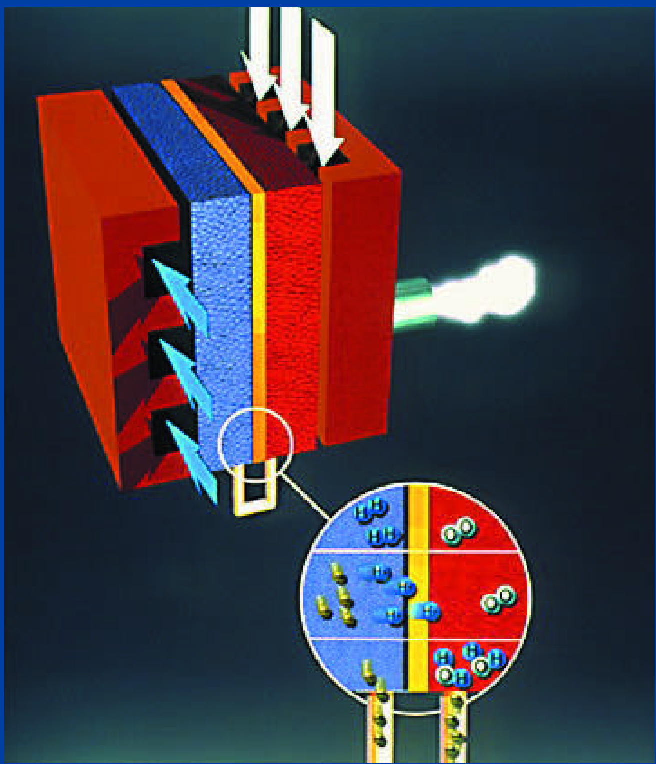
# Chief Scientific Adviser's Energy Research Review Group

## Report of the Group



### Recommendations to Inform the Performance and Innovation Unit's Energy Policy Review

Office of Science and Technology

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*The cover images show a computer illustration of the interior of a hydrogen fuel cell, and a plasma generated in a fusion experiment at the UK Atomic Energy Authority's research laboratory in Culham.*

# CHIEF SCIENTIFIC ADVISER'S ENERGY RESEARCH REVIEW GROUP

## REPORT OF THE GROUP

## RECOMMENDATIONS TO INFORM THE PERFORMANCE AND INNOVATION UNIT'S ENERGY POLICY REVIEW

## EXECUTIVE SUMMARY

1. This report has been prepared by the Chief Scientific Adviser and a group of twelve experts assembled to assist him in a review of Government support for research, development and demonstration activities. The review was commissioned by the Secretary of State for Trade and Industry to inform the wider review of energy policy being undertaken by the Performance and Innovation Unit.

2. The group was asked particularly to consider whether the overall level of expenditure on research, development and demonstration (RD&D) was sufficient, whether it was being targeted at the right areas and who should in future maintain an overview of expenditure.

3. The group agreed that increased RD&D effort was crucial to identifying new energy options which would deliver a secure and sustainable supply of energy with substantially lower carbon emissions. It welcomed the steps the Government was already taking to encourage innovation and the transition to a low-carbon economy.

4. The group concluded, however, that the UK's spending on RD&D should be raised to bring it more in line with that of its nearest EU competitors. The group laid particular emphasis on the importance of building a strong base of fundamental research activity. It felt that energy was still an insufficiently high priority for academic research and that the leading edge science was now going on elsewhere in the world. Consequently, UK companies could lose out on the opportunity to capitalise on publicly funded research and take advantage of the growing export market for energy and low carbon technologies.

5. The group believes that work is required to assess, quantify and seek remedies to any skills gaps in the UK energy sector.

6. The group called for more socio-economic research into the various factors that determine the uptake and successful commercialisation of new technologies, including the regulatory climate, the impact of fiscal incentives and public perception of environmental effects and lifestyle changes.

7. The group identified six broad areas of scientific research which it felt had the strongest case for being treated as priorities, based on criteria which included the degree of technological potential or 'headroom' for research to yield step-change benefits. These were: $CO_2$ sequestration; energy efficiency; hydrogen production and storage; nuclear power; solar

photovoltaics; and wave and tidal power. With regard to nuclear power, the group considered that, whether or not there is any commitment to new nuclear build, the priority for publicly funded research should be research into the handling and storage of nuclear waste. More generally, it emphasized the importance of exploring how different technologies could interact and the centrality of infrastructure issues to the commercialisation of alternative energy options.

8. The group noted the difficulties it had encountered in obtaining data on precise levels of spending in particular areas. It recommended that a suitable body be given the task of collecting and co-ordinating such data.

9. It also called for the establishment of a dedicated national research centre to boost the profile of energy research and attract high-calibre scientists into the field. The group emphasized that such a centre should be based on a multidisciplinary approach and would need to stimulate research into a range of cross-cutting technologies in order to support advances in the six key areas it had identified during the course of its work.

10. Finally, the group concluded that its review had raised many relevant issues which it had not had time to explore fully in the short time available for its work. It recommended that the Government find means to continue a strategic exploration of such issues, including the legislative and regulatory drivers for research, energy storage technologies and infrastructure, and socio-economic research. More detailed recommendations could then be developed.

11. The full set of the group's recommendations is in the following section.

## RECOMMENDATIONS

*Recommendation 1: Given their importance in determining the level and type of energy research being undertaken in the private sector, as well as the commercial uptake of technologies, there should be further strategic investigation and appropriate research into non-technical policy drivers, including regulatory as well as social, commercial and economic drivers. Particular attention should be paid to understanding the market context into which new technology is deployed.*

*Recommendation 2: Government should have regard to the impact which different accounting treatments have on how the environmental costs and benefits are assessed when evaluating different energy options.*

*Recommendation 3: In allocating funding for publicly supported energy research programmes, the Government should ensure that there is a sufficient focus on basic research activities.*

*Recommendation 4: Government should encourage and support more cross-boundary research to look at how different technologies might be optimised to deliver overall energy policy objectives.*

*Recommendation 5: Energy research and its proper co-ordination should be key priorities for Government. Spending, over time, should be brought more in line with that of our nearest industrial competitors in Europe. The opportunities for increasing co-operation with the European Commission and other EU Member States in jointly funded programmes and projects should also be considered.*

*Recommendation 6: Further work is required to assess and quantify the extent of skills gaps in the UK energy sector, and seek remedies to them.*

*Recommendation 7: Research is needed to support the continuing development of all the relevant technologies and practices, including the underpinning sciences. The following were identified as key areas:*

