
<td>Defra</td>
<td>Department for Environment, Food and Rural Affairs</td>
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<td>DELNI</td>
<td>Department of Education and Learning in Northern Ireland</td>
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<tr>
<td>DfT</td>
<td>Department for Transport</td>
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<tr>
<td>DGSI</td>
<td>Director General of Science and Innovation</td>
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<td>DIUS</td>
<td>Department of Innovation, Universities and Skills (merged with BERR in 2009 to form BIS) - formerly OSI</td>
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<tr>
<td>DTA</td>
<td>Doctoral Training Account</td>
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<tr>
<td>DTI</td>
<td>Department of Trade and Industry (abolished 2007 - many of its functions were transferred to BERR)</td>
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<tr>
<td>EDF</td>
<td>Energy de France</td>
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<tr>
<td>EPSRC</td>
<td>Engineering and Physical Sciences Research Council</td>
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<td>ERP</td>
<td>Energy Research Partnership</td>
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<tr>
<td>ESRC</td>
<td>Economic and Social Research Council</td>
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<td>ETI</td>
<td>Energy Technologies Institute</td>
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<td>EU</td>
<td>European Union</td>
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<tr>
<td>EURATOM</td>
<td>European Atomic Energy Community</td>
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<tr>
<td>fEC</td>
<td>Full Economic Costing</td>
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### Table of Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>FTE</td>
<td>Full-Time Equivalent</td>
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<tr>
<td>HE/HEI</td>
<td>Higher Education/Higher Education Institution</td>
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<tr>
<td>HECToR</td>
<td>High End Computing Terascale Resources</td>
</tr>
<tr>
<td>HEFCE</td>
<td>Higher Education Funding Council for England</td>
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<td>HECW</td>
<td>Higher Education Funding Council for Wales</td>
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<tr>
<td>HESA</td>
<td>Higher Education Statistics Agency</td>
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<tr>
<td>IP/IPR</td>
<td>Intellectual Property/Intellectual Property Rights</td>
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<tr>
<td>KT/KE</td>
<td>Knowledge Transfer/Knowledge Exchange</td>
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<tr>
<td>KTP</td>
<td>Knowledge Transfer Partnership</td>
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<td>KTN</td>
<td>Knowledge Transfer Network</td>
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<td>LFCF</td>
<td>Large Facilities Capital Fund</td>
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<td>MOD</td>
<td>Ministry of Defence</td>
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<td>MRC</td>
<td>Medical Research Council</td>
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<td>NAREC</td>
<td>National Renewable Energy Centre</td>
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<tr>
<td>NERC</td>
<td>Natural Environment Research Council</td>
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<tr>
<td>NERN</td>
<td>National Energy Research Network</td>
</tr>
<tr>
<td>NSF</td>
<td>National Science Foundation (US counterpart to UK Research Councils)</td>
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<tr>
<td>Ofgem</td>
<td>Office of Gas and Electricity Markets</td>
</tr>
<tr>
<td>OSI</td>
<td>Office of Science and Innovation (became DIUS (Dept. for Innovation, Universities and Skills))</td>
</tr>
<tr>
<td>OST</td>
<td>Office of Science and Technology (established in 2007 and then became the OSI)</td>
</tr>
<tr>
<td>PI</td>
<td>Principal Investigator</td>
</tr>
<tr>
<td>PPARC</td>
<td>Particle Physics and Astronomy Research Council (merged with CCLRC to form STFC)</td>
</tr>
<tr>
<td>RDD&amp;D</td>
<td>Research, development, demonstration and deployment</td>
</tr>
<tr>
<td>RA</td>
<td>Research Assistant</td>
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<tr>
<td>RAE</td>
<td>Research Assessment Exercise</td>
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<tr>
<td>RAL</td>
<td>Rutherford Appleton Laboratory</td>
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<tr>
<td>RCUK</td>
<td>Research Councils United Kingdom or Research Councils UK</td>
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<tr>
<td>RDA</td>
<td>Regional Development Agency</td>
</tr>
<tr>
<td>REF</td>
<td>Research Excellence Framework</td>
</tr>
<tr>
<td>SET</td>
<td>Science, Engineering and Technology</td>
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<tr>
<td>SFC</td>
<td>Scottish Funding Council</td>
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<tr>
<td>SME</td>
<td>Small/Medium sized Enterprise</td>
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<td>SR</td>
<td>Spending Review</td>
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<tr>
<td>SRIF</td>
<td>Science Research Investment Fund</td>
</tr>
<tr>
<td>STFC</td>
<td>Science and Technology Facilities Council (formerly PPARC and CCLRC)</td>
</tr>
<tr>
<td>TRL</td>
<td>Technology Readiness Level</td>
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<td>TSB</td>
<td>Technology Strategy Board</td>
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<td>UKERC</td>
<td>UK Energy Research Centre</td>
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<tr>
<td>UOA</td>
<td>Unit of Assessment</td>
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</table>
Acknowledgements

Panel members are grateful to the Steering Committee for their excellent preparatory work that led to a well-structured, albeit busy schedule. The Panel also offers an enormous vote of thanks to the EPSRC staff involved in managing the review, and to the other Research Council staff who assisted and provided information throughout the review process. Specifically, their tireless efforts in ensuring members of the Panel were in the right place at the right time, their overall project management and preparation, including distribution of documentation for the Review, and first-rate travel arrangements contributed enormously to a memorable experience and the success of the Review. The staff professionalism and insight formed the foundation which made such a complex review possible.

The Panel is appreciative of the time and effort given to the review by the institutions and their staff. Each day, the Panel was exposed to presentations of high quality. The Panel appreciates the enormous time and effort devoted to the RCUK Review by the Energy community. Talks and the interactions with the Panel formed the basis of lively discussions and an effective communication vehicle. The many frank discussions with academics and industrialists were invaluable and form the basis of the Panel’s findings and recommendations. The Panel and the UK can be proud to have active industrial engagement in early stage research and such active interest in participating to form the future of the UK energy research. Finally, the Panel is especially appreciative of the early career researchers that openly shared their experiences, these inputs may be some of the most important ones, as they are literally to form the future.
## 1. Table of Contents

1. **Table of Contents**

2. **Introduction and Background**
   - Purpose of the Review
   - Structure of the Review
   - Review Panel Activities
   - The International Panel

3. **Panel Responses to the "Framework and Subsidiary Questions"**
   - 3.A. To what extent is the UK energy community addressing key technological/societal challenges through engaging in new research opportunities?
   - 3.B. To what extent is the Energy Programme bringing together disciplines to form a coherent Energy research community?
   - 3.C. What is the level of knowledge exchange between the research base and industry/policymakers that is of benefit to both sides?
   - 3.D. To what extent is the UK energy research activity focused to benefit the UK economy and global competitiveness?
   - 3.E. To what extent is the UK able to attract talented young scientists and engineers into energy research? Is there evidence that they are being nurtured and supported at every stage of their career?
   - 3.F. To what extent are UK researchers engaged in “best with best” science-driven international interactions?
   - 3.G. What is the impact on a global scale of the UK energy research community both in terms of research quality and the profile of researchers?
   - 3.H. What evidence is there to support the existence of a creative and adventurous research base and portfolio?
   - 3.I. Other observations and recommendations
   - 3.J. Specific Disciplinary Comments and Recommendations

4. **Concluding Remarks**


**Annex B: Brief Biographies of Panel Members**
Table of Contents

Annex C: Review Week Itinerary 57
Annex D: Supporting Evidence and Information Provided 59
Annex E: SWOT Overview of Recommendations 63
Annex F: Steering Committee Membership and Role 67
2. Introduction and Background

Purpose of the Review
This is the report of an international panel of 16 experts convened by a cross-Council Steering Committee on behalf of all UK Research Councils to review the RCUK Energy Programme begun in 2002. The Steering Committee and review process was supported and staffed by the Engineering and Physical Sciences Research Council (EPSRC). The RCUK Review of Energy 2010 focused on the entire Research Councils’ Energy portfolio since 2002. The broad questions to be addressed by the Panel - the Terms of Reference - are as follows:

• assess and compare the quality of the UK research base in Energy with the rest of the world;
• assess the impact of the research base activities in Energy internationally and on other disciplines nationally, on wealth creation and quality of life;
• comment on the relevant skills availability in the UK and any issues relating to training and skills provision for the future health of the UK research base;
• comment on progress that would have occurred had a specific programme not been in place, and on what value had been added; and
• present findings and recommendations to the Research community and Councils, and state where these can have the greatest impact.

The review focused mainly on research and training in UK academic institutions, taking account of activities elsewhere in the context of knowledge exchange. The review also focused on how the 2050 targets would be delivered through the Programme.

Structure of the Review
The review process oversight was the responsibility of a Steering Committee chaired by Dr Sue Ion, Independent. The full membership is given in Figure 1.

This Steering Committee, after receiving nominations from the community, originally selected the Panel Chair, Professor Daniel Kammen, Class of 1935 Distinguished Professor of Energy at the University of California, Berkeley, USA to take on this role for the review in April. However, following the postponement of the April review due to flight disruptions caused by an Icelandic volcanic ash cloud, Professor Kammen was unable to continue in the role of Chair due to other commitments and Dr Carsten Westergaard, Vestas Technology R&D Americas, Inc. USA, was appointed. In concert with the Chair, the Steering Committee selected the other 15 members - all based outside the UK. The Panel members represented a balanced mix of international researchers spanning the RCUK disciplines and also with extensive experience in Energy. The names and affiliations of Panel members are shown on page 11 and brief academic biographies are included in Annex B.

The Steering Committee in concert with the Chair also 1) agreed on the high level questions to be addressed by the review panel - the Evidence Framework; 2) selected the 39 institutions to be visited by the Panel; 3) selected background data to be provided to the Panel; 4) created the agenda for the review week; 5) received a preliminary briefing from the Panel at the end of the review week; and 6) orchestrated the disposition and use of this final report. EPSRC provided Review Secretariat support for the organisation, planning and logistics.

The eight areas of the evidence assessment framework are summarised by the following questions:

• To what extent is the UK energy community addressing key technological/societal challenges through engaging in new research opportunities?
• To what extent is the Energy Programme bringing together disciplines to form a coherent Energy research community?
Introduction and Background

- What is the level of knowledge exchange between the research base and industry/policy makers that is of benefit to both sides?
- To what extent is the UK energy research activity focused to benefit the UK economy and global competitiveness?
- To what extent is the UK able to attract talented young scientists and engineers into energy research? Is there evidence that they are being nurtured and supported at every stage of their career?
- To what extent are UK researchers engaged in “best with best” science-driven international interactions?
- What is the impact on a global scale of the UK energy research community both in terms of research quality and the profile of researchers?
- What evidence is there to support the existence of a creative and adventurous research base and portfolio?

The framework was used extensively by the Panel in the review process described below. These questions are not a template for the organisation of this report, but responses to all questions are embedded in the report and also briefly summarised in Annex A within the full question framework.

Although the report scope is defined by the RCUK Energy programme specifically, it goes much further in several areas. The Panel felt that given the terms of reference, the framework and the evidence presented, commenting on the dissemination and impact opportunities was required; in particular as RCUK transfer its results through mechanisms with the ERP, TSB and ETI.

Review Panel Activities

During the week starting Sunday, 24 October 2010, the full Panel convened at Heathrow, UK, for the purpose of assessing the quality and impact of academic energy research in the United Kingdom (UK). After a briefing meeting on Sunday, the Panel travelled to Edinburgh and then Oxford during the ensuing Monday to Thursday for an intense week of review. The Review Secretariat, under the general supervision of the Steering Committee, provided an overview of research in Energy in the UK in terms of its people, funding, organisation and policy. Evidence in this document was compiled from the Research Councils’ management records and the UK Energy research community. The documentation included 1) descriptions on the structure, history and spending trajectories, 2) summaries of funded projects, and 3) summaries of surveys sent to grantees. The data provided for use by the Review Panel was published on the RCUK website on completion of the Review (documentation provided in confidence was not published). The Panel requested some additional information from the Secretariat as well as from grantees during the review week.

In a mixture of full and sub-panel formats, the Panel interacted with researchers from 39 institutions who receive Energy funding. As the Panel gathered inputs, four sub-groups of the Panel processed what we heard, read and observed against the eight areas of the Energy evidence assessment framework and also added additional topics as appropriate.

In closed meetings the Panel achieved collective understanding about the context, vision and opportunities afforded by the Energy Programme; made judgements on strengths and weaknesses of the Programme to date, and developed recommendations about the opportunities for the future and how to proceed to pursue them. This report is the final product from the Panel developed from further analysis and refinement of findings gathered during the review week.

Figure 1 - RCUK Review of Energy Steering Committee

- Dr Sue Ion (Chair), Independent
- Dr Paul Golby, E.ON UK
- Professor Ian Fells, Royal Academy of Engineering
- Mr Ian Welch, National Grid
- Mrs Catherine Coates, Director, Business Innovation, Engineering and Physical Sciences Research Council (EPSRC)
- Mr Adrian Alsop, Director for Research, Economic and Social Research Council (ESRC)
- Dr Janet Seed, Associate Director, Science Programmes, Science and Technology Facilities Council (STFC)
- Professor Janet Allen, Director of Research, Biotechnology and Biological Sciences Research Council (BBSRC)
- Dr Phil Heads, Head of Strategy, Science and Innovation, Natural Environment Research Council (NERC)
The International Panel

The panel members and their home institution or company are shown in Table 1. Brief biographies of the panel members are found in Annex B.

Table 1: Composition of International Review Panel

<table>
<thead>
<tr>
<th>Title</th>
<th>Organisation</th>
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<tbody>
<tr>
<td>Dr Carsten Westergaard (Chair)</td>
<td>Vestas Technology R&amp;D Americas, Inc., USA</td>
</tr>
<tr>
<td>Professor Göran Andersson</td>
<td>ETH Zürich, Switzerland</td>
</tr>
<tr>
<td>Professor Rangan Banerjee</td>
<td>Indian Institute of Technology Bombay, India</td>
</tr>
<tr>
<td>Professor Robin Batterham</td>
<td>University of Melbourne, Australia</td>
</tr>
<tr>
<td>Professor Frank Carré</td>
<td>French Atomic Energy Commission, France</td>
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<tr>
<td>Dr Andrew Dicks</td>
<td>Queensland University of Technology, Australia</td>
</tr>
<tr>
<td>Professor Rosemary Falcon</td>
<td>University of the Witwatersrand, South Africa</td>
</tr>
<tr>
<td>Professor Richard Flavell</td>
<td>Ceres, Inc., USA</td>
</tr>
<tr>
<td>Dr Clark Gellings</td>
<td>Electric Power Research Institute (EPRI), USA</td>
</tr>
<tr>
<td>Dr David Hill</td>
<td>Idaho National Laboratory, USA</td>
</tr>
<tr>
<td>Professor Martha Lux-Steiner</td>
<td>Helmholtz-Zentrum Berlin, Germany</td>
</tr>
<tr>
<td>Professor Brian Norton</td>
<td>Dublin Institute of Technology, Republic of Ireland</td>
</tr>
<tr>
<td>Professor Jonathan Parker</td>
<td>Structural Integrity Associates, Inc., Canada</td>
</tr>
<tr>
<td>Dr Teresa Pontes</td>
<td>National Laboratory for Energy and Geology, Portugal</td>
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<tr>
<td>Professor Susan Scott</td>
<td>Research Affiliate of the Economic and Social Research Institute, Republic of Ireland</td>
</tr>
<tr>
<td>Professor Dongxiao Zhang</td>
<td>Peking University, China</td>
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Left to right: Jason Green (EPSRC), Neil Bateman (EPSRC), Rosemary Falcon, Robin Batterham, Susan Scott, Martha Lux-Steiner, Rangan Banerjee, Richard Flavell, Brian Norton, Jonathan Parker, Teresa Pontes, Frank Carré, David Hill, Dongxiao Zhang, Andrew Dicks, Jo Garrad (EPSRC), Clark Gellings, Carsten Westergaard (Chair) and Göran Andersson.
Preamble
Affordable energy is well recognised as a prerequisite for economic growth and prosperity. Enormous geographical differences exist both in terms of opportunities to access energy but also in the response to energy supply issues. In the developed part of the world the current obstacles lie within financial investments whereas other parts of the world are fighting availability and/or stability to get out of energy poverty. At the same time it has become evident that human activity and in particular energy consumption challenges the environment and the long-term stability of the climate; directly becoming a threat to life in many parts of the world. Adding to the complexity are growing and rapidly changing demographics with even a higher demand for energy on the horizon. Renewable energy is on the agenda to address these issues; however, coal has been the biggest growing source of energy for the past decade and there is no evidence of a slow down. The discovery of shale gas has been characterised as an opportunity to close the gap for the future with less CO₂ emissions than coal, whereas other countries put significant efforts into revitalising nuclear energy because it is CO₂ neutral. It is evident that the energy production of the future must address these challenges: secure and sustainable energy is a requirement for success. The solutions to the global challenge lies within energy efficiency, technology development and a long-term, stable and consistent policy support from governments.

Needless to say, a national review of the UK energy research programme seeking to contribute critically to solving tomorrow’s energy challenges is not a small engagement, which is also reflected in the high level “terms of reference” and the specific questions developed for this review. Transformation of detailed technical information from the multitude of disciplines, structure of research and research programmes into a coherent set of recommendations is highly complex. The diversity and size of the panel ensured a capacity to understand the technical details and the team work following the physical meeting made it possible to collect impressions into such a set of high level recommendations.

The Panel did, with the support of the RCUK staff, plan the review week to allow for input to the review by multiple sources in various formats. In the review visit week several formats of interviewing were deployed, allowing both for structured and RCUK supported presentations by the universities to the Panel, but also including private debate with the Panel without the RCUK staff present. The latter ensured that the feedback was direct and did not pose a conflict for the presenting universities. Likewise, independent poster sessions with young academia, postdocs and students without presence of senior university staff or RCUK staff ensured the opportunity for unfiltered review. In general, the Panel found very little difference between the unfiltered and filtered evidence, which speaks to a healthy dialogue between the RCUK and their users of RCUK funding, these being the universities, the research staff or the students.

3. Panel Responses to the “Framework and Subsidiary Questions”
Although the Panel has been asked to review the RCUK sponsored Energy Programme, significant efforts have been spent in understanding and commenting upon the interfacing organisations of UK energy research and co-ordination, especially the different government bodies. This is particularly important as dissemination of research results are believed to be an important part to impact ambitious goals set by the UK government address, in particular climate change. The sense of urgency to do so from a research perspective is reflected in elements of UK funding mechanisms. The report delivered here is focusing on how these mechanisms could become more effective, in particular seen from the RCUK Energy Programme opportunities.

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

As most countries in the developed part of the world are looking to mitigate climate change in future energy supplies, most, including the UK, have identified that the future holds a multitude of energy technologies which are either renewable sources or existing sources, modified to meet the challenges. This is often referred to as “the energy mix” or “energy diversity”, which most countries or regions see as a necessity to meet future challenges. Some scenario planning has been developed in different contexts; for example, the European Commission’s Directorate General for Climate Action and UKERC¹ have developed a scenario for how an energy mix can be developed based upon different desires for reduction of carbon in the energy system and different policies. Results and required investments are discussed, but characteristically, these are not broken down to a focused set of details. Nor are the steps needed to be taken beyond policy planning quantified. The UK has been leading in describing its ambitions with respect to climate change, but without a coherent and focused approach that can ensure results in the 2020-2050 timeframe opportunities and targets may be missed. The next decade will require emphasis on narrow scoping, both for defined research programmes and open-ended research in order to deliver; whereas the long-term targets additionally require emphasis on diversity.