- *$CO_2$ sequestration;*
- *energy efficiency;*
- *hydrogen production and storage;*
- *nuclear power (nuclear waste);*
- *solar PV; and*
- *wave and tidal power.*

*Recommendation 8: There should be increased support for important cross-cutting energy efficiency technologies such as innovative software and hardware for energy management systems, sensors and controls, and for research into energy strategies and systems analysis. Projects which combine several energy efficiency technologies to demonstrate their cumulative impact and improve understanding of their relative contributions and interactions may be particularly advantageous.*

*Recommendation 9: The Government's research programme has thus far incorporated research on hydrogen into its work on fuel cells. It is now appropriate to establish a dedicated hydrogen research programme which would complement the continuing work on fuel cells. Research priorities should include storage technologies, particularly those which could lead to a step change in performance, and sustainable methods of hydrogen production. There should also be a limited demonstration programme.*

*Recommendation 10: The key priority for publicly funded research in relation to nuclear fission should be to improve the methods by which nuclear waste and spent fuel can be safely and cost-effectively handled and stored. Even if there were to be no new commitment to nuclear build, the need to deal with legacy wastes argues strongly for a research programme aimed at finding innovative ways of treating them.*

*Recommendation 11: With regard to nuclear fusion, priority should be given to work on materials capable of withstanding the heat and plasma fluxes in an operating fusion reactor for a sufficient length of time. Without such materials, realising nuclear fusion's potential as an energy source may not be possible.*

*Recommendation 12: R&D on novel emerging PV material systems such as organics/polymers could provide step-change decreases in the cost of production. Given that this is the case, it may be advantageous for the UK to focus efforts more on these innovative 'next generation' technologies and the associated systems.*

*Recommendation 13: A suitable body should be entrusted with the mission of collecting and co-ordinating information, so that policy makers and research planners in this area are able to avoid unwittingly funding activity which is already adequately supported elsewhere, or neglecting a strategic requirement because of inadequate or mistaken information about what others are doing. The body carrying out the task would need to be seen as independent and have access to the necessary data, or the powers to collect such data. Such a body need not be located in government, although if it were, it ought to be placed so as to access the relevant expertise.*

*Recommendation 14: Consideration should be given to setting up a dedicated national energy research centre. We welcome the proposals for such a centre currently being developed jointly by the Research Councils in collaboration with others. We also welcome the interest being shown by universities, business, the Energy Saving Trust and the Carbon Trust. Such a centre should be the hub of a wider network encompassing new and existing centres of excellence in specific areas.*

*Recommendation 15: The Government should find means to continue a strategic exploration of a wide range of relevant issues, including those raised by the review's original terms of reference as well as issues such as legislative and regulatory drivers for research, energy storage technologies and infrastructure, and socio-economic research. This would enable those charged with the task to work up more detailed recommendations based on the outline which we have set in place.*

**CHIEF SCIENTIFIC ADVISER'S ENERGY RESEARCH REVIEW GROUP**

**REPORT OF THE GROUP**

**RECOMMENDATIONS TO INFORM THE PERFORMANCE AND INNOVATION UNIT'S ENERGY POLICY REVIEW**

## Introduction

1. This Group was invited by the Government's Chief Scientific Adviser (CSA) to help him in a review of energy research. The review was commissioned by the Secretary of State for Trade and Industry. Its terms of reference were set out as follows:

   "The group will examine those programmes funded by Government to support energy research, (the term "research" to be understood as including development and demonstration activity) into energy technologies, including those associated with transport and energy efficiency as well as new energy sources. It will consider:

   (i) whether the overall level of expenditure is sufficient in the light of expected future energy needs and the capacity of established technologies to meet them;

   (ii) whether expenditure is being deployed appropriately and whether more resources should be directed towards areas currently receiving little or no Government support when account is taken of activity undertaken elsewhere; and

   (iii) who should be responsible for maintaining an overview of expenditure across Government.

   "The group's recommendations will inform the conclusions of the Performance and Innovation Unit's Energy Review."

*Timescale*

2. The group was assembled during the course of August and early September 2001, and asked to provide recommendations to the PIU's Energy Review by the end of November. In view of the limited time available to us, we have sought to focus on recommendations which draw out the broad themes. These recommendations, if accepted, will need to be filled out by further detailed work, which is beyond the scope of our immediate remit.

*Membership of the group*

3. The members of the group were drawn from experts in the energy field, from industry, academia and government. The membership is set out in full at Annex A. We were supported by a secretariat comprising officials from the Office of Science and Technology and the Energy Group of DTI. We were very grateful to Dr Tariq Ali of Imperial College, who acted as Technical Secretary to the Group. In forming our recommendations, we drew significantly upon a scoping study on low-carbon technologies carried out by Imperial College on behalf of the Carbon Trust, and published in September.

*Information gathering*

4. The Group met three times, on 27 September, 5 November and 21 November.

5. At our first meeting we had the benefit of evidence assembled by the secretariat from sources including UK government data, information from the Research Councils, overseas governments, the IEA Energy R&D Review 2000, and from consultations carried out with academics.

6. At the Group's second meeting, we heard evidence from experts in a number of particular areas, limited by the time available, where we felt more information was needed. These included solar photo-voltaics (PV), energy efficiency, radioactive waste handling, combined heat and power (CHP) and carbon sequestration. The secretariat held an open meeting on 29 October, which provided an opportunity to gather wider informed views.

7. In reaching our views, we have taken account of the broader context in which our recommendations need to be set. This includes not only the emerging work of the PIU on energy policy, but also the Royal Commission on Environmental Pollution's report – *Energy the Changing Climate* – and its scenarios for achieving 60% cuts in carbon dioxide emissions by 2050.

8. We also considered IEA figures on international government spending[i] and more recent data on spending by our key industrial competitors gathered for the purposes of this review, illustrative figures on private sector spending[ii] and IEA figures on the long-term trend in public spending in the UK[iii].

<u>General observations</u>

*Scope*

9. A preliminary issue concerned how widely our review work should range. Conventional definitions of 'research' in the energy area, and the terms of

reference for this study, include not only development, but also demonstration activity ("RD&D"). Accordingly, wherever the word 'research' appears in our report, it should be taken to include both demonstration and development activities.

10. The focus of the terms of reference require us to make recommendations relating primarily to government research. However, this cannot be looked at in a vacuum. Decisions on programmes and priorities need to take account not only of what industry is working on, but also the broader framework of government involvement in the energy sector and what is going on outside the UK.

*Wider Government Support*

11. We also noted, and welcome, the measures the Government has been taking to encourage innovative energy options. We recognize the importance of creating a climate in which viable new technologies can be readily commercialised and in which there are strong incentives to undertake the research which will yield such technologies. For example, the Renewables Obligation (which obliges all electricity suppliers to supply a specified proportion of electricity from renewable sources and is expected to cost consumers about £780 million per annum by 2010) and the exemption from the Climate Change Levy of electricity and heat generated from renewables should act as stimuli to the uptake of new technologies and further research. We note also that additional funding of some £260 million over the next three years has been made available for renewables projects. Some of this will be invested direct into research, although a substantial proportion will go towards capital grants to support deployment of well developed near-market technologies such as offshore wind and energy crops.

12. We also noted that, over the next two to three years, around £400 million per annum will be spent on the installation and promotion of energy efficiency measures in the domestic sector under schemes such as the Energy Efficiency Commitment, Warm Front and the Community Energy Programme, and through the work of the Energy Saving Trust. In the business and public sectors, the Carbon Trust will promote energy efficiency through the Energy Efficiency Best Practice Programme, develop and promote the Enhanced Capital Allowances scheme, and provide support for research and innovation. Around £150 million per annum will be available for these activities. We understand that higher standards of insulation in all new buildings and minimum efficiency standards for replacement boilers and windows should be set by the new Building Regulations, due to come into force in 2002. We note also the intention of the Government's Market Transformation Programme to encourage higher minimum efficiency levels for domestic electrical equipment.

*Non-technical drivers*

13. Although energy research can bring about technological developments, those developments will only be successfully translated into changes in the way we use energy if the relevant non-technical drivers, such as commercial, regulatory and fiscal drivers, are arranged coherently so as to encourage the private sector to do the research and marketing needed to bring the technologies into day-to-day use.

14. Different drivers have different lead times and impact in different ways. For example, fiscal incentives are probably more effective for near-market technologies than for those needing longer-term research because of uncertainty over how long a particular fiscal régime will remain unchanged.

15. It has been argued that regulation and economic incentives can promote the development of cleaner technologies by stimulating innovation (the 'Porter hypothesis'). Regulatory standards, with sensible lead times, could be an important instrument in stimulating basic research in the UK, particularly where the standards set are unattainable with current technologies. Such an approach can encourage industry to move into areas where substantial research is needed. We noted the example of California, where new legislation on car exhaust emissions forced the development of catalytic converters capable of reaching previously unachievable standards. Further theoretical and empirical research is needed to test the Porter hypothesis.

16. We also believe that research is needed on socio-economic aspects of technology development. These include research on consumers' attitudes and behaviour towards energy efficiency and new supply technologies, public perceptions as to the environmental effects and the impact of changing lifestyles and patterns of growth and development.

17. A range of policy instruments will be needed, but Government should keep in mind their overall effect on innovation and their interdependency.

*Recommendation 1: Given their importance in determining the level and type of energy research being undertaken in the private sector, as well as the commercial uptake of technologies, there should be further strategic investigation and appropriate research into non-technical policy drivers, including regulatory as well as social, commercial and economic drivers. Particular attention should be paid to understanding the market context into which new technology is deployed.*

*Costing energy options*

18. We also consider that approaches to costing are key to the evaluation of alternative sources of energy. It may be reasonable to deem one source of energy 'uneconomic' relative to another when the differences in cost between the two are very large, no matter what methods of accounting are used. But great care needs to be taken when making such calculations.

The outcome depends on how costs are attributed, for example, whether the costs of environmental damage are included or excluded, how the relative maturities of supply technologies have been taken into account, and on the magnitude and form of the discount rate employed. Sustainable development demands fundamental changes in the way environmental costs and benefits are included in comparisons of alternative methods of energy generation.

*Recommendation 2: Government should have regard to the impact which different accounting treatments have on how the environmental costs and benefits are assessed when evaluating different energy options.*

*Research programme planning*

*19.* We believe that programme planners should not automatically assume that technologies will progress in an orderly and essentially predictable fashion through the various phases of transition to market (basic research, applied research, development, prototype, demonstration and full commercialisation). Neither should they assume that the time horizons for each stage can be predicted with confidence. Innovation is a complex, iterative process, and programmes should be designed to take account of this. A range of basic and applied research, development and demonstration activities is of importance to the majority of energy technologies, including mature technologies. It is particularly important to have adequate emphasis on basic research, as it is from such research that step-change breakthroughs in technology are more likely to come.

*Recommendation 3: In allocating funding for publicly supported energy research programmes, the Government should ensure that there is a sufficient focus on basic research activities.*

20. Furthermore, we noted that conventional energy research is often vertically divided, so that research looks at improving the use of individual fuels, or energy use in particular industrial, commercial or domestic sectors. There needs to be more ‘cross-boundary’ and ‘systems’ research, looking at how different technologies might be optimised to deliver the overall objectives. One example of the type of interaction that could be analysed might be that between very high insulation levels, micro-CHP and other energy generation technologies.

*Recommendation 4: Government should encourage and support more cross-boundary research to look at how different technologies might be optimised to deliver overall energy policy objectives.*

<u>Adequacy of overall levels of expenditure</u>

21. The first of the specific issues we were asked to address was whether the overall level of expenditure was sufficient in the light of expected future energy needs and the capacity of established technologies to meet them.

22. As the DTI Energy Group's draft R&D strategy recognises, rigorous and demanding environmental emissions targets are in prospect, and we face a decline in the availability of fossil fuels. The demand for electricity is likely to continue to increase, the scope for switching to gas-fired generation will decrease, and, on current Government policy, the UK's existing nuclear generation capacity will be progressively diminished. New and renewable sources of generation will be required to make an increasing contribution towards the provision of secure, diverse and sustainable energy supplies in the future. We endorse this analysis and are fully supportive of the steps that the Government has taken to set targets for renewable energy and introduce a range of mechanisms to achieve those targets. Clearly, in order to meet them and, particularly, the long term environmental challenges such as those outlined by the RCEP, we will need innovative technological solutions fuelled by a strong research base.

23. In its draft strategy the Energy Group refers to the difficulty of making international comparisons of energy R&D on the basis of effectiveness or outcome. In the absence of such measures, international comparisons of funding are one way of benchmarking ourselves. Whilst accepting that the IEA data may be subject to inconsistencies and omissions, and therefore that any figures need to be treated with caution, we note that, according to the IEA, the US spent over $2bn on energy R&D in each of the years 1998 and 1999, France over $550m in 1998 and over $650m in 1999, Germany around $300m in 1998 and 1999, and Netherlands well over $100m in 1998. By contrast the UK was reported as spending around $75-85m in the same years.