A vision of the UK’s energy future & energy technology roadmaps are missing. The UK’s energy roadmap is currently stipulated at a high level² and is built around real progress by 2020 and 60% reduction of greenhouse gas emissions by 2050. This is insufficient guidance for RCUK and the research laboratories to act in a coordinated fashion and the UK is missing an opportunity. As a consequence, there is not a coherent plan against which to evaluate the medium and longer term energy research portfolio overall and the programmes of individual universities. The UK Energy Research Centre (UKERC) has drafted local roadmaps for some key technologies of the UK’s future energy mix, for example: solar photovoltaics, wind energy, nuclear power, biofuels, carbon capture and sequestration, but these are not yet integrated or implemented by RCUK. It was not clear who is, or should be, leading the production, review and dissemination of integrated roadmaps, including strategic development of human capital. In addition, there are no R&D roadmaps for many of the other generation technologies. Nor are there any for the electric power delivery system of the future (transmission and distribution) and none for the demand side which highlight the research needed for aggressive energy efficiency and electrification.

A.1 Recommendation

The Energy Research Roadmaps being prepared by BIS, UK Energy Research Centre, Energy Research Partnership (ERP)³, RCUK and others should be expanded to include generation, delivery and end use, aligned, publicised, debated, continuously honed and adopted by all research players and converted into research strategies for the medium and the longer terms, with indicative milestones. Pathways, i.e. developed by DECC, can be used to support impact of these roadmaps. The roadmaps with milestones should enable cross-cutting requirements and topics at the interface. This process, embraced by all the UK Research Councils and associated agencies as a whole; and, not by Research Councils working separately, will enable gaps and misalignments of activities with UK goals to be identified and research needs to be evaluated, prioritised and implemented. In undertaking the RCUK’s participation in this roadmap generation, the RCUK must secure a broad array of stakeholders including academia, industry, environmental activists, policymakers and others are involved.

³ A public-private body, with members from Government, industry, funders and academia, designed to give strategic direction to energy innovation in the UK.
The UK’s position relative to the strengths and weaknesses of overseas research should be assessed as part of this exercise. Based on the outcome of these processes, RCUK should provide useful guidance to universities to position their research optimally, especially for the longer term beyond the horizon of industry’s current interest. Accountability for measures on time to impact the government 2050 targets should be a requirement.

In the efforts of organising a roadmap, resources should be joint and coordinated. For example, ERP consist of an analysis team producing technological reports impacting on public policy and high level guidance. This work is to an extent partially sponsored by private companies. Although public-private partnerships are an efficient way to exchange experience and work on technical aspects of technology, it is clear that such an organisation cannot stand completely independent, if the organisation directly or indirectly works on future policies for deployment. It is also observed that the analyses performed in ERP on technical performance are partially overlapping with that done by a team performing analysis work in ETI. DECC and BIS also appear to have several elements of roadmap analysis in progress, although not yet completed.

### A.2 Recommendation

It would seem that merging the ERP analysis skill set combined with the ETI skill set and interaction with UKERC could improve the total analysis capacity for future fact-based guidance to the UK research portfolio. Synergies would be found in having government, academic and industrial focused analyses under one body. The synergy of developing research plans coordinated with the demonstration aspects is evident. Also, with a higher degree of coordination, linkage back to the development of human capital (in all aspects) focusing both on government, academic and industrial needs can be included. A clear mechanism from RCUK to adapt these roadmaps should be in place. Also, a methodology should be implemented to breakdown roadmaps into clear action plans within the respective energy discipline areas of defined multidisciplines and to finally define differences between near-term and long-term research goals. Human capital development must be included as a high priority item associated with the research. Finally, in the public-private bodies a clear separation between policy related work and fact based guidance (roadmap guided by performance metrics) must be transparent. Coordination is needed and acceptable but the work must still be clearly separated.

### Organisation of UK’s public research on energy

The UK has achieved many good results through multi-body collaborative efforts in research leading through to impact. However, the Review Panel found in several instances a lack of transparency due to an unclear separation of roles, responsibilities and even organisation. This clearly causes confusion and inefficiencies for both the Councils, the collaborators of the Councils and the recipients, resulting in less efficient execution by recipients of funding.

The research funding is complex owing to the number of organisations involved and the diversity of funding schemes: RCUK for academic research, TSB, ETI for applied research and demonstration, Carbon Trust and other funds at pre-industrial demonstration level. Also, the lack of a single strategy across the Research Councils means inefficient implementation in some cases. Further segmentation of research originates from the large number of universities working in parallel in the same field and on research programmes funded for 3 to 5 years only. As a result, the great number of interfaces and research funding processes inevitably leads to gaps and distortions that are likely to be detrimental to the overall efficiency of research in some areas.

### A.3 Recommendation

The UK’s public energy research organisation should be simplified. This could include stricter coordination between Research Councils, allocation of more RCUK grants to a smaller number of larger, multidisciplinary and multi-institutional projects to favour the building of critical mass and catalysis of research on key subjects. In the projected evolution of “responsive mode research” in 2011 appropriate research projects should be evaluated not only on scientific excellence and opportunities to create breakthrough concepts, but also on their relevance to obtain critical research volume.

The research institutions funded by RCUK are not well placed in technological subjects to deliver to civil society for the short-term (<2020) so obligations to address short-term solutions may undermine longer term oriented research. The need for moving discoveries from universities towards commercialisation...
highlights the gap that occurs between the funding of academic research by RCUK and the opportunity for continued funding towards commercialisation by TSB or ETI.

A.4 Recommendation
A roadmap should clearly outline how 2020 targets can be engineered and 2050 targets can be met. The roadmap would help focus government policies towards short-term and long-term commitments. This will make the appetite for industrial co-investment in research more attractive and thereby also focus the industry towards preparation for deployment investments. A long-term policy would also help in attracting young talent to research, education and, later, industry as clear commitment and certainty are demonstrated. Finally, this will enable planning of long-term research programmes having durations beyond 10 years; thereby truly impacting 2050 targets with innovative and game-changing solutions. To include such opportunities, it is important that long-term elements of the roadmap are kept sufficiently open, steering towards high level targets and being refined towards clear deliveries as time progresses.

Funding of UK’s research on energy. In 2009, the UK’s public research budget on energy was ~$407M compared to ~$783M in Germany, ~$1293M in France and ~$11,960M\(^4\) in the United States. Computed per capita, UK spend 6.6$ per capita, Germany spend 50% more and France spend 3 times more than the UK. Correcting these numbers for energy consumption or GDP does not change the positioning. The US clearly is leading and has accelerated energy research in recent years. These figures imply that UK funding for research and the volume of research being carried out is inadequate to meet the declared, extremely important, national objectives. The fragmentation of the research across so many objectives also contributes to lack of critical mass of funds in some areas. The success rate for responsive mode proposals is low on most occasions which suggest that the opportunity exists in the UK for carrying out much more research of high quality, especially for uncovering opportunities for post 2020 needs. Also the amount of money available to TSB and other downstream organisations appears to be too small to meet the needs of the UK.

A.5 Recommendation
Owing to the significance of energy security and climate change issues, the budget of public research on energy in the UK (other than Fusion) and its linkage to pre-commercial development needs to be significantly increased to meet the technology challenges underpinned by the Energy Policy Statement and to match the funding level of other (European) countries. The ratio between managed programmes and responsive mode research needs to be carefully considered in order to meet the 2050 objectives.

3.B – To what extent is the Energy Programme bringing together disciplines to form a coherent Energy research community?
Elsewhere we have noted the multidisciplinarity of SUPERGEN. The universities have on a large-scale clearly embraced the opportunity within energy research to combine disciplines and departments in different formats, ranging from informal unfunded networks to establishment of emerging energy institutes or focused programmes with clear strategies on how these fit into the big picture. In several cases universities have linked together to strengthen energy research regionally. The Regional development agencies have stimulated these moves. The major industrial investments into universities such as those by BP, Rolls Royce, E.On and many others have stimulated the bringing together of different disciplines. Some individual projects could have been significantly improved with an additional input from other disciplines. This could have been achieved by better co-ordination between the Research Councils. Examples of where socio-economics would have benefited projects included areas where behaviour was seen as having a perverse effect on the intended outcomes of the science, and socio-economics could additionally measure the potential economic impacts of technologies and policy scenarios, including macro-economic impacts. However, one university presented a coherent strategy for technologies encompassing the socio-economics aspect as their leading research strength.

Impressive examples of work “outside the box” were given, including studies of so-called engagement failures (as with CCS, GM or nuclear). Also, engagement failure with pollution charging was demonstrated, i.e. many surveys showing agreement that charging for pollution/emissions according to

\(^4\) This number includes American recovery act spending
amount caused was “fair” but was not implemented. One university addressed international issues (the geo-political response options to diversify risks of oil shocks). Politico-economic research could usefully investigate means of engaging the international community with the recommendation on world price for carbon, as made by Stern5 amongst others.

B. Recommendation
RCUK could give more leadership by supporting a cross-Council energy programme linking disciplines. Some projects seen during the review week could have been tightened up considerably with input from the economics/business discipline. In particular such disciplines could give an idea of short-term or long-term potential of the technologies and of what is needed for the project to perform its ultimate objective. Research Council publications talk about the need for indicators of final potential and of the potential commercial application of technologies, in order to help prioritise research areas that hold out most promise. Research proposers should continue to make economic/business cases when formulating their submissions on programmatic level.

B.1 What evidence is there that there is sufficient research involving multiple disciplines?
There is evidence of excellent research involving multiple disciplines: EPSRC’s SUPERGEN projects; materials science for varied energy technologies; strategic studies to advise industry and policy decision makers; and BSBEC focused on biofuels research. Multidisciplinary projects are definitely more efficient at making use of existing facilities (Diamond, ISIS…) and advancing research toward applications as they are more visible and capable of a better integrated vision of future research needs. There were many other examples where multiple disciplines were being brought together within and between universities, especially where major industries were involved.

Multidisciplinary projects may be useful instruments of university strategies to best allocate research money to maintain critical mass of skills for addressing priority research areas while adequately balancing their research between academic and applied, medium-term and long-term, directed (top down) and responsive (bottom up to maintain creativity).

B.1 Recommendation
There should be widespread recognition that many solutions to energy related problems demand multidisciplinarity. The energy community needs to take advantage of the projected evolution of “responsive research” in 2011/12 to have corresponding research projects evaluated not only for their scientific excellence, but also for their relevance or potential to lead to commercial technologies. Also, make the amount of available responsive research funding visible by clearly stating the amount of the total portfolio being used for open-ended research, but at the same time include and illustrate critical mass thinking. It appears that 20% of open-ended research is sufficiently aggressive for most research areas.

B.2 Are there appropriate levels of knowledge exchange between the energy community and other disciplines? What are the main barriers to effective knowledge and information flow and how can they be overcome?
Energy research in the UK has achieved good results through multi-body collaborative efforts in all aspects of funding and execution of impact. Many really good and emerging examples were found. However, the Panel found in several instances that a lack of transparency due to an unclear separation of roles, responsibilities and, even, organisation exists. This

5 Source: Stern review Section 4: “A broadly similar price of carbon is necessary to keep down the overall costs of making these reductions. Creating a transparent and comparable carbon price signal around the world is an urgent challenge for international collective action.”
clearly causes confusion and inefficiencies for both the Councils, the collaborators of the Councils and the recipients. The result is less efficient execution at the end for the recipients. We noted several examples where specific like-minded projects funded separately were not working closely because of the separate sources of funding.

**B.2 Recommendation**

Going forward, roles and responsibilities should be clearly identified, agreed and proclaimed to all stakeholders in order to induce the highest degree of transparency. A specific example is an unclear role for RCUK in the TSB involvement. RCUK should be a transparent and visible partner in TSB, which will also fuel better results.

**B.3 What evidence is there to demonstrate the influence that research council programmes have had in encouraging multidisciplinary research?**

There is clear evidence of Research Councils’ programmes having encouraged successful multidisciplinary programmes (SUPERGEN, BSBEC, materials science at Culham & Oxford where the attached industries cover a whole supply chain, etc.). The level of the programmes was further strengthened as several universities commented that the Regional Development Agencies had facilitated a process of knowledge exchange and were seen in a positive way to support such programmes. Also, the Panel noted that the existence of these consortia made the gaining of additional funds and students significantly easier.

**B.3.1 Recommendation**

Long before a consortium or programme (such as SUPERGEN and BSBEC) needs to be renewed or modified RCUK should assess what new science should be added to the consortium and old topics replaced to address the milestones of the national roadmap. For example, for the longer term, game-changing concepts in biomass production and CO₂ capture could be achieved by improvements in photosynthesis using synthetic biology that currently lie outside the energy field but could be focused into this area.

It is appropriate that university strategies are based on maintaining strength in core disciplines. That said much more is needed to encourage a greater degree of cross-cutting research, both within and across institutions. Networks and organisations need more flexibility to respond to economic and societal drivers as well as the challenges of cross-cutting scientific and engineering disciplines. We recommend that institutions funded by the RCUK should examine their practices to ensure that more cross-cutting research is encouraged. This includes rewarding the careers and developing the researchers who target cross-cutting work as well as those who follow the traditional path of ever deepening their standing in a particular discipline.

With respect to RCUK, some work is targeted for multidisciplinary teams and has been very successful. Examples of multidisciplinary work presented and associated projects clearly demonstrated the need and value of such work. Examples of where successful multidisciplinary teams have been developed solving a specific problem were also found. With such defined problems, teams are assembled from all the required skills and roles and responsibilities are then defined. At the end of the project the teams are either disbanded or refocused. It is important to emphasise that where the problem solving is long-term then stability is needed to ensure that the expertise is not lost.

However, academics have frequently needed to obtain funding from other sources because of real or perceived problems with the RCUK peer review and grant awarding process. Specific problems include:

- Differences between different Councils.
- Challenges in peer review process, in particular for the smaller responsive mode applications – frequently an application from a multidisciplinary team is reviewed by experts from one or other disciplines and the review process does not value the multidisciplinary aspects.

As far as the university system is concerned many institutions do not properly value multidisciplinary work, particularly when the teams are within a single institution. Specific issues include:

- Doctoral training has been very successful at producing excellent students but only a few of these have a multidisciplinary outlook.
- Current established methods for assessing research output focus on academic excellence (often judged on impact value of journal etc); multidisciplinary papers may be/are more difficult to publish in top journals.
Panel Responses to the “Framework and Subsidiary Questions”

- It is unattractive for young academics to engage in multidisciplinary work as the lower perceived impact can negatively influence career.
- Inter-institution multidisciplinary work is often easier than within an institution.

B.3.2 Recommendation

University strategies based on maintaining core disciplines (physics, chemistry, materials…) and dynamic reconfigurable network to respond to scientific, economic and societal drivers appear to be most appropriate (cf. University of Oxford, Imperial College). Such strategies indeed offer best prospects of preserving expertise while keeping critical mass in core disciplines and enabling sufficient flexibility to address varied research fields while implementing dedicated research groups or networks. It is recommended to support cross-cutting networks at universities.

B.3.3 Recommendation

Larger size multidisciplinary and multi-institution projects funded by RCUK, TSB and ETI are recommended to better seed research areas on key and new energy technologies. Specifically for the RCUK energy programme, considerations towards funding energy institutes and energy networks at universities directly could foster additional impact. The placement of CDTs in such focal areas could be an additional element to consider. It would be useful to assess how effective multidisciplinary EU programmes have been at stimulating new areas and strengthening existing topics.

B.4 Is there an adequate description of the top level challenges that the energy community can respond to?

Some description of high level challenges exists that the energy community should address, such as the roadmaps drafted for some energy technologies by the Energy Research Centre. However, developing a global vision of the UK’s energy future in the form of an integrated technology roadmap by the Research Councils as a whole (or by transforming the roadmaps to be developed under the expanded ERP work) would provide useful guidance for research institutions to position their research, especially for the longer term, beyond the horizon of industry’s interest as well as for identifying cross-cutting issues.

Cross-cutting issues could be for example:

- Focused areas of synergetic renewable energy sources, addressing:
  - Base load/intermittency.
  - Electrical generation combined with heat generation at a variety of scales.
- Energy vector/transport (not just electrical transmission):
  - Storage in generation and transmission.
- Reliability of renewable energy sources:
  - What requirements, if any, should society place on renewables?
  - What is the layout (technical, operational) of a dispersed system?
  - How do you plan demand response with intermittent production (forecasting and planning in system operations)?
- Environmental-specific areas where technical solutions and research can impact:
  - Water and energy.
  - Waste and energy.
  - Farming-food, feed, fibre and energy.

Key to the UK’s success in meeting society’s needs with increasing dependence on low carbon electricity will be a strong focus on the supply-side (electric power generation), delivery (both transmission and distribution) and utilisation of electricity (the demand side). Generation, delivery and the demand side are generally not strongly in focus from the RCUK energy programme. While some areas of research in generation are strong, e.g. Nuclear Fusion, others are very weak, e.g. enabling increased cycling of fossil units in order to help manage the intermittency of Renewables. Regarding delivery, there were examples of transmission R&D (SUPERGENs, Flexnet, HiDef and Amperes). Also, the SUPERGEN power network Hub (4M GBP) was launched in March 2010. Regarding the demand side, there seemed to be an attitude among UK researchers that there is no R&D that could have an effect within the next 20 years. For demand side research there were few examples of evolving frameworks for implementation of efficiency and electrification, in particular, in the short-term developing implementation plans and assessing feedback on outcomes of projects. For example, retrofitting 26 million UK buildings to improve insulation and to convert fossil-fuelled appliances
Panel Responses to the “Framework and Subsidiary Questions”

will need work on upfront attitudes, methods and training for installation and pre and post installation monitoring and data gathering and analysis. Impediments on the behavioural front need attention at the implementation stage, including education and accountability issues, not to mention transaction costs. Multidisciplinary projects are considered vital and can still influence short-term targets in these areas.

B.4 Recommendation
An assessment of the gaps in demand side knowledge should be made and mechanisms put in place to address the deficiencies. Also, there is insufficient knowledge of the effects of human behaviour and preferences on energy demands and these should be studied more acutely. Some policies and strategies fail because of nonacceptance by the public who have not seen the alternatives spelt out in an objective manner or a deep-seated objection is not addressed. The top level challenges need to be brought to the farming and forestry communities for biomass production.

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

Knowledge exchange between the research base and industry/policymakers is generally good. Exchange between university groups and industry is good, but engagement with government bodies and policymakers is variable and depends on the level of engagement of individual universities.

Industry’s interest in participating in public-private research is clearly found in the ETI configuration where applied research and demonstrations are taking place. Also, the large investments of big industry in universities such as Imperial College, University of Cambridge, etc, illustrate the value of public-private research. As this is closer to the industry work the benefits and risk sharing are relatively obvious. Evidence of positive influence from industry participating in university research has been clearly demonstrated in the review in various forms. One example is the Rolls Royce centre’s of excellence sponsoring an endowed chair at Strathclyde University and a range of activities in the University Technology Partnership at the University of Oxford. Both showed clear benefit for both parties. Loughborough University demonstrated successful industrial funding within the energy area, clearly exceeding the university average.

Finally, it was observed that industry partners were actively participating in the review week with the universities providing evidence of close interaction and thereby also knowledge exchange.