24. Furthermore, information we gathered on current UK spending and on international spending from UK embassies suggest that, although UK spend is beginning to rise with substantial commitments to stimulate the market for renewables, the relative figures for more fundamental research remain broadly unchanged. We recognise there are difficulties of comparison where the data may be inconsistent, and of deciding which of our competitors should be the appropriate comparator, given that each has its own unique national circumstances. Nonetheless, even allowing for these factors, it is difficult to avoid the conclusion that the UK is significantly underspending on energy research by comparison with some of our industrial competitors. We note that the Foresight Panel looking at zero-emission power generation technologies, felt that the basic message of the IEA figures was beyond doubt: a significant increase in funding would be needed if the UK were to be a leading player in the field and thereby able to participate in and benefit fully from international collaborations.

25. The Energy Group's draft strategy recognises that, notwithstanding concerns about the accuracy of the reporting on which they are based, IEA data suggest that UK public expenditure on energy related R&D may have

declined more rapidly than that of most OECD countries. The IEA publication *Energy Technology R&D Statistics 1974-1995* reports a ten-fold real terms decrease in UK public R&D over that period, with a distinct downward trend from 1984 onwards (at 1995 prices and exchange rates, falling from $744.42m to $81.79m in 1994 and $83.45m in 1995).

26. We noted in particular that, before the era of privatisation, the nationalised energy industries in this country provided an important source of research effort. As a result of privatisation this activity was transferred to the private sector. Whether it still continues, and the contribution it makes to the UK's energy effort, is difficult to measure. The apparent decline in research from this quarter may well have been an important contributor in the apparent decline in the UK's efforts. We were not able to determine precise levels of spending on energy research across industry. However, the tables on industry research budgets which can be found at Annex B may be helpful in offering a broad illustration of overall research spending in energy sectors.

27. We noted that the Government has been taking initiatives that would have as their effect a reversal of the previous decline. We welcome these measures. As regards spending on basic research, the Research Councils are expecting to spend around £5 million annually on renewables research over the next few years. This will be boosted by £10 million (over three years) earmarked for 'blue skies' research from the £100 million fund for support for renewables whose allocation was announced on 5 November. We also noted that energy research in a broader context was being considered as a priority for the Science Base in the next Spending Review, and that the Research Councils had assembled a proposal for a comprehensive sustainable energy technology programme. These sums should help enhance the level of basic energy research in the UK.

28. As regards funding for more applied research and development and demonstration activities, the DTI Energy Group has a budget of £55.5 million (over three years) for its New and Renewable Energy R&D Programme. In addition, some of the £100 million fund for support for renewables (mentioned in the preceding paragraph) will be allocated to RD&D activities, including £5 million for the demonstration of wave and tidal technologies and £18 million for the development and demonstration of advanced energy crops. There is a budget of £21.7 million (over three years) for cleaner coal R&D. Around £7.5 million per annum[1] is going towards research into nuclear fusion and around £3 million towards oil and gas (approximately £1.5 million of which is accounted for by research to support DTI's regulatory function). We also note that the Carbon Trust will be providing around £25 million per year over the next three years to fund

[1] On the domestic research programme. The UK also pays a hosting fee of £6.8m for the Joint European Torus experimental reactor and contributes about £23.5m to the Euratom fusion budget. The UK funds a programme of safeguards work carried out by the International Atomic Energy Agency, but this relates primarily to security of nuclear materials rather than to the development of nuclear power as an energy source.

research into low-carbon technologies and to promote their market deployment.

29. Nevertheless, our view is that energy research is not seen as a sufficiently high priority for academic study in this country, and the leading edge science is now going on elsewhere in the world. Furthermore, the seriousness of the challenges facing us in achieving greenhouse gas (GHG) emissions reductions and a secure and sustainable energy supply, means that energy research as a whole is of vital importance to all our futures.

*Recommendation 5: Energy research and its proper co-ordination should be key priorities for Government. Spending, over time, should be brought more in line with that of our nearest industrial competitors in Europe. The opportunities for increasing co-operation with the European Commission and other EU Member States in jointly funded programmes and projects should also be considered.*

30. In addition to recommending higher levels of funding to bring the UK's research profile, over time, more in line with that of our nearest EU competitors, we put a marker down that work is required to assess, quantify and seek remedies to any skills gaps in the UK energy sector. The pace at which spending can be increased will need to be determined by the capacity of the research community to absorb the new funding and put it to effective use.

*Recommendation 6: Further work is required to assess and quantify the extent of skills gaps in the UK energy sector, and seek remedies to them.*

*Rationale for intervention*

31. It could be argued that we should allow the decline to continue, and "buy in rather than build" the new technologies we shall need to meet any reasonably foreseeable objectives for our future energy and climate change policies. We believe this would be a mistake. It cannot be assumed that the technology which is available off the shelf will be immediately capable of application in the UK. Equally we should not seek to build an energy research programme as if the UK were to operate as an isolated player independent from the rest of the world. Nor would it be right to develop an energy research programme entirely on the basis of the commercial advantage it might bring to UK companies.

32. In the meantime, our companies will have been unable to draw on the output of publicly funded research in a way that their competitors in, say, US and Japan have been able to do. UK companies may well have been unable to capitalise fully on opportunities in the growing world export market for technologies and associated components.

33. We believe the rationale for funding is well set out in the Energy Group's draft strategy paper, namely that social rates of return on some R&D, for

example energy technologies that can contribute to environmental problems and which involve lengthy development timescales, are higher than private rates of return. Investment in these areas is therefore likely to be low without Government support or intervention. Examples are where environmental costs will not be fully reflected in market prices, where the 'free rider' problem exists, where there are market barriers to entry such as predatory pricing or action by incumbents, or where markets fail to realise innovation benefits because of lack of information or difficulties in sharing costs and benefits.

*Deployment of resources*

34. The second of the specific issues we were asked to address was whether expenditure was being deployed appropriately, and whether more resources should be directed towards areas currently receiving little or no Government support when account is taken of activity undertaken elsewhere.

35. So far as the current programme is concerned, we start from the view that we need a broad-based research strategy, capable of responding to all reasonably foreseeable energy policy objectives on timescales which deliver effective solutions. In the discussion which follows, we have identified those broad areas which we feel merit priority in any analysis of where future spend should be directed. There are of course other areas which, in time, may prove equally important. However the technologies we have identified are the ones which we felt currently had the strongest case for being treated as priorities, on the basis of criteria which included the degree of technological potential or 'headroom' for research to yield step-change benefits.

36. Nevertheless, we reiterate the importance of a broadly based strategy so that the UK can seek both to find innovative solutions and keep a range of energy supply options open. We recognise that any prioritisation will be viewed as an attempt to 'pick winners' by those who believe they may have lost out from the exercise. Nonetheless any research programme, no matter how large, will have some element of constraint in terms of what can be funded. An element of selection will always be unavoidable. We see this document as the beginning of a debate to which we anticipate many will wish to contribute.

*Policy Drivers*

37. It is clearly important that the government's energy research and associated infrastructure strategy and priorities should be capable of delivering the government's energy and climate change policy objectives. But the time horizons for energy research planning are often long, and well beyond the planning horizons of day-to-day or even medium-term policy makers. These long timescales imply a degree of uncertainty about the detail of future energy policy, and require the setting of research strategies and objectives which are sufficiently robust to be relevant irrespective of

possible changes of political direction, 'shocks' such as the oil price rises of the 1970s, and the setbacks to the development of nuclear power such as Chernobyl in the 1980s, or, potentially, the need to make faster progress towards GHG emissions reductions and a low carbon economy. Accordingly while our priority selection was informed by current policy considerations and by the PIU's developing work on energy policy objectives, we sought also to set them in the context of the most stable and definite assumptions we could make about the long-term policy drivers for energy research priorities.

38. Against this background, the long-term drivers which we saw operating were as follows:

- the need to mitigate the adverse environmental impacts of energy supply technologies, in particular global warming, with the concomitant imperative to take action, nationally and internationally, to reduce $CO_2$ and other GHG emissions;

- the need for a secure and sustainable energy supply to meet national needs as they develop in coming decades;

- the long-term depletion of fossil fuel reserves, particularly oil and gas; and

- the need for energy solutions to be consistent with maintenance of the UK's international competitiveness (including the fostering of international collaboration where it would be beneficial) and hence preservation of economic growth and living standards.

*Priority areas for research*

39. We considered a range of technologies which we saw as having the potential to contribute to meeting the challenges posed by these long-term policy drivers. These technologies were assessed against a set of criteria[iv] designed to enable an assessment of how far the technological developments would be capable of having a strategic impact on the policy drivers identified. The various technologies were also assessed against three further criteria based on the 'deliverability' of their potential benefits. These criteria included the development and technological potential: in other words the degree of 'headroom' or the capacity for research in that area to yield step change benefits, based on whether the technology was growing, mature, or ageing. Finally, in reaching our judgements, we took account of the expertise available from both within the group and from those whose evidence we heard. The analyses, which drew in large measure upon work done by Imperial College for the Carbon Trust, are set out in full at Annex C. The data we were able to gather are set out at Annex B.

40. These analyses identified two broad groups of technologies and practices which merit detailed consideration.

41. First, there are those with good medium term prospects, capable of yielding continual but incremental reductions of carbon emissions, either (a) through improvements in the efficiency with which energy is used or (b) through reductions in carbon emitted per unit of energy use. These include energy efficiency improvements in buildings, industry, transport and electricity supply from fossil fuels; renewable energy from biomass and onshore and coastal wind; carbon separation and sequestration with or without fossil fuel gasification; and micro-turbines for distributed generation and heat (CHP).

42. There is a second group of technologies with good long-term prospects of yielding very large reductions of carbon emissions, i.e. key step-change or ‘disruptive’ technologies on the path to a low carbon economy. These include: solar PV, offshore wind, wave and tidal energy; storage systems for stationary and transport applications, hydrogen production, distribution and storage technologies; and fuel cells for transport, and for distributed generation and heat (CHP).

43. To these groups we also added nuclear power. We see it as an exceptional case, given that the major constraint on its use is the need to find a scientifically, socially acceptable and cost-effective answer to perceived health and safety risks associated with the operation and decommissioning of nuclear plant and the handling and disposal of waste products. However, if these problems could be solved, nuclear power has the potential to make a significant contribution to a low-carbon economy.

44. From these broad groups of technologies we would focus on six areas (listed in alphabetical order) for which increased levels of funding could have a particularly significant impact on our progress to a low-carbon economy.

*Recommendation 7: Research is needed to support the continuing development of all the relevant technologies and practices, including the underpinning sciences. The following were identified as key areas:*

- *$CO_2$ sequestration;*
- *energy efficiency;*
- *hydrogen production and storage;*
- *nuclear power (nuclear waste);*
- *solar PV; and*
- *wave and tidal power.*

45. We have not ascribed an internal ranking within the six, and we believe that they should be accorded equal priority. There is no magic about having six areas, and we could have settled for slightly fewer or slightly more. However, we were conscious that programmes based on too few priorities could be unbalanced, and that setting out too many priority areas would devalue the exercise for research programme planners.

46. It is possible that further work to look strategically at energy research could identify additional priorities, or that further research in the years to come will alter our view of what the priorities should then be. For example, we noted that there were some good arguments for including biomass and energy crops on a priority list, although we were unable to reach a consensus on whether this area offered the same 'headroom' for technological development as others on the list.

47. Development of the key areas would be dependent on boosting high-quality research in a range of cross-cutting disciplines, including materials science and superconductors.

48. A detailed expansion of the analysis below can be found at Annex C, including supporting evidence for the categorisations used in the matrices.

*$CO_2$ Sequestration*

| CO2 Sequestration | Strategic Impact | | | | Deliverability | | |
|---|---|---|---|---|---|---|---|
| | Impact on Energy Efficiency/ Carbon Intensity | Competitive Advantage | Impact on Energy Security | Impact on UK's Technological capabilities | UK Competitive Position | Development Status and Technological Potential | Barriers to commercialisation |
| CO2 Separation | High | High | High | Moderate | Favourable | Mature | High |
| Geologic Storage of Carbon Dioxide | High | Low | High | High | Strong | Growing | Moderate |

49. The main constraint on the continued use of fossil fuels, particularly coal, is their emission of GHGs when burnt. Worldwide reserves are such that coal could prove a viable long-term resource if the problem of high levels of GHG emissions can be overcome. Coal could make a considerable contribution to maintaining the UK's energy security.

50. Technology to sequester $CO_2$, through separation and geological storage, has the potential to provide a solution to the pollution caused by the burning of coal. Such technology would also have considerable export potential, as it is likely coal will remain a plentiful source of energy in many of the world's regions over the next half-century and further into the future.