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

Whilst it was not possible for us to quantify the movement of trained people between the research base and industry/policymakers, it was apparent that there is a significant process whereby industry-funded doctoral students spend time in training and research at research bases and a number of the larger research and educational bases run limited time Masters courses. In addition, there was evidence of secondments from industry into research and educational bases for the purpose of cross-knowledge transfer. There is also evidence of at least one secondment from academia to DECC, as an example of transfer from the research base to policymakers, but there was little else in support of this trend. There was limited evidence of any further transfer/flow of people from the research base into policymaking bodies. It is assumed that this exchange would be facilitated through the Research Councils and their ongoing dialogue with government. The extent to which this happens is, in general, unclear. However, there appears to be a strong relationship between Scottish universities and the Scottish government, the local development agencies, and also between the Welsh Assembly and energy-related research in Wales, e.g. in Aberystwyth University.

C.1 Recommendation
Keep all the favourable mechanisms (RCUK, TSB, ETI, regional funding and combinations thereof) to continue attracting industry to universities supporting research, in particular TRL1 to 3. Make sure there are sufficient matching public funds for efforts by the universities and the Research Councils to rapidly follow industrial interest in research. Industry funding is a unique benefit at TRL1 to 3, but it should never become a unique requirement. Lack of public investment in changing industries puts pressure on TRL1 to 3 to become too applied; and thereby remove the unique benefits for having industry participation in early stage research. Thus, from an overall UK government funding policy, government matching of industry participation should be a government commitment to strategic
areas. Provide mechanisms to fund industry-academia workshops and internships (possible out of the CDTs) to enhance mechanisms.

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

Relationships between UK academics and industry are excellent both on a national and international basis, for example, with organisations such as BP, Rolls Royce, Alstom, etc. There are evidently relationships that have been established with UK policymakers, in terms of access to select committees, secondments, etc.

Several of the RCUK programmes have international partners. However, several universities expressed frustration over the ability to have contracts with international organisations where the funding will be transferred from the UK to another country. Examples given included jointly funding work with US organisations such as the National Science Foundation or the US Department of Energy National Laboratories, EU, India and China. Nevertheless, encouragement should be given to help reinforce the UK position and stimulate international solutions to common problems. Bodies such as ERP and ETI could play a very useful role representing views of policymakers and scientists internationally.

It should not be forgotten that seminal papers by the UK scientists are noticed by policymakers in other countries.

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

There does not appear to be a formal support scheme for knowledge exchange between researchers in the UK or between UK researchers and UK industry/policymakers. There is great scope for stimulating the direct contact between UK scientists and industry/policymakers more than is covered by ETI and ERP, given the importance of policies and industrial strategies in this particular area.

The Research Councils’ approaches include: raising the profile of knowledge transfer and exploitation at the application stage of research proposals, examining how to be a more effective partner with business, e.g. through strategic partnerships, additional funding to establish pilot “Integrated Knowledge Centres” with academic and industrial researchers working alongside each other on shared problems, with matched funding. A lot of resources from the research budget could be spent on these supply type efforts.

C.3 Recommendation

RCUK should sponsor, and continue to sponsor, a national thematic network (NERN) which directly supports the roadmap vision to be, in order to create greater knowledge exchange within the research community and specifically between common sectors of research. It is recommended that RCUK sets up a mechanism to improve knowledge exchange between sectors within the energy community, especially those consortia that have similar objectives. For example, this could bring together all of the researchers working in the fuel cell and hydrogen field. The Research Register or the National Energy Research Network (NERN) data compiled by UKERC might be arranged and abbreviated to list, in keyword form, all the topics covered (e.g. wind, smart meters, biochar, etc) in the research establishments. As the EU research programme is also adding further projects, not to mention new funds available for energy efficiency including buildings renovation, such a list could link with other keyword lists. With such an abundance of projects these would facilitate contacts between researchers in addition to helping avoid unnecessary duplication.
C.4 What is the scale of industrial R&D in energy nationally and internationally, and what is the trend? What are the implications for the UK energy research community, and to what extent is it well positioned to respond? Is there any way that its position could be improved.

The UK energy sector was one of the most research intensive sectors in the UK economy. Many of the major multinational industries have significant bases in the UK. Whilst the scale of industrial R&D was not assessed, it is clear that there has been a steady decline in R&D carried out within the UK energy industry over recent decades. For example, the demise of the Central Electricity Generating Board laboratories, the British Gas research centres and coal research laboratories. It is clear that centre initiatives, like NAREC, therefore have the important function of supporting large-scale national research facilities that are both a legacy from past UK energy research bodies, as well as promoting and establishing new facilities for new energy systems. NAREC and its facilities have permitted valuable interdisciplinary and inter-institutional research which would not have been possible by individual institutions. These have given, and will hopefully continue to give, researchers access to facilities at a scale that would not have been possible otherwise. This offers important long-term potential for up scaling and gives the UK a leading position internationally, so that the valuable role that was once provided by the national research laboratories is being resuscitated and expanded.

C.5 To what extent does the protection of Intellectual Property act as a barrier to energy research in the UK as compared to other countries?

In a general manner, a university retains most of the intellectual property of its own research. This has, on occasions, inhibited collaborations between competing universities. There is a need therefore to emphasise the importance of recognising mechanisms of managing joint IP, especially where breakthroughs are important for the UK.

It appears that the strong IP position that was once held by some universities has become more relaxed. This has helped to reduce the barrier to information exchange. At present UK universities generally have very flexible Intellectual Property (IP) strategies. RCUK does not place constraints on IP relative to the funding it awards to these universities.

Flexible IP strategies are essential in assuring that technology is transferred into society and industry collaboration does in general require high flexibility. Only after the technologies are adopted can their value be derived, and there are numerous examples of how inflexibility inhibits IP to be disseminated and thereby obtain a value. There may be situations where an industry claims the IP or exclusive rights to it when it funds most of the research expenses. This is particularly relevant in the development and testing of prototypes. Universities should be encouraged to use their IP in the national interest, as well as their own – keeping the dissemination aspect in mind.

The evidence of industrial collaborations through numerous mechanisms does in itself imply that IP policies are flexible, both at research level and also at early demonstration phases.

C.5 Recommendation

The RCUK should encourage flexible IP strategies within the funding it awards. In particular, the RCUK should emphasise that the priority in commercialising IP should be technology transfer. At the same time, when transferring IP to higher TRLs, for example through TSB and ETI, a higher degree of IP revenue potential should be ensured where the potential is realistic.

C.6 To what extent are the energy community openly communicating research results?

It is clear that some energy research areas communicate better than others. However, it is not apparent that the different competing clusters communicate with one another, for various reasons. Specifically, within marine research for example, an unnecessary fragmentation appeared partially due to two different funding mechanisms (regional and central) leading to the perception of competition. From a high level it appeared the two were complementary and at different stages of deployment; thus, if coordinated correctly they could have been complementary.

The example may have been an exception, but in general a wider dissemination of research results appeared to be ad hoc and inadequate at all of the three levels, namely between Councils, between consortia or research centres, or with the public at large. Engagement with the public could be important in the promotion of new research areas and facilities. For the production of biomass extensive communications are necessary with the forestry and agricultural sectors and these must be made and sustained.
C.6 Recommendation
It is recommended that the RCUK set up a regular programme of consultation and communication (a) within the research community, (b) between the Research Councils and (c) with the public at large. Sharing best practice from the different established energy collaboratives at the universities could prove very fruitful, for example, comparing strength and weaknesses in the very unique and individually designed setups at Durham, Glasgow, Loughborough and Strathclyde. The existence of a national roadmap would help to enable progress and problems in different areas to be shared more understandably and strategically.

D. Recommendation
Another method is direct RCUK support for acquisition of international experts to key, clearly identified strategic areas aligned with the suggested roadmap. The choices of technology slot into such acceleration schemes and should be made either because there is more developed progress of technology elsewhere (avoid reinventing the wheel) or because the area is strategic to the UK portfolio. Short-term impact cannot be achieved by organic growth of the capability for meeting 2020 targets. In short, focus more on acquiring knowledge from partnerships towards the short-term 2020 targets; and focus more on developing organically toward 2050 targets.

3.D – To what extent is the UK energy research activity focused to benefit UK economy and global competitiveness?

The UK strategy clearly states that internationally measured excellence is a target in dissemination of technology. As a logical consequence international collaborations are essential. Collaborations are established with India, US, Brazil and the EU and there is evidence that UK researchers actively use these collaborations to organically grow their own capabilities. However, in order to reach the short-term 2020 target it is generally suggested to focus harder on how to capitalise more on international partnerships to reach these targets; as an opposite to organic growth, where these will have only limited impact in the short-term.

However, there was evidence that in many of the collaborations the UK was a follower rather than a leader, in other words UK universities were often invited into European networks but seemed reluctant to be the lead organisation.

Throughout this report the Panel suggest various measures which contribute to definition of such measures.

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

The panel have found many solid and interesting contributions and innovations in the UK portfolio. Details of some areas are found in section J, including some specific recommendations.

Within renewable energy the UK have clear ambitions in marine based technologies. Offshore wind is being developed in deployment mode. The wind industry is clearly also maturing, transforming and accelerating. The transformation of research needs is evident, so close attention should be made in how to support wind on par with other mature industries in order to capture opportunities. Wave and tidal research is in an earlier stage and is characterised by a high degree of regional research support. It is likely the learning is from wind and increased focus on RCUK support could accelerate the UK ambitions and opportunities here.

In photovoltaic, UK researchers are participants in fast-moving research efforts internationally within a variety of solar cell concepts. Many of these could form new industries in the UK. The UK should also be aware of the general progression of solar towards more cost effectiveness meeting grid parity at the latitudes of the UK.

The recently envisaged roles for the use of biomass as feedstock for UK electricity generation via co-firing and in dedicated biomass boilers and also in transport...
biofuel production are noteworthy. Several recent UK studies indicate that the CO₂ reductions associated with biomass production, taking into account the greenhouse gases released from alternative land use, provide, in theory, an attractive proposition for electricity generation especially when combined with CCS. Bio-power companies are already burning biomass and this is planned to rise substantially. If this is done at scale it will be a major change for use of land in the UK as well as for the import profile of biomass. Some innovations will be required and many of these will be in farming, associated with new crop production, harvesting, storage and transport. In the biofuel production from biomass much innovation is required and this is a very competitive area of research at present internationally. It embodies plant science, plant breeding, biotechnology, chemical and biochemical conversion/fermentation processes and much biochemical engineering. BSBEC is currently focused in this area, having started formally in 2009.

New developments in 3rd and 4th generation fission reactors should be closely followed, as nuclear energy is a non-carbon technology which can prove to be invaluable in meeting the climate challenge. Many of the technologies associated with advanced high efficiency coal plant require specialist knowledge in materials science, fabrication techniques, instrumentation and control etc. There was evidence of RCUK support being fundamental to establishing successful supply chain networks in these key technologies between suppliers, component manufacturers, end users and universities. Similar approaches appear to be working in the area of CCS. Support for these activities is important since clean coal is likely to be an important source of electricity generation for some time to come.

By improving efficiency, research on electricity policy, power systems, the oil industry and on CCS is having an important impact on saving costs, aside from the high international standing of the work. Efficient network charging methods are expected to save hundreds of millions of pounds. Finding that energy efficiency and lifestyle change are least cost policies is a major benefit of scenario analyses. Demand-side work, including work on price elasticity, is highly esteemed and central to altering behaviour. Results of work on energy security, rebound effects and on attitudes to new technologies has deepened understanding of these linchpins.

Finally, it is clear that projects and research networks which included social and economics sciences in their portfolio and in communication of their portfolio proved a better business case.

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

Overwhelming evidence has been found of industry involvement, in particular larger corporations with universities and funding bodies, from basic research to demonstration and deployment (RCUK to Carbon Trust). Such involvement definitely ensures communication of industry needs and does to a certain degree warrant short-term innovation from the university and research community to have direct impact. Initiatives on research programmes, such as SUPERGEN, help to overcome barriers promoting basic research into direct, relevant and applied research. Strong elements such as TSB, ETI and Carbon Trust directly support these efforts. The joint approach supports the UK’s economy and global competitiveness in the short and medium-term (5-10 years); but the approach may be insufficient to prepare the longer term future and raises the question of how strong evolutions or breakthroughs can be anticipated in an energy diverse portfolio (if we disregard the efforts on the JET programme).

D.2.1 Recommendation

Research programmes (such as SUPERGEN) should be developed for long-term impact and have funding plans for no less than 10 years. Metrics and key performance indicators (see section I) will provide guidance on adjusting such programmes going forward. As previously pointed out, roadmaps and the maintenance of a long-term vision of the UK’s energy future and the role of each energy technology will contribute to better balanced academic research between short/medium and longer term, while not forgetting to allocate sufficient space for the long-term open-ended input. This should include, but not be limited to, directing how public research can meet 2050 objectives for mitigating climate change and enhancing energy security, complying with industry’s objectives of reducing costs and accelerating development.

Although the division between RUCK supporting basic research (TRL~1-2) and TSB/ETI supporting applied and demonstration research (TRL~3-4) exists, it was
recognised that an inadequacy at the knowledge transfer and deployment stages TRL3 also exists. A relatively nontransparent mechanism between TSB and RCUK, in the form of sharing staff in conjunction with a very large number of other types of initiative, was supposed to close this gap but inefficiencies remain. TSB seemed to be focused mostly on spin-out and SME type activities whereas ETI was aiming to get large industry to engage in demonstrations. For the ETI efforts, the formal involvement from RCUK’s side to promote transfer from TRL2 to ETI activities was not quantified.

**D.2.2 Recommendation**

Developing clear, separated and transparent mechanisms for closing the TRL2 to 3 gap can significantly improve the performance and impact of innovation in the UK portfolio. Harvesting the excellent intentions of the three bodies, identifying best practice and turning this into clear opportunity streams can impact the UK portfolio more than anything. A careful balance between large industry and SMEs should be considered, including how SMEs and large industry can collaborate under the umbrella of both TSB and ETI. A successful mechanism will prove fruitful for accelerating TRL2 to 3.

The Panel was made aware of the amount of effort now expended to encourage successful deployment of research results. A credible long-term price on all carbon emissions would ensure that this effort ultimately has greater impact, by increasing demand for these technologies⁶ and also stimulating R&D.

A great enthusiasm for educating foreign students and interacting with research abroad was noticed. However, very little evidence was found of funding for supported mechanisms allowing for import and export of technologies, in terms of allowing both people and research projects to transfer two-ways.

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

The universities have developed many initiatives such as training centres/programmes, institutes and cross-disciplinary programmes in order to attract students and young faculty members to energy research and energy programmes. The exchange of information between the panel members, doctoral and postdoctoral students at poster sessions confirm their enthusiasm for their subject and deep commitment to the framework of energy research. Students seem to easily find positions in public research organisations and industry after completion of their studies. A good number of non-UK students were found to be engaged in the UK research system, even though a number of EU regulations can make the integration less advantageous.

**E. Recommendation**

Keep varied initiatives alive to attract students and young faculty members and continue to improve the integration of overseas students (even if these are constrained by non-UK based regulations). A national thematic energy network (NERN) should actively include students; or it can even be considered if a student driven energy network should be sponsored as a stand alone initiative.

**E.1a Are the numbers of graduates (at first and higher degree level) sufficient to maintain the UK research base in this area?**

There are a few examples of successful Masters level programmes in Loughborough, Imperial and

Strathclyde focusing on renewable energy, built environment, etc. There are no clear statistics on the total number of energy graduates or postgraduates across the UK. There are about 700 PhD students in the UK in the energy area and about 1200 postdoctoral research assistants. At present there are no shortages in existing programmes. However, for the future energy research base the number of graduates and energy postgraduates in the UK is likely to be a constraint. Exchanges with doctoral and postdoctoral research assistants at poster sessions confirm their enthusiasm for their subject and framework of research. The performance metric suggestions in section I will also suggest how this can be gauged.

**E.1a Recommendation**

There is a need to scale up Masters level programmes and energy courses at the undergraduate level based on some of the best practices. The number of doctorates and postdoctorates needed to ramp up the energy research capacity of the UK needs to be established. A dialogue with industry and academics can form the basis for launching support schemes to meet the projected demand.

**E.1b Is there sufficient demand from undergraduates to become engaged in energy research?**

There seems to be increasing interest among undergraduates but there do not seem to be the initiatives to channel this interest to its full potential.

**E.1b Recommendation**

The RCUK should organise an activity which facilitates sharing of best practices among universities and offers financial support for public engagement dissemination activities in the energy area. Initiatives to incentivise undergraduate student research projects, undergraduate summer schools, involvement in multidisciplinary grand challenges and student competitions should be launched. The proposed national thematic energy network could become a carrier of such efforts and be part of RCUK sponsorship conditions.

**E.1c How does this compare with the experience in other countries?**

Many countries have specialised support for new programmes in energy and initiatives to enhance PhDs in the energy area. The US, Europe, China and India have made several interventions to enhance capacity in the energy area. The UK has initiatives for new centres for doctoral training but needs to integrate with initiatives at the undergraduate and masters level and become one of the first to implement effective programmes pipelining human capital.

**E.1c Recommendation**

The RCUK should institute specialised programmes in sciences related to energy and quantify these by clear metrics.

**E.2 How effective are public engagement activities?**

There is limited evidence of a few universities having effective public engagement. In some cases funding is obtained from the community development organisations and regional development agencies. In addition, attracting young scientists and engineers begins with creating interest among young school children. The energy education of the public is often focused on these school children in various outreach formats.

**E.2 Recommendation**

It is proposed that RCUK could impact future energy education significantly by supporting outreach programmes designed to educate teachers and provide exciting educational materials they can use. This would create a cascading effect of outreach to students, thereby directly impacting the universities capability to attract young UK talent to energy education and research. The creation of talent for RCUK CDTs in this way is no different than industry sponsoring research at universities to secure their pipeline of people and research. A clear Roadmap accessible to the public and teachers would help.

**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?**

There is a fear of shortage of researchers in the area of energy systems analysis, buildings, energy efficiency, energy economics and biomass production to meet the planned transition in the energy sector. Also, the fossil fuel sector should not be forgotten or down prioritised. Combined with the unclear career path for multidisciplinary research, opportunities are most likely missed. But, without clear metrics established, no such quantification can be made.
E.3 Recommendation
The RCUK should consider a general refocusing of resources to these areas. In particular, RCUK should give consideration to establishing dedicated centres for doctoral training and create chaired professorships into interdisciplinary energy areas such as energy economics. Again, the recommendation is to address this with clear metrics upon targets for people development.

E.4 How does the career structure for energy researchers in the UK compare internationally?
The funding at the postdoctoral level is not competitive when compared with the US and possibly more widely. For example, in the US there are a large number of postdoctoral and research positions in energy in the research laboratories. This is particularly acute since there are no national engineering-physical sciences laboratories in the UK. As a result there is uncertainty in career growth after a few years. Additionally, there are limited academic opportunities and, in some areas, industrial research positions available. Hence, this may affect the ability of the UK to retain research talent. Apart from the few EPSRC five year fellowships, there is a lack of longer duration fellowships for early career researchers. Also, the universities are reluctant to hire a multidisciplinary energy engineer as they are perceived to be less academically expert than traditional academics.

E.4 Recommendation
The RCUK should institute competitive longer duration fellowships across the Research Councils. In that aspect, consider how international elements can be incorporated into the effectiveness of such programmes.