51. In terms of its state of technological maturity, the technology of $CO_2$ capture is well understood, but the technology of storage is still relatively underdeveloped. Demonstration activity may well be a priority for capture, but more fundamental research needs to be undertaken into the long-term feasibility of geologic storage and the potential environmental and safety concerns arising from it. The UK is well-placed to take a lead, because the North Sea offers opportunities to use $CO_2$ for enhancing oil production, while exhausted fields provide possible storage facilities.

52. The DTI has been conducting a review of the case for Government support for a cleaner coal technology demonstration plant. This review

appears to be reaching a very similar conclusion to ours on the potential of $CO_2$ sequestration.

## *Energy Efficiency*

| Energy Efficiency –Buildings | Strategic Impact | | | | Deliverability | | |
|---|---|---|---|---|---|---|---|
| | Impact on Energy Efficiency/ Carbon Intensity | Competitive Advantage | Impact on Energy Security | Impact on UK's Technological capabilities | UK Competitive Position | Development Status and Technological Potential | Barriers to commercialisation |
| Building Envelope Improvements: Window and Insulation Retrofits | Moderate | Moderate | Moderate | Moderate | Favourable | Mature | Low |
| Building Heating and Cooling Technologies* | Moderate | Moderate | Moderate | Moderate | Favourable | Mature | Moderate |
| Efficient Lighting | Moderate | Moderate | Moderate | Moderate | Tenable | Aging (but light emitting diodes growing) | Low |
| Building Energy Management Systems | Moderate | Moderate | Low | Moderate | Favourable | Mature | Low |
| Standby Losses | Moderate | Moderate | Moderate | Moderate | Tenable | Mature | Low |

| Energy Efficiency - Transport | Strategic Impact | | | | Deliverability | | |
|---|---|---|---|---|---|---|---|
| | Impact on Energy Efficiency/ Carbon Intensity | Competitive Advantage | Impact on Energy Security | Impact on UK's Technological capabilities | UK Competitive Position | Development Status and Technological Potential | Barriers to commercialisation |
| Advanced Internal Combustion Engines | Moderate | Low | Low | Moderate | Strong | Mature | Low |
| Hybrid Vehicles | High | Moderate | Low | Moderate | Favourable | Growing | Moderate |
| Fuel Cell Vehicles | High | High | Moderate | High | Strong | Growing | High |
| Low weight, low energy loss design | Moderate | Low | Moderate | Moderate | Strong | Mature | Low |
| Traffic management systems | Low | Low | Low | Moderate | Favourable | Mature | Low |

| Energy Efficiency – Industry | Strategic Impact | | | | Deliverability | | |
|---|---|---|---|---|---|---|---|
| | Impact on Energy Efficiency/ Carbon Intensity | Competitive Advantage | Impact on Energy Security | Impact on UK's Technological capabilities | UK Competitive Position | Development Status and Technological Potential | Barriers to commercialisation |
| High-Efficiency Motors, Drives and Motor-Driven Systems | Moderate | Moderate | Moderate | Moderate | Favourable | Mature | Low |
| High Efficiency Separation Processes | High | Moderate | Moderate | Moderate | Favourable | Growing | Moderate |
| Advanced End-Use Electro-technologies | Moderate | Moderate | Low | Moderate | Favourable | Mature | Moderate |

* These comprise not only traditional boilers, but micro-CHP, ground-sourced heat pumps etc.

| Crosscutting Technologies | Strategic Impact | | | | Deliverability | | |
|---|---|---|---|---|---|---|---|
| | Impact on Energy and Carbon Intensity | Competitive Advantage | Impact on Energy Security | Impact on UK's Technological capabilities | UK Competitive Position | Development Status and Technological Potential | Barriers to commercialisation |
| Sensors and Controls | Moderate | Low | Low | Moderate | Favourable | Mature | Low |
| Power Management | Moderate | Low | Moderate | Low | Favourable | Mature | Low |
| Combined Heat and Power | High | Low | Moderate | Moderate | Tenable | Mature | Moderate |
| Process Integration | Moderate | Moderate | Low | Very High | Dominant | Mature | Low |

53. Although technologies aimed at improving energy efficiency may individually offer relatively small contributions to achieving solutions to our energy and climate change policy challenges, we considered that their cumulative and incremental effect could be considerable. We heard from many quarters the view that energy efficiency alone could make the biggest single contribution to achieving any reasonable set of energy and climate change policy objectives within the key policy drivers that we identified. We also took note of the view among some experts that energy efficiency measures will only be taken seriously once their markets pick up, possibly as a result of higher energy prices or tighter efficiency standards. By the same token, enhanced energy efficiency would also make price rises more palatable to customers, by helping them enjoy the same amenity provision for lower energy consumption. However, we also noted that, for a number of non-technical reasons, many cost-effective opportunities for energy efficiency improvements are not being taken up, which suggests that other ways of influencing behaviour must also be researched and utilised.

54. There were some reasons to regard the UK as being in a relatively favourable position to benefit from developments in energy efficiency technology. The housing stock is old and relatively inefficient at conserving energy. Therefore, for new buildings, and those undergoing significant refurbishment, the Building Regulations could drive research into improving energy efficiency. However, given the age of the UK housing stock and the cultural importance we attach to it, finding suitable new materials and approaches to refurbishment and retro-fit will also be a key approach to increasing energy efficiency in the domestic sector.

55. As a specific technological area, fuel cells in vehicles were considered to have particular promise. Fuel-cell-powered vehicles hold the potential for reducing transport emissions considerably in the decade after 2010. Beyond this time frame the combination of advanced fuel-cell technology and an infrastructure for supplying hydrogen offers the potential for a pollution-free propulsion system, depending on how the hydrogen is produced. The lack of adequate infrastructure and of on-board storage technologies for hydrogen are the greatest obstacles to its use as a transport fuel.

56. CHP also offers considerable potential in terms of improved domestic and commercial energy efficiency and reduced $CO_2$ emissions. In particular, the development of micro-CHP, perhaps initially in the form of engine based units but eventually using fuel cells could have widespread application in small-scale household generation. However this, in common with other forms of embedded generation such as solar PV, would raise a number of technical and commercial issues, which if not resolved, could constrain development. There is therefore a need for research to identify and address these issues if the considerable potential for energy efficiency and $CO_2$ reductions offered by this technology are to be realised. It was noted, however, that CHP might have less to offer in the longer term as more efficient insulation systems are developed and there is less demand for heating.