E.5 To what extent is the UK able to attract overseas energy researchers to the UK? Is there evidence of ongoing engagement either through retention within the UK research community or through international linkages?
The UK is able to attract overseas students based on the reputation and strength of its universities, but integration of non-UK students is inefficient. Often they are not eligible to apply for some fellowships. There appears to be funding constraints and inadequate international links to feed this. In addition there seems to be a lack of clarity in the applicability of the schemes for overseas students, including the EU.

E.5 Recommendation
Strengthen international links and have schemes for funding international students in energy. In addition the rules should be clarified across the Research Councils and widely disseminated.

3.F – To what extent are UK researchers engaged in “best with best” science-driven international interactions?
There is evidence that there is a fair amount of collaboration in select areas of research with some UK institutions making more of an effort in this regard than others. The majority of this collaboration is within the United Kingdom and the European Union, often around the European Framework Programme. In some cases there are islands of excellence, such as in Fusion. There was evidence of limited recent international collaboration with the USA, China, Brazil and India, in particular. The collaboration evidenced typically involves exchanges of information and visitations rather than true in-depth engagement. True in-depth engagement can involve one or more activities, such as: 1) seconding researchers in institutions in other countries; 2) hosting researchers from other countries in the UK; 3) co-funding developments in other countries; and 4) attracting co-funding and simultaneously technically co-managing research sponsored in part from foreign institutions.

F. Recommendation
The RCUK should identify and remove barriers toward increased international collaboration regarding the R&D it funds. The RCUK should encourage researchers to identify and engage with international collaborators in proposals for funding.
F.1 What is the nature and extent of engagement between the UK and Europe, USA, China, India and Japan?

Some of the most successful R&D programmes in the world are those that have international collaboration. Several of the RCUK programmes do indeed have international partners where travel grants have been specifically provided by RCUK. However, several universities have expressed frustration over the inability to have contracts with international organisations where the funding will be transferred from the UK to another country. Examples given included joint funding work with US organisations such as the National Science Foundation or the US Department of Energy’s National Laboratories (Idaho, Sandia etc.).

F.2 How effective is the engagement between the UK and the rest of the world?

It appears that UK researchers are often not aware of the “best” science-driven international research or it is perceived as competitive and therefore “out of bounds”. Awareness is a key prerequisite to actually engaging in international collaboration. That awareness is garnered by a range of activities including attending international conferences, sustaining active memberships in international scientific organisations and visiting key foreign organisations. Although it was stated that allocation of travel funds was not a constraint, UK student awareness of international R&D appeared to be weak. This contributes to the lack of awareness of international collaboration opportunities among the university community as a whole.

F.2 Recommendation

RCUK should assure that adequate funding is available for universities to engage internationally in order to develop awareness of the “best” science-driven research capabilities in the world, while also ensuring that the allocated funds are used to their full extent.

F.3 Are there particular issues for the energy research area? What could be done to improve international interactions?

The US has particular strengths in energy research through its DOE National laboratory system. There are many ad hoc links from the UK with these laboratories, but they could be stronger with centrally organised links that embody training as well as exchange of results. There are also Centres such as the Energy Biosciences Institute at Berkeley and Illinois to which some links have been made but better, more formal links could be made. We noted some exchanges of young researchers with Brazil. In general, formalisation and emphasis on targeted interactions may prove beneficial to UK research.

F.3 Recommendation

RCUK should institute a Fellowship programme and solicit applicants from UK PhD students wherein 20 to 30 are selected each year to be seconded in universities and/or research laboratories in foreign countries. It is also suggested that programmes for young researchers to bring their research funding with them on overseas assignments can tremendously improve the opportunities and impact upon return.

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

A consequence of the privatisation of the UK electricity and gas production and distribution industries was the collapse of corporate and national research laboratories. The UK Research Councils were instrumental in retaining research capability and a stream of doctoral training opportunities. This has provided the expertise now in place. There is evidence that the UK energy research community contributes high quality published outputs that make timely, and occasionally seminal, advances to their respective topics internationally. There exists a set of leading edge researchers who have achieved strong international recognition. In some areas (notably demand-side management, energy-in-buildings, nuclear fission, solar thermal, biomass processing) the UK is not leading internationally.

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

The UK is leading internationally in nuclear fusion, 3rd generation photovoltaics, solar/hydrogen, processes of photosynthesis, transformer diagnostics and electricity networks, wave and tidal energy, fuel cells, lithium energy storage, fast pyrolysis of biomass, energy policy, and consumer behaviour in energy purchase decisions. The Energy Materials research capabilities at Culham are outstanding. Evidence of both large-scale institutional commitment spanning
many aspects of energy research (e.g. Imperial College, University of Cambridge, University of Oxford) and smaller agile multidisciplinary university groups, for example in Aberystwyth: IBERS consolidates biomass, environmental and rural, energy use and land use policy, strength and depth with good facilities. The UK has also produced some excellent examples of world class coal related research and teaching across multiple institutions.

G.2 What are the opportunities/threats for the future?
There is the opportunity for a clear, consistent energy proposal evaluation process to be put in place across all the Research Councils that set common threshold quality criteria. A decline in core funding for universities may render it impossible for leading institutions to recruit/retain research leaders. The Panel recalled the loss of the BP Energy Biosciences Institute to Berkeley, California. High profile bids were made for this ($500 million over 10 years) from several consortia of UK universities but better bids with stronger institutional backing were forthcoming from the USA. The UK could learn from this opportunity and the threats coming from better organised institutions elsewhere.

G.3 In which areas is the UK weak?
UK research is weak by current international comparisons in cyber security, demand-side management, heat storage and distribution, energy-in-buildings particularly new façade and control technologies, nuclear fission, compressed air energy storage, and small-scale hydro. The RCUK funded wind energy research is not yet internationally leading on a comprehensive scale. Some research programmes are only of recent origin (for example “BSBEC” only started as a 5 year programme in 2009) so that significant outputs are yet to emerge. There are strong sub-projects, each with its merits, but limited evidence of overall strategic cross-fertilisation that sets specific research results in the wider context of other contemporary developments in energy research.

G. Recommendations
Funding priorities need to be reassessed with the objective of achieving strength both in depth and scale in key research themes. The UK carbon reduction targets cannot be met without an aggressive, end-use energy efficiency programme. It is thus critically important that research on energy efficient new and retrofitted building fabrics, appliances and devices, biomass generation and exploitation grows with substantially increased funding. Present structure of support for energy research is essentially a legacy with overlapping Research Council remits that create problems of coordination and act against the achievement of synergies. Given the unique need in the energy area for research to underpin specific time-bound national policy goals, it may be appropriate to have a single common cross-Research Council programme with a regularly updated roadmap.

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

H.1 Is the current balance between high-risk/high-return and “safe research” appropriate?
Long-term (2050) energy innovation will depend on contemporary creative and adventurous research presently funded by the RCUK (TRL1-2). Such adventurous research is high-risk, but can potentially yield high-return. This may lead to disruptive technologies in the energy arena. However, with exceptions, this does not initially attract industry funding.

There are examples of creative and adventurous research projects in research institutions and by diverse researchers. Some of the existing adventurous research projects are of high quality and may lay foundations...
for future large-scale, mission-driven research. But there is no evidence of a systematic, creative and adventurous research base and portfolio. Also, there did not appear to be a clear allocation of funds for high-risk/high-return research allowing researchers to understand the metrics to be met by adventurous research.

**H.1 Recommendation**

It is found that with a roadmap established, strategic guidance for adventurous research can have a higher impact by formally allocating a percentage of RCUK's funding for creative and adventurous research in order to attain the UK's 2050 energy targets. Thus, create a RCUK wide pool of funding to support adventurous and creative research projects of interdisciplinary nature. At the same time, embrace the need for collaboration between RCs to enable solving complex problems. Encourage joint calls for proposals for creative and adventurous research in interdisciplinary areas, by two or more UK Research Councils as part of a common programme.

**H.2 What are the barriers to more “adventurous research” and how can they be overcome?**

More high-risk/high-return research is required to provide transformative technologies to meet the UK's 2050 energy targets. This requires an increased level of funding, improved funding mechanisms and cooperation among RCUK. A first hurdle seems to be the attraction of research teams to provide short to medium-term research in which industry is generally interested and funds. The mechanisms for implementing such research represent another barrier to adventurous research. There appears to be a consensus that safer research is preferred. Where blue sky research is project funded it is becoming difficult to fund doctoral students. Owing to the existence of 7 Research Councils and lack of adequate coordination in certain areas, there are blue sky research areas that fall in the gaps between the Councils.

It was apparent that young academic staff were (either by themselves or with encouragement) looking to play the system through a strategy that would (apparently) improve their career prospects. For example:

- There is presently a fear of failure culture in some academics. Submitting a speculative grant application which fails to be funded can be considered to jeopardise a career.
- Sometimes an application is made for a larger but safer grant because the additional value of research income is considered.
- Since academics must demonstrate scholarship through publication then highly speculative research may lead to few if any publications.

**H.2 Recommendation**

A carefully selected smaller number of adventurous research projects with more adequate funding and longer time duration shall be preferred over a large number of small, short-term projects. Also, it is of the highest importance that these are associated with a career path opportunity.

**3.1 Other observations and recommendations**

**Metrics, objectives and measuring results of research**

There are many papers in the Councils’ literature covering this topic. A quote appeared during the review week with reference to Treasury: “how much benefit did UK plc get?” Metrics that are relevant specifically to energy research are needed and this narrower focus may be somewhat easier to address. The production of roadmaps indicating the routes to 2050 goals requires metrics simply because there is an overall delivery requirement to reduce climate change.

The threefold objective of research on energy as already stated is to improve its affordability, environmental performance and security.

It is widely acknowledged that measuring the results of research is difficult and some reports record the inputs as if they were the outputs. That is useful in so far as one wants there to be a vibrant research sector per se, but it is inadequate as a measure of results. A range of metrics of results appears in various international studies. These include broad measures of the impact of research as a whole, for example, the share of fast growing innovative firms in the economy or improvements in labour productivity, as well as the widespread use of numbers of patents that measure intellectual property produced, and publications and citations that can be a gauge of research quality.

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While these measures play an important role, some more focused measures can be investigated for the results of energy research. Concentrating on the threefold objectives mentioned above and simplifying somewhat, the following metrics are a useful starting point:

- **Affordability**: research aims to reduce energy costs or raise its efficiency and the metrics here could be the reduction in the cost of providing a useful MWh (£/MWh) and the cost of using that provided MWh in buildings (£/m²) or industry (£/unit of production).
- **Environmental performance**: research aims to reduce abatement cost. The desired metric in the case of carbon is the carbon abatement cost (£/tCO₂ abated) (University of Edinburgh, with an abatement cost curve for different sorts of biochar, and Aberdeen, with least-cost modelling of different CCS technologies, estimate these, for example).
- **Security**: this is improved through use of more secure energy sources, including renewables and provision of storage and the like. The objective of research is to reduce the cost of these energy sources (£/MWh). The elements can feed in to a ‘security of supply cost curve’ as given in a project by Cambridge’s Electricity Policy Research Group.

These metrics are all expressed as costs, which reflect the underlying fact that there are many technologies for reducing carbon but reducing their high cost is an imperative. However, many research projects result in more nuanced improvements such as reliability, safety, quality or convenience. These are not readily amenable to such metrics though, in fact, in some cases they could be. Others are important such as company spin-offs, licences taken out on patents and export potential, a measure which is very difficult to exploit in a 2050 strategy.

What is not difficult to assess is the need for human capital. Clear high level targets on European level and the UK level require a certain deployment of various technologies within nuclear, renewable and fossil fuel management, etc. In addition, the supportive needs such as advanced transmission and distribution systems with high levels of energy cyber security need, etc, can all be used to assess future needs and thereby present actions needed to educate and thereby perform research. If there are not enough people, there will be no impact: No people – no impact.

### I.1 Recommendation

The development of a set of metrics to be used with a roadmap is urgently required. The metrics should not be constraining, but support wise decisions of direction for both programmatic and open-ended research in an open and transparent way. The subject of metrics is given further consideration with a view, perhaps, to having a centralised framework that could be used. Those teams that already undertake such estimates could, perhaps, provide the service to others working in similar fields. While a time consuming procedure should be avoided, shedding light on potential reductions in abatement costs is valuable for suggesting technologies to be developed for meeting stringent CO₂ targets.

### I.2 Recommendation

The US Department of Energy operate cost-of-energy models throughout the lifetime of new energy sources. The metric is used, amongst others, as a metric to judge potential impact requirements to new research, in terms of CAPEX, O&M and yield. Combine such a cost-of-energy model with DECC models for emissions and continue to run these models for the next 40 years, while at the same time recording progress of all areas of industrial deployment, in terms of MWh (produced or saved) and industry turnover, and very good guidance to research can be made on a high level. A specific example can be found in DoE’s 2030 roadmap for wind energy. More high level examples can be found in the European Climate Commission 2050 roadmap.

### I.3 Recommendation

Roadmaps for 2050 should not constrain new initiatives but need to be realistic about time to impact. The time to impact is an absolute and must be rationalised in terms of resources needed (CAPEX, people, technology breakthrough, established industry versus SME and start-up, etc). To ensure this, the roadmap needs to be broken down to different levels with expectations on how areas develop over the next 40 years. As an example, for the sake of argument: out of a 50% renewable requirement in 2050 to meet emission reductions through one scenario, at present time 20% of the technology portfolio to meet this may be unknown in terms of which renewable resources can deliver impact; whereas for coal the requirements for reduction are known
but the technological solution is defined. These two statements alone show how a roadmap can be directive, supportive and highlight needs, and thereby provide much sharper guiding of programmatic as well as open-ended research toward successful implementation of the UK targets set by the Government.

The second level of details should go towards area specific research needs and include measures such as industry maturity, industry readiness and industry capability of scaling technology to impact with reliability and security. As an example: if an industry is based on a forest of start-ups the TSB, ETI and nurturing capital is important for any research to have any impact. If the industry is mature, such as the wind industry, these needs are maybe more in matching research needs from other established industries (aerospace, offshore, material science, etc) on a basic level.

I.4 Recommendation

No people – no action. A Roadmap must be broken down to development of human capital and back-projected to when such development must begin. For example, if 30% of the UK energy supply is wind energy by 2050, an anticipated industrial turnover can be estimated. At that time, the industry is fully mature and 1% to 3% of public spending in research may be adequate. Out of this public research spending 5% to 15% should be spent directly on doctoral developments and thereby a first level of human capital can be quantified. The scenario should be back-projected for each technology area. Early public research spending should be much higher, say 10% of industry turnover, but the share of doctoral development may be different. Even for the unknown, a plan for human capital should be in place, say x% for renewable and y% for nuclear, z% for clean coal, etc. An analysis and best practice for industrial impact should establish the actual metrics which here is indicated as an order of magnitude. For 2020 needs, industry surveys need to be conducted which can provide good checks for the long-term goals. Overall, it appears the UK already has a good direction as mentioned in several places of this report, so may be a matter of making this visible.

3.J Specific Disciplinary Comments and Recommendations

IMPORTANT: Please note that section J is meant to originate specific area comments for future reviews and further reflection. It is by no means a complete topic overview and does not cover all topics presented in the review. The choice of topics is a function of the Panel’s expertise combined with particular areas of observations from the review week, thus several areas have been omitted.

The energy research in the UK is wide and covers many different topics as illustrated in the distribution of the figure below:

Figure illustrating the energy portfolio by sub-theme by commitment for financial years 2002-2010 (£M)
Research on Biomass and Bioenergy

We heard that following several recent analyses, e.g. by ETI and BIS, the role of biomass in the UK energy portfolio is now much more significant than previously articulated by policymakers. It is particularly beneficial for meeting CO₂ reduction targets in electricity production, especially when combined with CCS. Currently, the roles of key dedicated biomass crops in the UK energy strategy, willow and miscanthus and also of UK forestry and wastes from other agricultural crops for biofuel and bio-power production are still unclear. Furthermore, the biomass improvement activities are not joined up with other parts of energy research in RCUK and crucially with the relevant policies. This needs to be remedied with coherent strategic plans to develop the multidisciplinary technologies, address the problems and develop demonstration projects as rapidly as possible. We understand that BBSRC has recently taken on the coordination of bioenergy research across RCUK. Defra has discontinued sustained funding for the willow and miscanthus breeding programmes that are necessary to provide the essential improvements in these crops. This is inconsistent with having a coherent and supported strategy for renewable energy. The conclusion that biomass will be an important source of renewable energy for the UK implies that the farming and forestry research and grower communities, and also those concerned with land use and C sequestration in UK soils, need to be integrated into the energy policies.

The advances in processing biomass into biofuels for transportation, most developed in the USA and Brazil, could benefit the UK. In the US there are advances in chemical processing of biomass to “drop-in” hydrocarbon fuels and not only to alcohols. The existing very large-scale production of ethanol from corn starch (US) and from sugarcane (Brazil) provide a base for adding cellulose processing to ethanol to these bio refineries to make them even more efficient in the near future. Stand alone bio refineries making biofuels from cellulose are being planned. The positions of leadership in the USA and in Brazil are a consequence of the scale of the opportunity and/or policies. However, the Panel noted the effectiveness of energy handling in the large UK sugar beet bio refinery.

J.1 Recommendation

With the apparently renewed clarity on the essential role of biomass in the UK renewable energy strategies for reaching declared carbon reduction targets and renewable biofuels, the roles of home-grown and imported biomass should be stated clearly and the relevant policies, economic and social science research, technology development and problem solving put in place to enable these developments to occur rapidly. The relevant agricultural and farming communities need to be positioned as energy providers. All aspects of biomass research and the associated soil carbon research should be under the umbrella of the common RCUK energy programmes, whatever the source of funding. RCUK and BSBEC in particular should monitor closely what is happening internationally and adjust their strategies accordingly.

J.2 Recommendation

The crop breeding programmes and associated germplasm management for miscanthus and willow should be sustainably funded urgently before the teams become disbanded. It is likely that the preferred solution to enhance coordination is for these activities to be taken over by RCUK, closely linked to other aspects of plant science, soil chemistry, agriculture and energy production pipelines.

Research on Coal and CCS

The UK has produced some excellent examples of world class coal-related research and teaching, with topics undertaken on an interdisciplinary and inter-
organisational basis. This relates to multiple advances in carbon (CO$_2$) capture (pre-, during and post-combustion systems) and TRL1-2 levels with regard to CO$_2$ storage in collaboration with centres in China, US and EU with some links to India and Brazil. Of particular note are the following:

- Imperial College, University of Edinburgh, University of Leeds and Nottingham University are among the largest groups researching Carbon Capture and Storage (CCS) although many other universities and research organisations are heavily involved in this area. The University of Cambridge is developing leading technology most specifically using chemical looping for CO$_2$ capture using circulating fluidised bed with oxy-fuel firing and, at its BP Institute, is having a number of research efforts on geological carbon storage.

- The University of St Andrews is working with Sasol (the coal-to-liquids South African specialists) in the development of liquid fuels from gas using Fischer Tropsch technology, whilst the University of Newcastle in the Sir Joseph Swan Centre, as well as the British Geological Survey and the University of Leicester, are exploring the potential for underground coal gasification and the country’s shale gas resources.

- Both Universities of Loughborough and Nottingham are producing leading technologies in terms of increased efficiency in power generation from fossil fuels. Nottingham University’s Energy Technology Research Institute specifically heads up carbon abatement in fossil energy production from which a world class industrial doctoral centre in clean fossil energy and carbon capture and storage has arisen.

- The Universities of Loughborough and Birmingham appear to be the leading universities developing high temperature and high pressure Materials and technologies for new generation coal-based power plants of the future. This research and development is essential for future low-carbon supercritical pulverised fuel power stations. The University of Oxford is producing world class research in CO$_2$ conversion into liquid fuels through the use of chemical biology. Whilst not directly associated with coal technology per se, the results of this research could have significant impact on the use of coal worldwide in the future.

The development of postgraduate Masters courses and centres for doctoral training (CDT) is highly commended at various universities and specifically the interdisciplinary Midlands Energy Consortium in which the Universities of Nottingham, Birmingham and Loughborough collaborate to produce the Midlands Energy Graduate School with the specific inclusion of low carbon energy technologies.

**J.3 Recommendation**

In terms of an overview, there does not appear to be a long-term vision with respect to integrating the new clean coal technologies into a metric based energy roadmap for the country. Each sector or grouping is working on its own specific aspects and little time or effort appears to have been spent on integrating the developing clean coal technologies relative to other energy sources. It is recommended that metrics be taken into account when integrating clean coal and alternative energy-based technologies for a low carbon emission coal or energy-based roadmap going into the future. Interdisciplinary research is also recommended on the role of CCS in meeting the UK’s 2030 and 2050 emission targets.

**J.4 Recommendation**

Although the UK scientists have had a large number of research activities pertinent to the fundamental issues of CCS, there does not appear to be any significant efforts or a clear roadmap in carrying these activities into large-scale pilots. Without such pilots, the UK may quickly lose its competitive edge in CCS technologies over other countries.

**J.5 Recommendation**

Whilst the current programmes may have undertaken research with respect to US and EU coals, there is little, if any, broadscale intercontinental understanding of the coals – their qualities, technological performances and emission characteristics – that are encountered in the many non-OECD countries and specifically South America, Africa and India. This is vital because the coal products available for use in the primary energy field in those countries are of a significantly lower grade and, as such, they perform differently to those conventionally used and tested in the UK, EU and USA. These facts are vital as experience has indicated that major problems in terms of adaptability, efficiency and danger to human health (including death) can arise when imposing first world technologies onto third world coal-based users. Given that coal will continue to be the primary source of energy in
Panel Responses to the “Framework and Subsidiary Questions”

those non-OECD countries for decades to come, it is strongly recommended that UK coal-research centres collaborate with specific research centres in those countries to ensure that a common carbon-reduction technology is to be adopted worldwide.

J.6 Recommendation
Little or no consideration of the tenet to “Eliminate Energy Poverty as the First Priority”, this being the major international call of the UN Framework Convention on Climate Change, Copenhagen Accord: Social Development Key. The documents state that cooperation is required in order to achieve “the peaking of global and national emissions as soon as possible… bearing in mind that social and economic development and poverty eradication are the first and overriding priorities of developing countries and that a low emission development strategy is indispensable to sustainable development”. It is well known that the Western industrialised countries seek to implement advanced emissions reducing technologies and this is undoubtedly the reason for the advanced coal-related research work in the UK, but third world non-OECD countries seek to expand the most cost effective energy sources (most of which are coal) in order to uplift the living conditions of the impoverished in those regions. Under the latter conditions, metrics and the cost of energy related to community affordability becomes an overriding factor, leaving adequate emissions control a far more and longer term challenging issue than the OECD countries have to face. If Britain is to be all things to all people, it is recommended that third world initiatives be factored into international programmes in order for long-term mitigation and global emissions reduction to be met by 2050.

J.7 Recommendation
On a more specific basis, and in the apparent absence of a clear target of research going towards 2050 in which coal will still play a significant part in the energy mix, it is recommended that coal research should include programmes that cover alternative coal-based energy technologies. One such technology is fluidised bed combustion and gasification. This technology has not been discussed or presented in any form in the Review with the exception of an oxy-fuel firing CO2 abatement exercise. Given the nature of the coals available to most non-OECD countries, this technology and its various forms are likely to be the technologies of choice in future for reasons including the flexibility of source materials, use of low grade coals and multfuels, reduction in SO2, NOx and CO2 emissions and higher efficiencies. Much work is yet to be done in this regard to render it suitable for future large-scale use.

Demand Side, Demand Response and Energy Efficiency
The UK needs to aggressively pursue Demand-Side Management (DSM) in order to meet its energy, economic and environmental goals. RCUK funding needs to support areas of R&D for DSM technology development. Demand-Side Management is the active intervention by government, utilities and others to modify and control the purchase pattern and amount of the demand for energy, and as the UK electrifies, particularly for electricity. Properly implemented, DSM can dramatically reduce carbon emissions, reduce energy use, electrify inefficient uses of fossil fuels, increase energy infrastructure asset utilisation, reduce peak electricity demand and enable the integration of large-scale renewable power generation resources. The UK will be unable to economically meet its carbon reduction goals without pursuing DSM. DSM is a necessary component of an overall energy strategy.

There are three major components of a DSM: Energy Efficiency, Electrification and Demand Response. They consist of the following:

Energy Efficiency is the upgrading of existing energy consuming technologies, processes, and building energy systems and the deployment of highly efficient processes, systems and appliances in new installations. Upgrading existing end-use technologies embodies replacing or retrofitting older equipment with new, innovative, highly efficient technologies.

UK policy efforts in this area are targeted to aggressively pursue these efficiency opportunities. For example, the UK’s “Green Deal” programme, which targets the need to retrofit 20 million buildings in the UK within the next ten years, would substantially improve end use energy efficiency in the country. In order to complete the Green Deal successfully and to cost effectively increase the efficiency of the average UK building as much as practical, new technologies, techniques and an expanded infrastructure (e.g. service providers and work force development) will be needed.

Electrification is the conversion of fossil fuelled end uses to electric end-uses and the expansion of end-
use applications of electricity. However, the electric technologies available today are less than optimal and need further R&D. In addition, the optimal application and installation of these technologies require further research.

**Demand Response** is the active control or influence of the end-use of electricity and associated energy systems. It allows for optimal flexibility in meeting the energy needs of consumers through several means.

RCUK funding for Demand-Side Management including Energy Efficiency, Electrification and Demand Response appears to be relatively limited in terms of overall system identification.

**J.8 Recommendation**
RCUK should develop a programme of research that seeks transformative step-changes-in space heating, domestic water heating and industrial process heating technologies.

**J.9 Recommendation**
RCUK should substantially increase funding of research targeted to Demand-Side Management both with regard to the retrofit of existing building fabrics and processes as well as long-term technology development.

**J.10 Recommendation**
RCUK should fund research to identify the potential for electrification and to identify targets for technology development aimed at replacing the use of fossil fuels with electricity where substantial overall reductions in CO₂ emissions will result.

**J.11 Recommendation**
The RCUK should identify the UK priorities for Demand Response and identify technology needs and R&D gaps to enable this technology.

**J.12 Recommendation**
The RCUK funds some valuable R&D on consumer acceptance of new technologies. Understanding how consumers will potentially adopt technologies which may assure a low carbon future for the UK is extremely important. There are few such efforts in the world and so this work should continue.

**J.13 Recommendation**
RCUK should initiate cross-disciplinary research to understand factors affecting adoption of energy efficient retrofits and incorporation of passive solar features in buildings. Benchmarking of the performance of existing residential and commercial buildings and incentivising the adoption of energy efficient retrofits needs analytical and research support. Building simulations and adoption of DSM and passive solar technologies in buildings needs appropriate training of architects and utilities. RCUK could support cooperative programmes between utilities and universities to have well designed DSM pilots that help analyse and evolve cost effective strategies.

**J.14 Recommendation**
The UK research community had made pioneering contributions to pinch analysis and process integration. However, at present, there are relatively few groups working on benchmarking and improving industrial process efficiency and reduction of carbon footprints of industrial processes. This should be an area where RCUK can support industry–academia joint applied research.

**Research on Fission Reactors**

Research on nuclear fission is inherently difficult and expensive, relying for the most part upon large facilities such as research reactors and hot cells for post-irradiation examination. Nuclear energy is also inherently an international endeavour since mistakes in one part of the world would profoundly impact the viability of nuclear energy as a carbon-free energy option everywhere. As a result, most countries with mature nuclear energy programmes have downsized and consolidated their research capabilities while seeking more extensive international cooperation in research in order to stay current with developments worldwide. The UK largely abandoned nuclear fission research in the 1980-90s when the whole energy sector was privatised.

At the same time, the UK chose to retain its fusion research capability largely because of the EU supported JET tokomak at Culham. By doing so the UK has been able to preserve a world leading fusion programme which includes many disciplines applicable to fission energy research (reactor physics, advanced structural materials, irradiation damage in materials, etc). Furthermore these capabilities have been nurtured in the various universities that support the fusion programme.
Together, these circumstances have led today to a position where the nuclear research portfolio is biased, financially at least, towards fusion.

If the UK is to maintain its nuclear fleet, either by life extension, new build or both, there is a clear need for indigenous base capability and a trained workforce capable of supporting the fleet of nuclear reactors. The UK has invested in programmes such as Keep the Nuclear Option Open (KNOO) as well as a Centre for Doctoral Training at Manchester and Sheffield to help in this regard. However, in the absence of a focused strategic R&D agenda in nuclear fission there is a distinct possibility that the (human) products of these schemes will seek work abroad where there are more opportunities.

The UK recently created a National Nuclear Laboratory at Sellafield but, as yet, its R&D portfolio is modest and mainly focused on fuel cycle back-end and radioactive waste management. The UK faces a strategic dilemma as to the direction of nuclear fission research; how much should be done domestically and how much should be left to others? At the same time, there is a need to identify strategic research areas that should be timely developed to support a reliable development of light water reactors in UK’s nuclear fleet. Furthermore, owing to its extended experience on fast neutron reactors and gas cooled reactors, the UK should be encouraged to become more directly involved in research for Gen-4 nuclear systems so as to better share its experience on these reactor types and be more influential on goals assigned to future nuclear energy systems in terms of safety, security and performance, as well as on pre-normative research likely to forge future international standards for these systems.

In order to identify the part of research on fission reactors that is strategic enough to become a national programme, an articulation of the UK’s place in nuclear fission (and fusion) research for the next 40 years is required. After the strategic direction is agreed then high level roadmaps can be formulated and funding decisions made in the appropriate context. Without this high level guidance, research funding will inevitably be incoherent.

**J.15 Recommendations**

The UK urgently needs to establish a strategic direction for nuclear fission which addresses:

- Research needs for existing reactors
- Research needs for future (Gen-3) light water reactors
- UK involvement in Gen-4 research internationally
- UK involvement in EU programmes aimed at demonstrating Gen-4 systems
- Waste management strategies
- Underlying technology research
- Roles and responsibilities for the various sectors of the nuclear enterprise in the UK including industry (Rolls Royce, EDF Energy, British Energy…), government (NNL, Culham, RCUK…) as well as academia.

**Research on Fusion**

The UK has recently commissioned a separate report on nuclear fusion, the results of which were available to the Panel. The Panel endorses the results of that review and observes that the fusion research carried out in the UK is indeed world leading. The key ingredient of this successful programme is that of an anchoring facility, JET and a robust international collaboration around the facility. The panel also notes that the involvement of the academic community in the fusion research is exemplary.

The Panel urges the UK to consider the lessons of JET that may help recreate a successful research programme on fission reactors.
Today, the UK ought to transition from its world leading position to that of a strong partner in ITER that is a worldwide endeavour. Its current skills in research for fusion and the JET facility both constitute definite assets to achieve this transition. However, defining the best strategy for the UK to contribute to ITER and the R&D associated with it as well as the next step DEMO is a challenge.

**J.16 Recommendation**

The UK should carefully consider the future trajectories of fusion research in addressing the needs for fission research capability in the UK and incorporate lessons learned from the success of the UK fusion programme into the strategic decisions for fission research.

In particular, the UK should consider the role that its research and JET may play for demonstrations required around 2015 on key feasibility aspects of ITER such as plasma monitoring in specific modes, control of interaction with the first wall and integration capability of multiple equipments for plasma heating and vacuum diagnostics.

**Research on Ground Source Heat**

The UK is well placed in the commercial use of shallow geothermal resources, largely for the heating of buildings. While deeper geothermal resources have been in evidence since Roman times, their exploitation has not been successful in the UK. Indeed, the EU funded deep geothermal project in Cornwall is now seen as having targeted inappropriate structures.

The deep geothermal work pioneered at Newcastle University is a good example of sound academic work combined with local geological knowledge and the opportunity to use regional funding to test a particular target. The success has been in both academic terms (e.g. the publications on deep biological communities) and in real world applications in developing the first "hot springs" in the UK since Roman times.

The researchers at Newcastle and collaborators at Durham have gone on to drill a second well and demonstrate that water can be injected over 1 km deep and recovered in the primary well. This is a critical step and is leading the world in demonstrating the extraction of heat from deep granitic rocks. The potential of even deeper holes where the temperatures are suitable for power generation is an application that could transform the UK emissions profile in much the same manner as offshore wind or nuclear. It therefore warrants serious consideration.

**J.17 Recommendation**

The success of the Newcastle University deep geothermal project is sufficient to justify an expanded strategic programme to map and test the deep geothermal resources of the UK.

**Research on Smart Grid**

A key element of the future UK energy system must be a fully functional electric power delivery system or a “Smart Grid”. The term “Smart Grid” refers to a modernisation of the electricity delivery system so it monitors, protects and automatically optimises the operation of its interconnected elements – from the central and distributed generator through the high-voltage transmission network and the distribution system, to industrial users and building automation systems, to energy storage installations, and to end-use consumers and their thermostats, electric vehicles, appliances, and other household devices.

The present electric power delivery infrastructure was not designed to meet the needs of a restructured electricity marketplace, the increasing demands of a digital society or the increased use of renewable power production. To compound matters, investment in expansion and maintenance of this infrastructure has been lagging for decades and the existing infrastructure has become vulnerable to various security threats.

As a result, there is an imperative to modernise and enhance the power delivery system. The Smart Grid is envisioned to provide the enhancements to ensure high levels of security, quality, reliability and availability (SQRA) of electric power; to improve economic productivity and quality of life; and to minimise environmental impact while maximising safety. Achieving this vision will require careful policy formulation, accelerated infrastructure investment, and greater commitment to public/private research, development, and key to the RCUK’s activities, research, development and demonstration (RD&D) to overcome barriers and vulnerabilities.

The Smart Grid poses many procedural and technical challenges as the UK migrates from the current grid with its one-way power flows from central generation to dispersed loads, toward a new grid with two-way power flows, two-way and peer to peer customer
interactions, and distributed generation. The Smart Grid will entail a fundamentally different paradigm for energy generation, delivery and use.

Achieving a Smart Grid will require R&D to evolve a suite of advanced technologies. These will include R&D in the development of smart grid equipment, communications systems, data management systems, cyber security techniques and new software applications.

Another area of great importance, which is related to Smart Grids, is the development of HVDC grids. Activities in this area are going on in the UK, but since these networks are very viable candidates for integration of offshore wind power they should be a salient part of the UK research portfolio on power grids. Furthermore, plans for a European super grid in the form of an HVDC grid are steadily advancing and a further integration with the European continent will most likely take place through such a grid.

J.18 Recommendation
RCUK should establish a smart grid advisory panel consisting of representatives from stakeholders including the owners, operators, and users of tomorrow’s power delivery infrastructure as well as the research community, including UK Universities. The advisory panel should establish a vision for the UK’s Smart Grid, including identification of the technology research needed. This vision should be used by RCUK to identify gaps in the research it funds.

Research related to Social, Economic and Policy Issues
Research presented to the Panel under the heading social, economic and policy covered a broad range. It was generally of a very high standard and highly relevant, viz. peer-reviewed publications, papers read on prominent national and international platforms and presentations made to important audiences consisting of utilities and representative groups including government committees.

Deployment: As with the physical sciences, results from Research Council research under the social, economic and policy heading can inform decisions taken at various levels in society, whether or not the recommendations are deployed. A negative policy response may indicate that there are further questions that need to be answered. The slow adoption to date of buildings energy efficiency, shown to be the least cost means of driving down energy demand, is a case in point. Another example of poor deployment of research results is carbon pricing,8 despite backing from international top-academics. A carbon price increases the relative advantage of low versus high carbon technologies, helping deployment of the results of renewable R&D, energy efficiency in general and investment in R&D,10 thereby encouraging both the demand and supply sides of R&D.

J.19 Recommendation
The obstacles to policy response need investigation with attention paid to aspects of concern on many fronts that impede implementation. These include robust studies of building upgrades, fuel poverty and energy policy effects on competitiveness. The frame of research needs to be extended to include international trade law to address issues such as tax law and pollution havens, and also ethics and human rights including how to pay for climate protection. The aim should be to improve the uptake of physical research on energy in an efficient manner.

The Panel was informed that the physical possibility of achieving the nation’s objectives is not in question, but that the cost is still largely very high. Thus development of better and cheaper energy technologies and behaviours is imperative. Energy issues often involve major resource allocation and therefore making good economic choices is important. Support for energy economics PhDs in the new framework was said to be

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8 For example, UKERC, 2009. Making the transition to a secure and low-carbon energy system: synthesis report, and M. Ralf et al (2009). The Effects of the Climate Change Levy and Climate Change Agreements on Businesses in the United Kingdom, ESRC.
9 For example, see: United States Government Accountability Office, 2008. Climate Change – Expert Opinion on the Economics of Policy Options to Address Climate Change, GAO-08-605. “...the majority of panelists agreed that the United States should establish a price on greenhouse gas emissions as soon as possible, most of the panelists preferred either a tax on emissions or a hybrid policy that incorporates features of both a tax and a cap-and-trade program.” Meanwhile China is considering a tax on carbon dioxide, see China Daily, http://www.chinadaily.com.cn/bizchina/greencchina/2010-10/19/content_11429383.htm
at a disadvantage. Impediments of this sort would be unfortunate, given the wide scope of socio-economics and the significance of the policy levels wanting advice. While alternatively some commercial users could commission the work, the results would no longer be serving the public interest, and the benefits of work that is peer reviewed and the international collaboration, not to mention the independence, would be foregone.

**J.20 Recommendation**

The disciplinary complexion of energy research and indeed the manner in which the direction of research is determined needs careful consideration. It is recommended that the RCUK carefully consider the appropriate involvement of economists, who in turn should make a firm case on the questions that they address and the expected benefits of having answers.

**Research on Solar, which is both Photovoltaic and Solar Thermal Energy**

Solar energy research is largely confined to new forms of photovoltaic, solar hydrogen production and conversion efficiency improvements to current photovoltaic technologies. There is also limited research on photovoltaic systems and applications. The contributions to research on organic solar cells hot carrier and multiple extinction per photon cell concepts are strong internationally. The UK is not a significant contributor compared to peer countries to solar thermal research, nor more broadly, to passive use of solar energy in buildings (see recommendation under demand-side, demand response and energy efficiency).

**J.21 Recommendation**

The current commitment to research on third generation photovoltaics should be maintained. Solar heat research should be grown as part of a broader enhancement of research into demand-side management in buildings.

Solar irradiation in UK is 600 …1000kWh/m² annually depending on location. Thus, due to costs and lifetime of current photovoltaic solar systems in UK photovoltaic generation costs are between 0.50 and 0.30 €/kWh. Further cost reductions will be achieved by enlarged manufacturing capacities in PV production companies and innovations achieved by R&D (TRL 1-3). Following the learning curve of photovoltaic and the development of average prices of electricity (residential, commercial, industrial) in the UK, grid parity will be reached in South England in 2020 and all over the UK in 203011.