57. *Recommendation 8: There should be increased support for important cross-cutting energy efficiency technologies such as innovative software and hardware for energy management systems, sensors and controls, and for research into energy strategies and systems analysis. Projects which combine several energy efficiency technologies to demonstrate their cumulative impact and improve understanding of their relative contributions and interactions may be particularly advantageous.*

*Hydrogen production and storage*

| | Strategic Impact | | | | Deliverability | | |
|---|---|---|---|---|---|---|---|
| | Impact on Energy Efficiency/ Carbon Intensity | Competitive Advantage | Impact on Energy Security | Impact on UK's Technological capabilities | UK Competitive Position | Development Status and Technological Potential | Barriers to commercialisation |
| Hydrogen | High | High | High | High | Tenable | Growing | High |

58. We considered that research into the production and storage of hydrogen had the potential to offer step-change benefits to the UK's energy system. In the future, hydrogen may be the key energy vector for portable power, stationary power and transport applications. Hydrogen-based energy systems have great potential as a key enabling technology and could impact positively on all of the UK's long-term policy drivers. For instance, the production of hydrogen through the gasification of coal would release its energy more cleanly and efficiently than combustion, provided $CO_2$ sequestration is implemented. Producing hydrogen through the electrolysis of seawater, powered by renewable forms of energy, could potentially provide a versatile and exceptionally clean method of energy production. Hydrogen storage technologies could offer a way of saving excess power generated by intermittent renewable energy technologies such as wind and solar. It therefore has potential as one possible means of overcoming the problems associated with intermittency, which could be key to enabling the widespread use of renewables. However, we recognise that there are other promising technologies that may prove effective in this role.

59. Hydrogen has great potential as a fuel for cleaner transport through the replacement of the internal combustion engine by fuel cells. Methods of storage could be of key importance, including, for example, the use of compressed gas and liquid hydrogen. These are required because hydrogen is a gas with very low volumetric energy density, and so compression, liquefaction or other means of compact storage are needed for transport applications. Another current area of research is the use of carbon nanofibres, which offers the potential for hydrogen storage at relatively high energy densities near atmospheric pressure and ambient temperatures.

60. Other priorities should include support for the demonstration of hydrogen energy systems and research into hydrogen infrastructure issues, particularly those associated with phasing-in the technology. A hydrogen infrastructure is likely to be developed firstly for niche markets, such as fleet vehicles with standardised trip cycles (e.g. buses or taxis) in urban centres. Further support for demonstration projects, such as the planned hydrogen bus project in London, would be needed.

*Recommendation 9: The Government's research programme has thus far incorporated research on hydrogen into its work on fuel cells. It is now appropriate to establish a dedicated hydrogen research programme which would complement the continuing work on fuel cells. Research priorities should include storage technologies, particularly those which could lead to a step change in performance, and sustainable methods of hydrogen production. There should also be a limited demonstration programme.*

*Nuclear fission and fusion*

| | Strategic impact | | | | Deliverability | | |
|---|---|---|---|---|---|---|---|
| | Impact on Energy Efficiency/ Carbon Intensity | Competitive advantage | Impact on energy security | Impact on UK's technological capabilities | UK competitive position | Development status and technological potential | Barriers to commercialisation |
| Nuclear waste handling and encapsulation | High* | Moderate | High | Moderate | Favourable | Growing | Moderate |

*Assuming the successful resolution of waste issues, both technical and social, facilitates new build.

61. The use of nuclear fission power is not significantly constrained by the need to reduce GHG emissions or by resource depletion. The key constraints on the use of nuclear fission are the health and safety risks associated with the handling and storage of radioactive waste and the decommissioning of plant and the public attitude to those risks, and the consequent costs and regulatory risk for the industry. We noted that the Government is currently consulting on the development of policy to manage radioactive waste in the UK.

62. We believe that, given uncertainty about the future when considering such long timescales, no technological options for energy supply should be ruled out. It is possible that nuclear power could go some way towards developing a low-carbon UK energy economy, particularly if the risks associated with nuclear energy can be minimised and are in future considered to be less than the risks associated with continued fossil fuel supply and use. It is therefore sensible to support research that could help to overcome these risks and maintain this particular option for consideration.

63. Over the next two decades or so, the UK's stock of nuclear generating capacity will be progressively decommissioned, and without new build, the proportion of our energy derived from nuclear will correspondingly diminish. Irrespective of whether there is any commitment to new nuclear build, this will leave a growing legacy of radioactive waste and spent fuel.

64. It is often argued that the current nuclear generating technology such as PWR generates less emissions and less waste on decommissioning than the older generation of stations, such as AGR and Magnox, which make up the bulk of the UK's generating capacity. Whilst this may well be true, public attitudes to new nuclear build may well require research into the handling of the 'legacy' wastes, irrespective of whether the problem of waste would be much diminished if not eliminated by future generations of reactors.

65. Research into the development of any new reactor designs should be chiefly a matter for the industry. In such a scenario the government's role would be to undertake the policy and regulatory research required to be able to oversee the safe operation and eventual decommissioning of such reactors in the UK. We noted that only one university-based reactor remained in operation in the UK and was reaching the stage where decisions had to be made about whether to implement closedown or to refurbish.

*Recommendation 10: The key priority for publicly funded research in relation to nuclear fission should be to improve the methods by which nuclear waste and spent fuel can be safely and cost-effectively handled and stored. Even if there were to be no commitment to nuclear build, the need to deal with legacy wastes argues strongly for a research programme aimed at finding innovative ways of treating them.*

66. <u>Fusion</u> We note that research into nuclear fusion enjoys a relatively high level of funding compared with other potential new energy technologies. The European Union funds a programme, in which the UK is a participant, and the proposed International Thermonuclear Experimental Reactor (ITER) project offers the potential for further collaboration in this area. We note also that, of all the technologies we have studied, fusion has one of the longest projected time horizons to market, and that one of the greatest obstacles to its commercial application could be a lack of suitably robust materials to form the 'first wall' of the plasma containment vessel. If

fusion's potential as an energy research project is to be realised, we believe that priority will need to be given to work on materials. This would be designed to establish conclusively whether materials can be developed capable of withstanding the required levels of heat and neutron flux for sufficiently long without damage to make a commercially operating plant a feasible proposition. If such materials cannot be developed then the long term feasibility of the current generation of experimental magnetic confinement reactors must be in doubt.