Limiting the photovoltaic research to the sets of technologies, which reached already pilot or mass production, may be risky for two reasons: (i) flat-plate single junction modules are limited to efficiencies not exceeding 25%, and (ii) the photovoltaic industry would miss opportunities afforded by step-changes in technology. Beyond-evolutionary technologies can either be based on low-cost approaches related to extremely low consumption of materials and energy in production or approaches that push the photovoltaic efficiencies beyond 25% achievable with incremental improvements to photovoltaic devices based on traditional designs. In fact, the goal to develop photovoltaic technologies significantly relies on disruptive breakthroughs in the field of novel technologies.

R&D towards developments presently, taking place in material and device science (nano-materials, self-assembly, nanotechnology, plastic electronics, photonics), is needed to explore these opportunities in an early stage. Some of these technologies for which at least one “proof-of-concept” exists can be considered as longer term options that will disrupt the development of the established solar cell technologies; other ones can potentially lead to disruptive technologies, the likely future conversion efficiencies and/or costs of which are difficult to estimate.

In the areas of the novel photovoltaic technologies (advanced inorganic thin-film technologies, thermophotovoltaic, organic or hybrid photovoltaic), the UK has built up a strong R&D position, in particular on the explorative stage (TRL1). First steps towards commercialisation in the UK are being taken in few of them, all of which essentially aim at very low production costs with efficiencies around 15%.

Internationally the UK plays its most important role in the category of high efficiency technologies, in which a distinction is made between approaches that tailor the properties of the solar cell base materials to better match the solar spectrum and approaches that modify the incoming solar spectrum and function at the periphery of the active device, without

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Panel Responses to the “Framework and Subsidiary Questions”

fundamentally modifying the active layer properties. To both approaches advances in nanotechnology and nano-materials are relevant. Innovations in both R&D topics will be a long-term challenge offering the UK the opportunity for licensing, technology transfer and setting up national manufacturing companies just in time of demand. The R&D in the UK fits well with the Strategic Research Agenda and the SET-Plan in Europe.

J.22 Recommendation
The UK should rely on its highest reputational photovoltaic competence expertise and strengthen the R&D activities on mid to long-term challenges. The emphasis in the coming years should be on novel competitive solar cells and modules, making use of:

- Nanotechnology (nano-particles, and methods of growing and synthesising them). The international community is expecting that the first successful demonstration of concepts based on the use of such materials will occur in a few years.

- Theoretical and experimental tools to understand manufacture and characterise the morphological and nano-scale opto-electrical properties. Data in materials science and device processing are needed to accomplish the vast majority of research work related to the disruptive technologies. Earliest identification and selection of the most promising concepts from those researched and turned into commercial products through research into cost reduction, and research into the environmental implications of mass production scenarios, will offer national PV large-scale manufacturing on national and worldwide demand.

- Long-term national networking in programmes such as SUPERGEN. The successful development of disruptive PV technologies requires universities to team up with institutes with a strong background in photovoltaic. A close collaboration will ensure that good ideas are rapidly taken up and that the potential of each of the innovative PV technology is looked at objectively and dispassionately.

Research on Wind
It is clear that the UK has seen the opportunity in meeting its targets for renewable energy by deploying wind, specifically focused on offshore deployment. As the strategy for this effort is short-term impact (2020) it is particularly important that clear observations of the industrial problems, the stage of the industry and its needs are analysed and understood in a framework going forward; as the opposite of performing historical analysis. In particular, the ETI, TSB and Carbon Trust efforts are important for the short-term so research should be gauged towards fulfilling system components requirement both to support utility, owners and operators, OEMs and, in particular, component suppliers. These are all enablers of a mature and growing industry. Problems, such as turbine design for the short-term, is best solved by the industry itself, in particular as the market players are global companies in competition.

The wind research arena has clearly been dominated by Danish, Dutch, German and Spanish efforts for many years. However, closely observed there are clear efforts to be “best-in-class” on clearly identified areas of excellence. In the offshore wind industry, deployment has quickly become leading in the UK. Also, the UK has been leading in identifying new opportunities on some fundamental development for the offshore wind deployment, i.e. the Carbon Trust competition on offshore foundation design. Such important efforts should be continued for additional impact. Germany, France, Norway and Denmark are also moving very fast in this area but the UK is uniquely poised to impact.

J.23 Recommendation
For the short-term research supporting demonstration efforts it is generally recommended that RCUK should support the demonstration efforts by supplying comprehensive data collection and analysis towards solving fundamental research needs. This is a strong combination when this occurs in parallel to industrial efforts. Fundamental research is very valuable in connection with upcoming offshore demonstration sites addressing fundamental problems around the cost intensive components such as infrastructure (port, deployment and electrical), environmental impact on design (wind, wave scouring, wild life, radar, etc.) and foundation development. More guidance can be identified in the European Wind Energy Technology platform (TPWind) Strategic Agenda Document.

J.24 Recommendation
The RCUK funded university centres have shown multidisciplinary approaches combining non-
technological studies to technological achievement are effective. It is recommended to investigate if such strength of research within public support and environmental impact studies combined with technology will serve industrial needs and make deployment more effective. Guidelines could be identified from the DECC description of the offshore wind challenges. Also, it is recommended to begin research investigations of repowering onshore turbines. Studies in other countries have shown significant opportunities can be identified.

J.25 Recommendation
For the long-term, wind research and open-ended research should be encouraged as impact on such timescales should not be missed and may not be covered by industry. This should, however, not replace or displace fundamental research in basic needs of a, by then, very mature industry (forward planning as opposed to historical planning). Support of original SMEs addressing key supply chain issues and component developments could be an important element in innovating the future wind industry.

Research on Wave and Tidal
On wave and tidal energy UK universities and companies have been developing a significant number of devices, some of which have been tested in the sea, in testing areas namely at the European Marine Energy Centre (EMEC) in the Orkney Islands. The Wave Hub in Cornwall (SW England) was developed for testing small arrays of wave energy converters, with a present capacity for 20 MW, it being planned to increase to 50 MW in the future.

The most well known UK wave energy converters that have achieved the demonstration and pre-commercial stages are the deep water Pelamis (developed in Scotland by Pelamis Wave Power) and the near shore bottom-mounted Oyster (developed by Queen’s University Belfast and Aquamarine Power). A second version of Pelamis is planned to be tested at EMEC shortly; with important investments by private companies being announced. The Oyster was also tested at EMEC. Various other wave energy converters (WECs) are under development, namely the second version of the AWS (AWS Ocean Energy, UK) and the Anaconda (Checkmate Seaenergy Ltd).

On what concerns tidal current energy conversion, Seaflow and Seagen (Marine Current Technologies, UK) have been demonstrated at full scale, with a 1 MW Seaflow system being deployed and grid connected off the west coast of Northern Ireland. Other tidal current energy converters are being developed in the UK. These include the Hydroventuri (HydroVenturi Ltd, UK) and the Pulse-Stream device (Pulse Tidal) among others.

J.26 Recommendation
The development of the wave and tidal current energy converters seems to have been made using mainly funds provided by local governments and regional agencies and, in a less extent, by RCUK. It was also understood that the universities that are developing the various systems do not have a significant level of collaboration among them (except when they participate in the SUPERGEN programme). We therefore recommend that higher level of collaboration should be implemented under the umbrella of RCUK in order to secure the UK in a continuous leadership position.

Full usage of the Rutherford Appleton Laboratory
The facilities mode of operation and research at the Rutherford Appleton Laboratory (RAL) were described in detail. It is clear that the RAL facilities are world class. Access is on a peer reviewed basis as is common with such facilities in countries that do not have the benefit of national laboratories equipped with high end research infrastructure, as in the USA. This has ensured that the research undertaken is of the highest quality. The examples presented for review were demonstrably at the leading edge of international research.

The facilities are an exemplar for a large-scale international facility but the low utilisation (only 150 d/y) needs attention. There is significantly more energy R&D that would benefit from access to the RAL facilities and would do so if the utilisation were higher.

J.27 Recommendation
Consider funding a higher utilisation of the RAL facilities for energy related research.
4. Concluding Remarks

This first review and comprehensive presentation of the UK’s energy research has indeed been a very interesting experience for the Panel. The elements in the review itself does prove many of the points made throughout the recommendations. As climate awareness and call for action has become evident there is an urgent need to understand the routes to successful mitigation. This places an enormous pressure upon energy research as results with impact must be achieved. Clean, reliable and affordable energy is the key to success, not only in the UK but in the world. Failure is simply not an option; thus, nurturing and supportive roadmaps combined with metrics are required to monitor progress to the not so distant 2050. It is important to understand that roadmaps and metrics should not constrain programmatic as well as open-ended research, but only secure that progress is evident towards 2050.

Energy is cross-cutting into many disciplines. Concerning integration of environmental sciences with energy research, the Panel felt that a stepwise integration of focus areas would be the best way forward in order to have successful inclusion, basically because a new dimension is added to the complexity and delivery may be posed at risk. Specific first steps are proposed in section B.4.

The UK has generated a number of mechanisms to support energy research funded through the RCUK, TSB, ETI, regional funding and combinations thereof, see the figure below. Similarly, a number of entities have developed specific roadmaps. All of this work is excellent; however, an overarching plan and roadmap to address the long-term targets is not in place. This is a shame because synergistic effects of coherent movement may be missed or cannot be deployed because resources were not planned in due time to impact. As action towards climate mitigation is urgent, energy action is even more urgent; thus an overarching roadmap is urgently required, as early action implies higher impact.

![Figure illustrating the funding transfer from TRL1-2 and through into early deployment, including the UK funding mechanisms beyond the Research Councils](image-url)
Concluding Remarks

The energy scene is also changing rapidly and the connections between an R&D portfolio and its impact on the achievement of its objectives are complex. Regular reviews of the impact of the R&D effort should be undertaken using metrics such as impact potential, abatement cost, workforce availability, workforce planning and industrial deployment are needed. The cost of energy and energy security must be evaluated. Again, some high level metrics is required to secure the targets.

It was noted that the UK’s research portfolio predominately addressed the developed part of the world.

On the people side, the UK is on a great trajectory to develop a successful pipeline. The UK has done a great job in implementing CDTs. More needs to be done but the starting point is excellent. The UK does have excellent methods for industrial involvement at all technology readiness levels and these mechanisms will undoubtedly direct future impact. The industry interest in early research was impressive.

Overall, the UK has the tools and mechanisms that are required for its energy research programme but they are too complex and need to be optimised. Critical mass can be achieved through combining resources and clear specification of objectives. However, fundamentally it is clear that the UK funding level to energy research is low in comparison to that of other countries and may be too low in relation to the ambitious targets set by the UK Government. Most importantly, any initiative made must contain commitments to address energy development that are long-term in order to strengthen the structural coherence of UK energy research and its ultimate impact.

Finally, the Panel decided to include area specific comments (beyond the terms of reference) as the Panel believes this could be useful feedback. However, it is important to notice that section J is by no means a complete topic overview and does not cover all topics presented in the review. The choice of topics is a function of the Panel’s expertise combined with particular areas of observations from the review week, thus several areas have been omitted. An omission has no particular importance.
Annex A


Introduction
The following was provided to assist the Panel during the review week to help ensure coverage of all relevant strategic issues. The Framework was not intended to restrict the Panel; additional issues were addressed as they arose. The questions below were also used for the public consultation exercise which provided additional input to the Panel.

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

• What are the key technological/societal challenges and research directions in energy research? To what extent is the UK energy 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?

• In terms of the defined remits of the relevant research council programmes, are there any areas which are under-supported in relation to the situation overseas?

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

• 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 Energy Programme bringing together disciplines to form a coherent Energy research community?

• What evidence is there that there is sufficient research involving multiple disciplines?

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

• What evidence is there to demonstrate the influence that research council programmes has had in encouraging multidisciplinary research?

• Is there an adequate description of the top level challenges that the energy community can respond to?

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

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

• How robust are the relationships between UK academia and industry/policymakers both nationally and internationally and how can these be improved?

• To what extent does the energy community take advantage of research council schemes to enable this knowledge exchange? Is there more that could be done to encourage knowledge transfer?

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

• To what extent does the protection of Intellectual Property act as a barrier to energy research in the UK as compared to other countries?

• To what extent are the energy community openly communicating research results?
D. To what extent is the UK energy research activity focused to benefit the UK economy and global competitiveness?

- What are the major innovations in the energy area, current and emerging, which are benefitting/could benefit the UK? Which of these include a significant contribution from UK research?
- How successful has the UK energy community (academic and industrial) been at innovation? What are the barriers to successful innovation in energy 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 energy research? Is there evidence that they are being nurtured and supported at every stage of their career?

- 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 energy research? How does this compare with the experience in other countries?
- How effective are public engagement activities?
- 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?
- How does the career structure for energy researchers in the UK compare internationally?
- To what extent is the UK able to attract overseas energy researchers 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?

- What is the nature and extent of engagement between the UK and Europe, USA, China, India and Japan?
- How effective is the engagement between the UK and the rest of the world?
- Are there particular issues for the energy research area? What could be done to improve international interactions?

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

- Is the UK the international leader in energy research? In which areas? What contributes to the UK strength and what are the recommendations for continued strength?
- What are the opportunities/threats for the future?
- In which areas is the UK weak?

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

- Is the current balance between high-risk/high-return research and “safe research” appropriate?
- What are the barriers to more “adventurous research” and how can they be overcome?
Annex B

Brief Biographies of Panel Members

Dr Carsten Hein Westergaard

Dr Carsten Hein Westergaard earned his PhD in 1994 at the Danish Technical University. His dissertation from the physics department encompassed optical computing and optical turbulent flow measurements. Part of his research was completed with Professor Ronald Adrian at the University of Illinois. During his student years he had internships at CERN, Switzerland and in the US oil industry.

Dr Westergaard started his industrial career in wind technology as an aerodynamics blade designer participating in a number of European community funded research projects. From 1999 to 2006 he held a variety of management roles with Dantec Dynamics A/S, a manufacturer of scientific measurement instruments. Prior to joining Vestas, he worked for Force Technology, providing energy and flow consultancy services to industry.

At Vestas Technology R&D, he established Vestas’ office on the campus of the National Laboratory for Sustainable Energy in Denmark (Risø). He successfully funded joint projects through the Danish Advanced Technology Foundation, while participating in Danish, European, and US policy and strategy groups. He also developed a scholarship programme for Vestas to sponsor PhDs, MScs and Professorships in connection with Vestas’ global research centres.

Currently, he is assigned to Vestas’ new research office in Houston as Director of Global Technology, guiding the establishment of Vestas’ R&D portfolio in Houston. He is also working with University collaborations and other external partnerships, such as TheWindAlliance.org.

Throughout his career, he has mentored and supervised numerous MSc and PhD theses, and actively participated in the scientific communities relevant to his industrial occupations, while publishing more than 35 conference and journal papers.

Professor Göran Andersson

Professor Göran Andersson was born in Malmö, Sweden. He received his MSc and PhD degrees in engineering physics from Lund University in 1975 and 1980 respectively. After that he joined ASEA, now ABB, in Ludvika, Sweden, where he worked with power system simulation, control and design, in particular with High Voltage Direct Current (HVDC) applications. In 1986 he was appointed full professor in Electric Power Systems at Royal Institute of Technology (KTH), Stockholm, where he was until joining ETH. At KTH he was the head of the power systems group. Main research topics were power systems dynamics and stability, e.g. voltage stability and angular stability, and power electronics in power systems. Most of the projects were carried out in collaboration with research groups abroad.

His research focuses on the use and application of system theory tools from e.g. control theory, operations research, optimisation and, more recently, financial mathematics in power system analysis. A main ambition is to develop models and tools based on advanced theories and methods to be used by practising engineers in the electric power industry. The ongoing deregulation, or liberalisation, of the energy industry sector has created new research topics that require new tools.

Professor Andersson is a Fellow of the Institute of Electrical and Electronic Engineers (IEEE), member of the Royal Swedish Academy of Sciences (KVA) and member of the Royal Swedish Academy of Engineering Sciences (IVA).
Annex B: Brief Biographies of Panel Members

Professor Rangan Banerjee

Professor Rangan Banerjee is a Professor of the Department of Energy Science and Engineering and currently the Dean of Research and Development at the Indian Institute of Technology Bombay. He was Associate Dean (R&D) of IIT Bombay from 2003-2006 and Head of the Department of Energy Science and Engineering (2006-2009).

He is a Convener Lead Analyst for Industrial End Use Efficiency and a member of the executive committee for the Global Energy Assessment (2008-2010) coordinated by the International Institute for Applied Systems Analysis. He is also an Adjunct faculty (Honorary) in the Department of Engineering & Public Policy, Carnegie Mellon University.


He has been involved in industrial projects with organisations like Essar, Indian Chemical Manufacturers Association, KSIDC, HR Johnson, Tata Consulting Engineers, BSES, Sterlite, International Institute of Energy Conservation and sponsored projects with the Department of Science & Technology, UN, MERC, PCRA, MNES, Hewlett Foundation.

His areas of interest include energy management, modelling of energy systems, energy planning and policy, hydrogen energy and fuel cells. He has conducted two international training programmes on solar energy and several National programmes on renewable energy and Energy Management.

Professor Robin Batterham

Professor Robin Batterham is President of the Australian Academy of Technological Sciences and Engineering, until recently was Group Chief Scientist, Rio Tinto Limited and is now Kernot Professor of Engineering at the University of Melbourne. Within Rio Tinto, Professor Batterham has had senior responsibilities in R&D and Innovation.

He has had a distinguished career in research and technology, in the public and private sectors in areas such as mining, mineral processing, mineral agglomeration processes and iron making.

Professor Batterham was Chief Scientist to the Australian Federal Government from 1999 to 2005 and remains on the Prime Minister’s Science, Engineering and Innovation Council.

He has been President of the Institution of Chemical Engineers and the International Network for Acid Prevention and is President of the International Mineral Processing Congress as well as chairing the Australia India Collaborative Research Fund. He chairs the International Energy Agency Expert Group on Science for Energy. He is an elected Fellow (or Foreign Fellow) of the Royal Academy of Engineering, the National Academy of Engineering, the Swiss Academy of Technological Sciences, the Australian Academy of Science, the Australian Academy of Technological Sciences and Engineering as well as Fellow of several learned societies.

Professor Frank Carré

Professor Frank Carré is Scientific Director of the Nuclear Energy Division at the French Energy Commission (CEA). He is also lecturing professor at the École Polytechnique and professor at the National Institute for Nuclear Sciences and Techniques.

He graduated in 1974 as Engineer from the École Centrale de Paris, in 1975 as Master of Science in Nuclear Engineering at the Massachusetts Institute of Technology (USA) and in 1976 as pre-Doctoral student in Reactor Physics at the University Paris XI (Orsay).

Since he joined the CEA in 1976, Professor Carré contributed in successive managerial positions to studies on advanced nuclear systems including light water and fast-neutron reactors, advanced fuel cycles, fusion reactor blankets and space power reactors. From 1997 to 2000 he served as Assistant Director of the Strategy and Evaluation Division of CEA in charge of strategic planning of the CEA’s civilian activities. From 2001 to 2006 he acted as Programme Director for Future Nuclear Energy Systems within the Nuclear Energy Division. In this responsibility he contributed to shaping and managing national R&D programmes on fast neutron reactors with advanced fuel cycles.
and high temperature reactors for the cogeneration of process heat and hydrogen. From 2007 to 2009 he acted as Deputy Director for Nuclear Development and Innovation within the Nuclear Energy Division of CEA. In this position, he co-managed national programmes on future nuclear systems both in Europe and the Generation IV International Forum.

He was elected a member of the International Nuclear Energy Academy in July 2009.

Dr Andrew Dicks

Dr Andrew Dicks was formerly Principal Scientist with BG plc and Advantica Technologies in the UK, where he led research in fuel processing and fuel cell systems from 1985 to 2000. During this time he worked with leading fuel cell developers in two major collaborations supported by the European Commission. He also led collaborations between the UK, the USA and Canada, including chairmanship of a major development of PEM fuel cells funded by BG, NSERC (Canada) and Ballard Power Systems. In 1991 he was awarded the HE Jones (London) Medal of the Institution of Gas Engineers for his work on high temperature fuel cells and has since co-authored the leading textbook on fuel cell systems that has been translated into both Japanese and Chinese. During the 1990s he was a member of the EPSRC Engineering College and the DTI Fuel Cell Advisory Panel.

Dr Dicks moved to Australia in 2001 to take up a research fellowship in nanomaterials at the University of Queensland. In 2004 he became a Director of the Australian Institute of Energy and has contributed to developing a national interest in Hydrogen Energy systems and technologies, including the National Hydrogen Technology Roadmap published in 2008. In the same year he chaired the World Hydrogen Energy Conference held in Brisbane. From 2006 to 2009 he was Director of the National Hydrogen Materials Alliance, a CSIRO supported network of 12 university research groups and ANSTO. Since then he has become the founding President of the Australian Association for Hydrogen Energy. In December 2009, whilst continuing as an adjunct academic at the University of Queensland, he took up a research capacity building appointment at Queensland University of Technology, where he also lectures on energy systems and fuel processing. His publication record includes several book chapters and 10 international patents. He has been a committee member of the Royal Society of Chemistry, and is on the editorial boards of the Journal of Power Sources and the International Journal of Hydrogen Energy. He has been engaged by governments in Sweden, Canada and Singapore to review their fuel cell research programmes, provides advice and due diligence to venture capitalists and other funding agencies, and is on the advisory boards of several international conferences. Dr Dicks received his PhD from Loughborough University and is a Fellow of the Royal Society of Chemistry and Chartered Chemist.

Professor Rosemary Falcon

Professor Rosemary Falcon has a BSc, MSc and a PhD from the University of the Witwatersrand. She has worked in the South African coal industry for 46 years. Following training overseas in Germany and the UK, she set up a Coal Laboratory in 1976 at the University of the Witwatersrand, and in 1982 she started her own company, Falcon Research Laboratory Pty Ltd, undertaking research and investigations for a wide range of coal producers, users, traders and investors both in South Africa and internationally. She remains Managing Director in this company.

During the 1990s she was President of the Associated Scientific and Technical Societies (AS&T) coordinating and promoting science, engineering and technology in all the SET professions and also in schools and communities. During her career she has been awarded the Gold Medal from the SA Institute of Mining and Metallurgy, the Draper Memorial Award of the Geological Society and the 2006 Prestige Award from the Fossil Fuel Foundation of Africa.

In recent years Professor Falcon was appointed Visiting Professor in a part-time capacity at the Universities of Witwatersrand and Johannesburg where she currently lectures on undergraduate, postgraduate and industrial courses. She is also Director of the Fossil Fuel Foundation of Africa and continues to conduct her professional consultancy in legal, industrial and commercial purposes through her company.

In 2007 Professor Falcon was awarded the Chair of Clean Coal Technology at the University of the Witwatersrand. This Chair was recently created by the Government to promote high level research in coal and energy-related topics in this country.
Annex B: Brief Biographies of Panel Members

Professor Richard Flavell

Professor Flavell joined Ceres in 1998 as Chief Scientific Officer (CSO) and has been a board member since 2009. Ceres is a seed company specialising in the development of crops to serve as feedstocks for the biofuels industries.

From 1987 to 1998, he was the Director of the John Innes Centre in Norwich, UK, a premier plant and microbial research institute. He has published over 200 scientific articles, lectured widely and contributed significantly to the development of modern biotechnology in agriculture. His research group in the United Kingdom was among the very first worldwide to successfully clone plant DNA, isolate and sequence plant genes, and produce transgenic plants.

Professor Flavell is an expert in plant biotechnology, biomass production and plant genomics, having produced the first molecular maps of plant chromosomes to reveal the constituent sequences. He has been a leader in European plant biotechnology, initiating and guiding a pan-European organisation to manage large EU plant biotechnology research programmes more effectively.

In 1999, Professor Flavell was named a Commander of the British Empire (CBE) for his contributions to plant and microbial sciences. He received his PhD from the University of East Anglia and is a Fellow of EMBO and The Royal Society of London. In addition to being CSO of Ceres, he is currently an Adjunct Professor in the Department of Molecular, Cellular and Developmental Biology at the University of California at Los Angeles.

Dr Clark Gellings

Dr Clark W. Gellings holds the position of Fellow at the Electric Power Research Institute (EPRI) and is responsible for technology strategy in areas concerning energy efficiency, demand response, renewable energy resources and other clean technologies.

Dr Gellings joined EPRI in 1982 progressing through a series of technical management and executive positions including seven vice president positions. He was also Chief Executive Officer of several EPRI’s subsidiaries. Prior to joining EPRI, he spent 14 years with Public Service Electric & Gas Company. He received distinguished awards from a number of organisations, including the Illuminating Engineering Society, the Association of Energy Services Professionals and the South African Institute of Electrical Engineers. He is a 2003 recipient of CIGRE’s (International Council on Large Electric Systems) Attwood Award for notable contributions. He is the 2010 recipient of EnergyBiz Magazine’s KITE (Knowledge, Innovation, Technology, Excellence) Lifetime Achievement Award. He is currently a Member of the Board of the University of Minnesota's Center for the Development of Technology Leadership and several National Academy of Sciences Committees.

Dr Gellings has a Bachelor of Science in electrical engineering from Newark College of Engineering in New Jersey, a Master of Science degree in mechanical engineering from New Jersey Institute of Technology and a Master of Management Science from the Wesley J. Howe School of Technology Management at Stevens Institute of Technology. Dr Gellings is a registered Professional Engineer, a Fellow in the Institute of Electrical and Electronics Engineers, a Fellow in the Illuminating Engineering Society, and a Distinguished Member and President of the US National Committee of CIGRE. He is the author of 12 books and over 400 articles and papers.

Dr David Hill

Dr David Hill is Deputy Laboratory Director for Science & Technology, Idaho National Laboratory. An internationally acknowledged expert on nuclear reactor and fuel cycle issues, Dr Hill has extensive experience in the area of international nuclear matters, working with the countries of both Western Europe and the former Soviet Union.

He joined Idaho National Laboratory from Oak Ridge National Laboratory, where he was Associate Laboratory Director, Energy and Engineering Sciences. Previously, Dr Hill served at Argonne National Laboratory, where he was Deputy Associate Laboratory Director of Engineering Research, having held positions as Director of the divisions of Reactor Analysis and Engineering, Reactor Engineering and the International Nuclear Safety Center. He holds a bachelor’s degree in Mathematics and a doctorate in Mathematical Physics from Imperial College, London and an MBA from the University of Chicago.
Annex B: Brief Biographies of Panel Members

**Professor Martha Lux-Steiner**

Professor Martha Lux-Steiner is Head of the Institute of Heterogeneous Material Systems at Helmholtz-Zentrum Berlin, Germany.

Professor Lux-Steiner’s institute mainly focuses on compound semiconductors. Her research interest is also focused on nanotechnology with particular emphasis on surface nanostructuring with STM, AFM, ion, electron and photon beams, characterisation of compound semiconductor surfaces and metal/insulator nanostructures grown on semiconductors, and development of scanning probe microscopy/spectroscopy techniques. Professor Lux-Steiner is also a member of various international and national advisory boards and committees and has been awarded the Bundesverdienstkreuz Erster Klasse (Federal Cross of Merit 1st Class) by the President of the Federal Republic of Germany in 1999 for outstanding services in the area of research and development and for activities to enhance cooperations between research centres and the industry (especially SMEs and spin-offs) within the region Berlin/Brandenburg.

Over the years, Professor Lux-Steiner has held the following positions:

- Dr. sc. Nat. at Institute of Toxicology at ETH Zurich: “Development and optimisation of an inductively coupled plasma system for analysis of organic materials” (research performed at PHILIPS Nat. Lab.; Eindhoven, Netherlands) (1980)
- Scientist at Universität Konstanz, Germany (1980 – 1985)
- Senior Scientist at Universität Konstanz, Germany (1985 – 1990)
- Research Fellowship at Princeton University, Department of Electrical Engineering, USA (1990 – 1991)
- Assistant Professor at Universität Konstanz, Germany (1991 – 1995)
- Full C4 Professor at Freie Universität Berlin, Germany and Head of Institute Heterogeneous Material Systems within the division Energy at Helmholtz-Zentrum Berlin GmbH, Germany (formerly: Hahn-Meitner-Institut Berlin GmbH) (since 1995)

Professor Lux-Steiner’s memberships and referee work (selection) includes:

- First chairwoman of the Association “Arbeitsgemeinschaft Solare Materialien” (since 1996)
- Member (and 2002 chairwoman) of the Directory of the Forschungsverbund Sonnenenergie FVS (now: FVEE) (since 1996)
- Member of the EUREC Agency (2001 – 2007)
- Member of the Eidgenössische Energieforschungskommission CORE (CH) (since 2001)
- Member of the task force “Frauen in Forschungszentren – akfiz” (HGF) (2003 – 2004)
- Member of the WTA supervisory board at the Forschungszentrum Jülich (FZJ, HGF) and member of the Scientific Council for Energy Research Activities within the energy programme of the FZJ (2001 – 2006)
- Member and chairwoman of the Scientific Council of Berlin’s Institut für Kristallzüchtung (IKZ) (since 2003)
- Deputy chairwoman and member of the Hochschulrat of the Universität Oldenburg (2003 – 2007)
- Member of the Scientific Council of Sulfurcell Solartechnik GmbH (since 2003)
- Member of the jury for the ERWIN-SCHRÖDINGER-PREIS of the HGF (since 2004)
- Mentor within the Helmholtz Network Mentoring Programme (since 2005)
- Member of the Scientific Council of the Forschungszentrum Rossendorf e. V. (FZR) (2005 – 2008)
- Member of the board of trustees of the Forschungsverbund Berlin e.V. (since 2006)
- Chairwoman of the executive and scientific committee of the symposium “Nanotechnologie für eine nachhaltige Energieversorgung” (2007)
Professor Brian Norton

Professor Brian Norton became President of Dublin Institute of Technology (DIT) in September 2003. DIT is one of Ireland’s largest and most diverse higher education institutions. Previously, Professor Norton was Dean of Engineering and Built Environment at University of Ulster from 1996, having served as Professor of Built-Environmental Engineering at University of Ulster since 1989. He has very extensive international links and over €10 million in grants principally for solar energy research. Author or co-author of five advanced texts and over 350 papers including over 170 in major international learned journals. He has supervised thirty-four doctorates. He serves as Associate Editor of “Solar Energy” - the premier international journal in the field and serves on three other editorial boards. He is currently President of the Solar Energy Society of Ireland.

Professor Norton has chaired the World Renewable Energy Network, the BSI Technical Committee on Solar Heating, the Eco-Energy Trust and still chairs Action Renewables. He served on the Board of the UK Building Research Establishment. He has been a ministerial appointee to the Construction Industry Training Board and has chaired its Audit Committee. He was a member of the Built Environment Panel for the 2001 UK national universities Research Assessment Exercise and Chaired the Northern Ireland Business Education Partnership. In 2001/02 he acted as Specialist Adviser to the Enterprise, Trade and Investment Committee of the N.I. Assembly. He currently is a member of a group overseeing the implementation of the Irish national strategy for science, technology and innovation. He also serves on the Council of the Irish Academy of Engineering. He is an elected board member of the Council of Dublin Chamber of Commerce and the Audit Committee of Dublin City Council.

He has a BSc (Hons) in Physics from University of Nottingham and MSc and PhD degrees, in Engineering Experimentation and Applied Energy respectively, from Cranfield University and DSc from the University of Nottingham. He is a Fellow of the Energy Institute and the Institution of Engineers of Ireland, a Chartered Engineer (both in Ireland and the UK) and Fellow, Higher Education Academy. Among his awards are the Napier Shaw Medal of the Chartered Institute of Building Services Engineers, the Roscoe Award of the...
Annex B: Brief Biographies of Panel Members

Institute of Energy. He is an Honorary Fellow of the Chartered Institute of Building Services Engineers and a Fellow of the Irish Academy of Engineering. He is an Honorary Professor of both the University of Ulster and the Harbin Institute of Technology, China.

**Professor Jonathan Parker**

After obtaining an Honours degree in Physical Metallurgy and a PhD from the University of Wales, Professor Jonathan Parker was employed by the Central Electricity Generating Board (UK), Ontario Hydro (Canada), Replication Technology Inc. and Failure Analysis Associates, Inc. (both USA). These positions, working for energy sector companies, typically involved the application of fundamental science and engineering to the solution of real problems. As a research professor and then Head of the Department of Materials Engineering at University of Wales Swansea (UK), he was responsible for advanced collaborative research, training and consultative programmes involving companies in Europe, North America, the Far East and Australia as well as South Africa.

Professional contributions have been made to key National and International committees and technical activities, including:

- Member of the Engineering and Physical Sciences Research Council Structural Materials College
- Academic Director and Member of the Steering Committee of the EPSRC Engineering Doctorate Programme in Steel Technology
- Institute of Materials, Materials Engineering and Structural Integrity Committee
- External Expert Reviewer Materials Engineering Programme, Royal Institute, Sweden
- Chairman, International Institute of Welding Expert Group, “Creep”
- Steering Committee and Technical Auditor for the EU supported Plant Life Assessment Network
- Academic Expert on DTI study mission to Japan and Korea
- Editorial Board: Journal of Strain Analysis for Engineering
- Editorial Board: Journal of The Science of Technology of Welding and Joining

Personal expertise in characterisation of materials structures and properties has been applied to industry relevant issues such as damage assessment, failure analysis and prevention, life prediction and asset management, as well as optimisation of manufacturing processes. This technical expertise, leveraged by extensive international contacts from industry, research organisations and Government Agencies, complements the established engineering and inspection capabilities within his present employer Structural Integrity Associates, Inc. Currently he is contributing to the work of the Electric Power Research Institute (EPRI) and many major Electricity Generating Utilities throughout the world on projects involving knowledge creation, technology transfer and development of optimised approaches to performance assessment of power plant.

He is a Chartered Engineer of the Engineering Council (UK), a Fellow of the Institution of Mechanical Engineers and a Fellow of the Institute of Materials, Minerals and Mining. He has been editor or co-editor of 4 Conference Proceedings, author or co-author of 9 major texts and reports and has over 200 expert publications and presentations.

**Dr Teresa Pontes**

Dr Teresa Pontes, Chemical Engineering MSc and Mechanical Engineering PhD from Lisbon Technical University, has published more than 70 papers about wave energy, namely resource assessment, site selection and policies, and has been involved in more than 25 national and international contracts.

She has participated in the following European projects: European Wave Energy Pilot Plant on the island of Pico, Azores, Portugal and European Wave Energy Pilot Plant on the island of Pico, Azores, Portugal – Phase II: Equipment, Wave Studies and Development of Resource Evaluation Methodology and WERATLAS (European Wave Energy Atlas), being general coordinator of these two contracts; WENET (Wave Energy Network), SeaROUTES (Advanced Decision Support for Shiprouting based on Full-scale Ship-specific Responses as well as Improved Sea and Weather Forecasts including Synoptic, High Precision and Real-time Satellite Data), CA-OE (Coordination

She participated in various national projects, namely the following: Performance Improvement of OWC Power Equipment; Modelling, Optimisation and Control of Offshore Wave Energy Systems; Impulse Turbines for Wave Energy Conversion; and Advanced Ocean Surface Data (coordinator). She coordinated ONDATLAS (Nearshore Wave Climate and Energy Atlas – Portugal mainland and Madeira Islands) and PEMAP (Potential of Marine Energies in Portugal) a GIS database that was useful for wave energy site selection in addition to other applications.

She was a Member of the Steering Committee on Wave Energy, DGXII CEC (in action 1991-1993 that launched the EC programme on Wave and Tidal Energy), she has been Portuguese Delegate to the “Working Part on Renewable Energies” of the International Energy Agency (since 1994), Vice-Chair of the ECOR/IOC/UNESCO “Working Group on Wave Energy Conversion” (1996-2003), Vice-President of Associação Portuguesa de Energia (Portuguese Committee – Member of World Energy Council, 1997 - 1999). She launched the Implementing Agreement on Ocean Energy Systems (International Energy Agency) being National Delegate since its creation in 2001, Ex Co-Chair (2001- 2004) and Vice-Chair in 2005; she was member of the Board of Directors (2004-2006) and is President of the Scientific Council (since 2008) of the Wave Energy Centre (Portugal), and is Lead Author of Ocean Energy chapter of the IPCC Special Report on Renewable Energy and Climate Change Mitigation – SRREN (2009-2010). She has been Project Evaluator for the European Union and UREKA.

She was Principal Researcher of INETI (National Institute for Engineering and Industrial Technology, Ministry of Economy and Innovation) where she founded the Ocean Energy Group in 1985. She retired in December 2009, continuing as Resident Researcher of LNEG (National Laboratory for Energy and Geology, Ministry of Economy and Innovation), the successor of INETI.

Professor Susan Scott

Professor Susan Scott is an economist and affiliate of Ireland's Economic and Social Research Institute (ESRI) where she was employed until October 2009. Her work has concentrated on energy and environmental issues including pricing, taxation, demand projections, efficiency, investment and distribution in relation to policies on energy, carbon, water and waste services, agriculture, forestry and transport. While she was head of the ESRI's Environment Policy Research Centre her group laid research foundations for many environmental issues in Ireland today.

Her work has been published in the journals “Energy Economics, Utilities Policy”, the “Journal of Environmental Planning and Management” and the “Journal of the Social and Statistical Society of Ireland”, in books published by Gill and MacMillan, Ashgate, Springer, Edward Elgar, Oxford University Press, the Central Statistics Office and the European Commission, and on the OECD and World Bank websites as well as in the ESRI publication series. She was editor/co-author of a book on the “Polluter Pays Principle”, which provided an overview of the scope for good pricing and efficiency in Ireland. Investment in water infrastructure and the introduction of weight-based waste charging are the subjects of recent publications. She is a contributing author of the book “Carbon-energy taxation – a case study of Europe”, recently published by Oxford University Press, based on the COMETR analysis of competitiveness and environmental tax reform.

Her scientific statement “Market-based policies for reducing carbon dioxide emissions” was published by the Royal Irish Academy while she was serving on its Committee on Climate Change. She has been appointed Council Member of COMHAR – the Sustainable Development Council of Ireland, as a representative of the professional/academic sector and is engaged on the European Environment Agency's environmental taxation awareness project.
Annex B: Brief Biographies of Panel Members

Professor Dongxiao Zhang

Professor Dongxiao Zhang earned both his Masters degree and PhD in hydrology and water resources in 1992 and 1993 respectively, from the University of Arizona.

He is an Associate Dean at the College of Engineering, director of the Institute of Clean Energy, and a Chair Professor at the Energy and Resources Engineering Department at Peking University (Beijing).