*Recommendation 11: With regard to nuclear fusion, priority should be given to work on materials capable of withstanding the heat and plasma fluxes in an operating fusion reactor for a sufficient length of time. Without such materials, realising nuclear fusion's potential as an energy source may not be possible.*

*Solar PV*

| | Strategic Impact | | | | Deliverability | | |
|---|---|---|---|---|---|---|---|
| | Impact on Energy Efficiency/ Carbon Intensity | Competitive Advantage | Impact on Energy Security | Impact on UK's Technological capabilities | UK Competitive Position | Development Status and Technological Potential | Barriers to commercialisation |
| Photovoltaics | High | High | High | High | Tenable | Growing | High |

67. We believe that solar PV is an area of research with a great deal of potential to reduce the carbon intensity of electricity generation. We considered that there were a variety of approaches to achieving practicable solar PV, some well-developed and some at the conceptual/experimental stage. We also considered that further work on the PV/buildings interface would be beneficial in identifying the best use of the power generated, whether that is on-site or as part of a decentralised generation infrastructure.

68. The International Energy Agency estimates that the installed cost of conventional solar PV is reducing by 20-35% for each doubling of the cumulative volume of production. Continued progress at such rates, facilitated by continued support for research projects, means that conventional PV could be competitive within 10-20 years for most applications and sooner for niche applications.

69. However, we also considered that some countries, including Germany and Japan, had a significant lead over the UK in the more established aspects of the technology.

*Recommendation 12: R&D on novel emerging PV material systems such as organics/polymers could provide step-change decreases in the cost of production. Given that this is the case, it may be advantageous for the UK to focus efforts more on these innovative 'next generation' technologies and the associated systems.*

*Wave and tidal power*

| | Strategic Impact | | | | Deliverability | | |
|---|---|---|---|---|---|---|---|
| | Impact on Energy Efficiency/ Carbon Intensity | Competitive Advantage | Impact on Energy Security | Impact on UK's Technological capabilities | UK Competitive Position | Development Status and Technological Potential | Barriers to commercialisation |
| Wave and Tidal Stream | High | High | Moderate | High | Strong | Growing | Very High |

70. We believe that both wave and tidal stream technologies have the potential to play a significant role in helping to meet the challenge of a secure, sustainable, low-carbon energy supply. As the House of Commons Science & Technology Committee noted in its report on wave and tidal energy, the UK has abundant oceanic resources, considerable marine engineering expertise, and a competitive edge in researching the technology. We therefore believe that the UK is particularly well placed to grasp opportunities in this field, but considerable further research is needed. We also note that the predictability of tidal flows would mitigate the problems of intermittency faced by some other forms of renewable energy.

71. One potential problem is the transmission of electricity generated from wave, tidal or offshore wind sources to the centres of demand, which are highest in the south-east of England. As such, we welcome the announcement by DTI of a feasibility study for an undersea power cable running from north-west Scotland to Wales to provide additional electricity infrastructure for new generation capacity.

<u>Who should be responsible for maintaining an overview of expenditure across Government</u>

72. We were asked to consider who should be responsible for maintaining an overview of expenditure across government. We believe that the difficulties this group has experienced in data gathering, which echo those experienced by the Energy Group while putting together its own strategy document, demonstrate the lack of transparency of information in this area. The lack of information on industrial research may reflect the fact that energy utilities are now found far more often in the private sector than used to be the case. The difficulties of obtaining information on overseas activities may be as much a problem of comparability of data, as of accessibility. But some of the difficulties arise from the rather diffuse nature of the UK research effort, divided as it is between DTI, the Research Councils, the Carbon Trust, and, to a lesser degree, the involvement of other government departments, although we noted that these parties are working to co-ordinate their activities.

73. We would question whether any body in or outside government could easily take an overview, unless there is more availability of information, not only about what the public but also the private sector is doing in this area.

*Recommendation 13: A suitable body should be entrusted with the mission of collecting and co-ordinating information, so that policy makers and research planners in this area are able to avoid unwittingly funding activity which is already adequately supported elsewhere, or neglecting a strategic requirement because of inadequate or mistaken information about what others are doing. The body carrying out the task would need to be seen as independent and have access to the necessary data, or the powers to collect such data. Such a body need not be located in government, although if it were, it ought to be placed so as to access the relevant expertise.*

Energy Research Centre

74. We have referred to the relative under-funding of energy research in the UK. The research challenges are many and diverse. Nearly all cross the boundaries of physical science, engineering, environmental science, socio-economic and socio-political sciences, and life sciences. A multidisciplinary approach is essential in this area as the socio-political and regulatory regime, environmental and health impacts and public acceptability must all be taken into account in the development of technological solutions to future energy supply. We believe a UK energy research centre should bring together key stakeholders from government, industry and academia and help enable constructive collaborations to maximise returns from research investments and the leveraging of private sector funds.

75. A centre of this type could become a ‘networking’ centre, and play a key role in co-ordinating UK research, facilitating collaboration with industry and UK participation in international projects, as well as becoming a centre of excellence in its own right. The centre would also signal the importance the UK attaches to energy research, with the aim of attracting high-calibre scientists and graduates into the area and encouraging interdisciplinary working.

76. A possible focus of the research centre could be work on alternative energy futures, integrated assessment models, long-term priority technologies and the energy systems needed to deliver them. To enable these we recognise the crucial role of cross-cutting technologies such as super-conductors, advanced ceramics, carbon nanotubes, control of chemical reactivity, biotechnology and surface chemistry and physics. The centre could also facilitate the collection of reliable, useful and comprehensive energy research data to benchmark the UK against other industrialised nations.

77. The Group did not have time to consider in detail the likely cost of such a centre, but thought that the Hadley Centre for Climate Change, whose annual budget is £10m, represented the type of institution, in terms of mission and scale, which might provide a realistic model for what was needed.

*Recommendation 14: Consideration should be given to setting up a dedicated national energy research centre. We welcome the proposals for such a centre currently being developed jointly by the Research Councils in collaboration with others. We also welcome the interest being shown by universities, business, the Energy Saving Trust and the Carbon Trust. Such a centre should be the hub of a wider network encompassing new and existing centres of excellence in specific areas.*

Next Steps

78. Finally we would wish to place on record the views of the group that the issues raised merit far more exploration than we have been able to give in the time available to us.

*Recommendation 15: The Government should find means to continue a strategic exploration of a wide range of relevant issues, including those raised by the review's original terms of reference as well as issues such as legislative and regulatory drivers for research, energy storage technologies and infrastructure, and socio-economic research. This would enable those charged with the task to work up more detailed recommendations based on the outline which we have set in place.*

Energy Research Review Group

[i] IEA Review of Government Energy R&D Spending 2000
[ii] Financial Times
[iii] IEA Energy Technology R&D Statistics 1974-1995
[iv] Source – Scoping Study on R,D&D options for the Carbon Trust by ICCEPT