He has held positions as Chair Professor at the University of Southern California, Miller Chair Professor at the Department of Petroleum and Geological Engineering at the University of Oklahoma, and Senior Scientist at Los Alamos National Laboratory. He has also been a “Chang Jiang” (guest Chair) Professor at Nanjing University. Professor Zhang is the recipient of the National Thousand Talents Plan and the recipient of the National Natural Science Foundation Outstanding Young Researcher Award.

His research interests include: stochastic uncertainty quantification for hydrology and petroleum reservoir simulations; multiscale modelling and simulation of flow in porous media; geological sequestration of carbon dioxide.

He has authored two books and published over one hundred papers.
## Annex C

### Review Week Itinerary

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<thead>
<tr>
<th>Date</th>
<th>Hosted by University of Edinburgh</th>
<th>Details</th>
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<tbody>
<tr>
<td><strong>Sunday 24 October 2010</strong></td>
<td>Welcome/briefing session</td>
<td></td>
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<tr>
<td><strong>Monday 25 October 2010</strong></td>
<td>Presentations showing: Overview of research strategy; Research Highlights; and Knowledge Exchange and Economic Benefit. Four parallel sessions took place.</td>
<td>&lt;br&gt;1. Strathclyde&lt;br&gt;Glasgow&lt;br&gt;2. Leeds&lt;br&gt;St Andrews&lt;br&gt;3. BSBEC Group/Aberystwyth/Aston/Centre for Ecology and Hydrology/Lancaster&lt;br&gt;4. Edinburgh&lt;br&gt;Aberdeen&lt;br&gt;Poster session with early career researchers&lt;br&gt;Open discussion and Q&amp;A with all participants&lt;br&gt;Panel discussion with Technology Strategy Board, National Renewable Energy Centre, Energy Technologies Institute and the Carbon Trust&lt;br&gt;Private session for Panel</td>
</tr>
<tr>
<td><strong>Tuesday 26 October 2010</strong></td>
<td>Presentations showing: Overview of research strategy; Research Highlights; and Knowledge Exchange and Economic Benefit. Four parallel sessions took place.</td>
<td>&lt;br&gt;1. Durham&lt;br&gt;2. Newcastle&lt;br&gt;3. Manchester&lt;br&gt;4. Cardiff&lt;br&gt;Open discussion and Q&amp;A with all participants&lt;br&gt;Poster session with early career researchers&lt;br&gt;Private session for Panel</td>
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### Wednesday 27 October 2010
**Hosted by University of Oxford**

Presentations showing: Overview of research strategy; Research Highlights; and Knowledge Exchange and Economic Benefit. Four parallel sessions took place.

1. RAL/Culham
   - Belfast/Warwick/York
2. Cambridge
   - Birmingham
3. Loughborough
   - National Oceanography Centre/Plymouth/Plymouth Marine Laboratory/Scottish Association for Marine Science
4. Imperial College London
   - University College London

Poster session with early career researchers
Open discussion and Q&A with all participants
Private session for Panel

### Thursday 28 October 2010
**Hosted by University of Oxford**

Presentations showing: Overview of research strategy; Research Highlights; and Knowledge Exchange and Economic Benefit. Four parallel sessions took place.

1. East Anglia/Tyndall Centre
   - Sussex
2. Nottingham
   - Bath
3. Oxford
   - British Geological Survey
4. UKERC
   - Surrey

Poster session with early career researchers
Open discussion and Q&A with all participants
Panel discussion with the Departments for Energy and Climate Change, Transport, Business, Innovation and Skills, and Communities and Local Government
Private session for Panel

**Thursday 28 October 2010 (late pm)**
Commenced drafting report

**Friday 29 October 2010**
Agreed main findings and recommendations for future actions; presented these to Steering Committee

**Saturday 30 October 2010**
Panel departed
Annex D

Supporting Evidence and Information Provided

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

Overview: Funding of Science and Innovation in the UK: This described the key developments that had taken place over the last 7 years concerning public funding arrangements for science and innovation in the UK and provided a high level overview of how the science budget was secured and distributed. It also contained broad descriptions of various Research Council mechanisms for supporting research and training.

Background Data: This provided RCUK-related grant and studentship data, information about relevant TSB activities and information on other potential funders and collaborators. It was prepared as a companion to ‘Funding of Science and Innovation in the UK’ to give more detailed contextual data relevant to Energy research in the UK.

Consultation Responses: As part of the preparation for the review a public consultation was held to gather evidence for the Panel. Responses were specifically invited from the institutions who visited the Panel, from others who did not visit the Panel and from any other interested person/organisation via a public call on the Research Council websites. A standard template was used to ensure that submissions addressed the Evidence Framework agreed by the Steering Committee. The Panel was provided with both a summary and the full text of all responses received. Responses were received from:

Institutions/individuals:

- Aberystwyth University
  Iain Donnison
- British Geological Survey
  Mike Stephenson
- Centre for Ecology and Hydrology
  David Howard
- Durham University
  Peter Tavner
- Loughborough University
  Ken Parsons
- Newcastle University
  Dermot Roddy
- Rothamsted Research
  Angela Karp
- The Scottish Association for Marine Science (SAMS)
  Michele Stanley
- University of Aberdeen
  Dominic Houlihan
- University of Bath
  Jane Millar
- University of Birmingham
  Kevin Kendall
- University of Cambridge
  Lynn Gladden
- University of Cardiff
  Nick Jenkins
- University College London
  Tadj Oreszczyn and Robert Lowe
- University of Dundee
  Claire Halpin
- University of East Anglia
  Jacquie Burgess
- University of Edinburgh
  Robin Wallace
- University of Glasgow
  Richard Cogdell FRS
- Imperial College London
  Nigel Brandon
- University of Leeds
  Jenny Jones and William Gale
Annex D: Supporting Evidence and Information Provided

- The University of Manchester
  Adisa Azapagic
- University of Nottingham
  Colin E Snape
- University of Oxford
  Patrick Grant
- University of Plymouth
  Martin Attrill, David Wheeler and Deborah Greaves
- University of Sussex
  Jim Watson
- University of York
  Howard Wilson
- UK Energy Research Centre (UKERC)
  Jim Skea

Other Stakeholders:
- BP
  Robert Sorrell
- Doosan Power Systems
  J Farley
- Energy Generation and Supply KTN (Fuel cells and hydrogen stream)
  Celia Greaves
- Heriot-Watt University
  Confidential
- National Grid
  Jenny Cooper
- Northumbria University
  Sara Walker, Nicola Pearsall and Geoff O'Brien
- Chair, Engineering Panel in RAE 2008
  Dame Ann Dowling
- Queen Mary University of London
  Chris Lawn
- Royal Society of Chemistry
  Rebecca Sage
- Society of Biology
  Laura Bellingham
- The Institute of Physics
  Tajinder Panesor
- The Royal Academy of Engineering
  Philip Greenish
- University of Bristol
  Mark Beach
- University of Cardiff
  Tony Moses
- University of Liverpool
  Confidential
- University of Sheffield
  Jim Swithenbank
- University of Southampton
  Neil White, Alun Vaughan and Steven Swingler

Research Group submissions: Energy Research Groups at each institution with which the Panel met were requested to prepare in advance brief details of their strategic plans and individual research activities. A standard template was used to ensure that submissions addressed the Evidence Framework agreed by the Steering Committee. The following institutions/consortia submitted details relating to the projects/groups listed below:

- Aberystwyth University
  Biorenewables & Environmental Change
- Aston University
  SUPERGEN Bioenergy
- British Geological Survey
  CCS, Renewables and Energy Security, Advanced Seismic Techniques
- Centre for Ecology and Hydrology
  Lancaster Environment Centre
- Durham University
  Durham Energy Institute Energy & Society, Physics, New and Renewable Energy SubGroup
- Imperial College, London
  Fuel Cells Network, Oil & Gas Network, Centre for Carbon Capture Storage, Smart Energy Network (Power Engineering), Solar Network
- Lancaster University
  Professor Elizabeth Shove
- Loughborough University
  Low Carbon Buildings, Solar
- National Oceanography Centre
  School of Earth and Ocean Sciences, University of Southampton
- Newcastle University
  Sir Joseph Swan Centre for Energy Research
Annex D: Supporting Evidence and Information Provided

- **Plymouth Marine Laboratory**
  Bioprospecting Group, Carbon Capture Storage Group, Low Carbon Energy Team (Offshore Energy), Socio-economics Group

- **Queen’s University, Belfast**
  Centre for Plasma Physics

- **Rothamsted Research**
  Centre for Bioenergy and Climate Change

- **Tyndall Centre**
  Tyndall, The University of Manchester

- **The University of Manchester**
  Combustion, Marine Energy, Materials Performance Centre, Nuclear Engineering Industrial Doctorate Centre, Nuclear FiRST Doctoral Training Centre, Nuclear Technology Education Consortium

- **UK Energy Research Centre**
  UKERC

- **University College, London**

- **University of Aberdeen**
  The Centre for Transport Research, Institute of Energy Technologies

- **University of Bath**
  Institute for Sustainable Energy and the Environment (I-SEE)

- **University of Birmingham**
  Institute of Energy Research and Policy

- **University of Cambridge**
  Earth Sciences, Paul Dupree, Electricity Policy Research Group, The Martin Centre for Architectural and Urban Studies

- **University of Cardiff**
  Institute of Energy, School of Chemistry/McKeown Research Group, Understanding Risk/School of Psychology

- **University of Dundee**
  Lignin Research Group

- **University of East Anglia**
  School of Environmental Sciences

- **University of Edinburgh**
  Institute for Energy Systems, Scottish Centre for Carbon Storage

- **University of Leeds**
  The School of Process Environmental and Materials Engineering (SPEME)/Bioenergy, Nuclear Research Group, Sustainability Research Institute, Faculty of Engineering/Centre for Computational Fluid Dynamics

- **University of Nottingham**
  Energy Technologies Research Institute

- **University of Oxford**
  Applied Mathematics (Mathematical Institute), Chemistry for Energy, Lower Carbon Futures, Civil Engineering Research Group, Nuclear materials (Materials Department), Ultrafast X-rays & Laser-Plasma Interactions, Solar energy & Photovoltaics, Transport, Transport Studies Unit (School of Geography and the Environment)

- **University of Plymouth**
  Marine Institute

- **University of St Andrews**
  Energy Conversion and Storage

- **University of Surrey**
  Industrial Doctorate Centre (IDC) – Engineering Doctorate (EngD) in Sustainability for Engineering & Energy Systems (SEES), Research group on Lifestyles, Values and Environment - RESOLVE

- **University of Sussex**
  Sussex Energy Group

- **University of Warwick**
  Centre for Fusion, Space and Astrophysics

- **University of Strathclyde**
  Faults and fluid flow (FAFF), Institute for Energy and Environment: Integrated Energy Initiative; SUPERGEN HDPS/HiDEF Consortium; SUPERGEN Wind Energy Technologies Consortium

- **University of York**
  Centre for Novel Agricultural Products (CNAP)/Biology Department, The Green Chemistry Centre of Excellence/Chemistry Department, Plasma Physics and Fusion

The following international and UK collaborating bodies made representatives available to the Panel during their meetings with the institutions:

- Adam Smith Co
- Axeon
- British Petroleum (BP)
Annex D: Supporting Evidence and Information Provided

- Carbon Trust
- Caterpillar
- Department of Energy and Climate Change
- e2v
- E.ON UK
- Environment Agency
- First Group plc
- Fuel Cell Today
- Garrad Hassan and Partners
- INEOS
- International Energy Agency
- Jaguar Land Rover
- National Grid
- National Nuclear Laboratory
- National Renewable Energy Centre
- Navetas
- Rolls Royce
- RWE NPower (Rheinisch-Westfälisches Elektrizitätswerk)

- Serco
- Scottish and Southern Energy plc
- Scottish Hydrogen & Fuel Cell Association
- Strata Technology Ltd
- Unilever

Specific meetings were also held between the Panel and the following:

- Carbon Trust
- Communities and Local Government
- Department for Business, Innovation and Skills
- Department of Energy and Climate Change
- Department for Transport
- Energy Research Partnership
- Energy Technologies Institute
- National Renewable Energy Centre
- Technology Strategy Board
Annex E

SWOT Overview of Recommendations

This summary is made across the recommendations in order to provide an overview. Elaboration can be found in reference to Executive Summary (EX) and Sections (A) to (I).

### Strength

- **(EX, A)** Cross-Council, collaborative efforts between funding sources around energy have achieved significant results and deliver good value, in spite of historical defragmentation. More can be done to impact 2050 in particular on structure and transparency.

- Favourable mechanisms, RCUK, TSB, ETI, regional funding and combinations thereof, support both long-term and applied research with industrial participation.

- **(EX, B)** There is evident commitment from the universities to encourage interdisciplinarity. The universities have made effective use of funding, the SUPERGEN programme in particular.

- **(EX, E)** There is a good pipeline of doctoral students and postdoctoral research associates. Each CDT initiative is effective, more matching future HR needs in academia and industry will be well received.

- **(C, F)** US, China and India collaboration is evident.

- **(C)** Interaction with stakeholders, government and industry is evident.

- **(EX, A)** World class research is evident in strong islands of brilliance.

### Weakness

- **(EX, E)** There is no clear career path within interdisciplinary energy research.

- **(G)** No significant developing countries initiatives or activities fighting energy poverty were identified in the portfolio.

- **(EX, B)** The subject of system analysis, energy buildings and demand side is weak compared to the challenges faced.

- **(EX, B)** Lack of a coherent energy research programme, competition between the funding bodies, a lack of transparency particularly as perceived by the researchers.

- **(C, I)** There is too little SME activity in ratio to large corporation involvement in the UK energy research. It is, however, important to point towards a balance for both the 2020 and 2050 targets, but also balance needs for the rapid maturing industry. Metrics must be applied to meet climate targets.

- **(E)** It appears that programmatic funding (i.e. SUPERGEN) is disconnected from CDTs (mostly due to historical timing).

- **(EX)** Weakly executed or weakly established mechanisms for moving technologies from the research (TRL1, 2) stages to early demonstration, application and deployment (TRL3, 4 and beyond). Close the funding gap, so no opportunities are missed.
Annex E: SWOT Overview of Recommendations

Opportunities

- **(EX, B, E)** Further promotion, recognition and rewarding of interdisciplinary research must be actively identified and implemented.

- **(EX, A)** Provide a common vision and strategy and avoid conflicting priorities, there needs to be a single, well defined, cross-Councils energy research budget. Such a coordinated approach should also enhance the linking of RCUK funds to wider resources. Seek urgently from TSB, BIS, etc. the weighted and prioritised needs for research to fulfil the national policies.

- **(EX, I)** After apportioning the energy RCUK budget, task a standing RCUK body with drawing up a plan and roadmap by which funds will be dispersed in a prioritised way to maximise the probability of achieving balanced progress towards the UK goals and based on the different modes of funding. Metrics is needed; include a plan for development of human capital, in particular development of doctoral students.

- **(B)** Identify best practices from universities where roadmaps include social, economic and technological sciences for greater impact (these collaborations clearly did better than those who didn’t).

- Identify best practices from universities who have excelled; promote these to TRL2 recipients (SME, IND, TSB, ETI, etc.) and generate mechanisms to empower these from RCUK.

- **(E)** Development of MSc energy courses clearly can boost research and CDT programmes (Sussex and Loughborough).

- **(J)** Emerging areas TRL should clearly use best practices from early areas, such as wind. It was claimed that Marine could be the UK’s “Danish Wind adventure”.

- **(EX)** The allocation process for strategic programmes needs to be more transparent and anchored to clear plans to ensure better research community involvement and acceptance as well as a better targeting of deliverables.

- **(EX)** The current level (~20%) of support for open ended programmes is seen as appropriate and should be continued.

- **(B, C)** A clear strategy for interdisciplinary innovation within new additional CDT and complementary programmes over the next 15 years should produce the game changing technologies for impact in 2050.

- **(C)** Flexible IP platforms for energy related dissemination will continue to attract industry for all TRL levels.

Threats

- **(EX, A)** Meeting climate change targets of necessity requires reduction in energy demand across the board. R&D on demand reduction needs a higher profile in the R&D portfolio and may warrant a dedicated programme.

- **(A, D)** Deployment is handicapped in the absence of a credible long-term price on all carbon emissions. Research targets suffer as a consequence.

- **(I)** There are no metrics of research output towards 2050 targets. Coherence must be established across the RCUK with a strong sense of urgency. Even though work has started, there is clear evidence of this existing work already defragmenting.

- **(EX, A, E, I)** Human capital: No metrics or targets for produced “knowledge raw material” (i.e. number of PhDs trained and postdoctoral positions) is implemented. Thus there is no secure pipeline to future research, nor industry acceleration securing 2050 impact (the train for 2020 already left!).

- **(EX, E)** Postdoctoral people are a critical element of the UK’s human capital. To ensure long-term engagement in the UK, there needs to be more attention and resources directed to career paths both in industry and academe. It is recognised that international careers are beneficial.

- **(A)** 2020 targets should be met aggressively through ETI, Carbon Trust, etc. Involving universities too strongly in these activities will
defocus universities from their strengths and severe risk of missing 2050 targets are imposed by placing too much emphasis on applied research now.

- (C) Many institutions demonstrated significant shares of industry funding. Although industrial involvement is highly recommendable and appreciated, there were incidences where one could see the trend would cause the public service obligations to take a step back and end up being counter productive in terms of reaching 2050 targets. The conflict is clearly that the industry is highly active and the public sector is not able to match the industry interest, i.e. the budget is not aggressive enough.

- (A) The funding level for the UK energy research is significantly lower than other key countries.

- (A, E) There is no traction or clear plan for research towards 2050 targets. Lack of long-term policy creates confusion and hinders a coherent long-term development. Also, long-term programmatic investments in research beyond 10 years are required, in order to capitalise.
Annex F

Steering Committee Membership and Role

The Steering Committee membership was as follows:

**Dr Sue Ion (Chair), Independent**
Dr Paul Golby, E.ON UK
Professor Ian Fells, Royal Academy of Engineering
Mr Ian Welch, National Grid
Mrs Catherine Coates, Director, Business Innovation, Engineering and Physical Sciences Research Council (EPSRC)
Mr Adrian Alsop, Director for Research, Economic and Social Research Council (ESRC)
Dr Janet Seed, Associate Director, Science Programmes, Science and Technology Facilities Council (STFC)
Professor Janet Allen, Director of Research, Biotechnology and Biological Sciences Research Council (BBSRC)
Dr Phil Heads, Head of Strategy, Science and Innovation, Natural Environment Research Council (NERC)

Rothamsted Research, Rutherford Appleton Laboratory, Scottish Association for Marine Science, St. Andrews, Strathclyde, Surrey, Sussex, Tyndall Centre, UCL, UEA, UK Energy Research Centre, Warwick, York

- **Select** the **Chair & panel** following community nominations
- **Selection Criteria:** Area of expertise, international balance, industrial representation, gender/age balance

- **Agree on the Evidence Framework:**
  Setting out the high level questions to be addressed by the Review Panel

- **Background data** to be provided to the Review Panel:
  Contextual data available from BBSRC, EPRSC, ESRC, NERC and STFC, bibliometrics, stakeholder consultation, academic/industrial interface

- **Outline** for the Panel's visit to the universities

- **EPSRC** provided **Secretariat** responsible for organisation and planning

**OBJECTIVES of the Steering Committee**

- **Role of the Steering Committee:**
  o Assist in the implementation of the review process
  o Discuss with the Review Panel their findings and provide advice where appropriate
  o Participate in the dissemination of review findings to the wider stakeholder community

- **Select** the **Institutions** to be visited by the Panel: