



**International Dimensions of Climate Change**  
**Discussion paper 7: The state of climate change**  
**science and technology in the UK**

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# The state of climate change science and technology in the UK

## Introduction

Climate change presents both challenges and opportunities for science and technology. The challenges arise as we try to understand climate change, the processes that drive it and the effects that it could have on our environment and society. The opportunities are in developing better ways to understand climate change and to devise strategies and technologies to mitigate our impact on the environment and to adapt to the changes that will inevitably happen.

In his introduction to the new *Guidelines on the Use of Scientific and Engineering Advice in Policy Making*, the Government Chief Scientific Adviser, Professor Sir John Beddington, writes: “Climate change, security, pressures on the supply of energy, food and water, health and migration pose unprecedented and inter-connected challenges to the world. Science and engineering are central to identifying, understanding and addressing these challenges.”

The importance of science and technology is also clear from the statement by Rajendra Pachauri, chairman of the Intergovernmental Panel on Climate Change (IPCC). “There are huge gaps in the effort as far as scientific research is concerned,” Dr Pachauri said in an interview before last year’s round of climate change negotiations, COP16, in Cancun, Mexico.

This review is a contribution to the Foresight Project International Dimensions of Climate Change (IDCC) which is providing input into the UK Climate Change Risk Assessment (CCRA). The Department for Environment, Food and Rural Affairs (DEFRA) is undertaking the CCRA in accordance with the requirements of the Climate Change Act (November 2008). The CCRA “will assess the risks (and opportunities) to the UK from current and predicted climate change”.<sup>1</sup>

As a part of the IDCC project, the focus of this review is on international developments and their possible impacts on the UK. This review of S&T does not attempt to provide a detailed overview of everything that is going on in UK to address the scientific and technical challenges posed by climate change.

The review draws on various sources, including reports and papers published in refereed journals. Given the extensive nature of the literature, the review cites only a small fraction of the material available. The emphasis is on international reviews. Where appropriate, it also draws on the other papers in the Foresight Project International Dimensions of Climate Change.

The importance of climate change is reflected in the scientific effort that is under way on all three fronts, understanding, mitigation and adaptation. While they inevitably

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<sup>1</sup> <http://www.theccc.org.uk/asc-home/adaptation/climate-change-risk-assessment>

overlap, these three categories are used widely to help to focus the discussion. This review considers each aspect in turn. Within each, the review also considers the key sectors that came up in the initial scoping exercise for the project. These sectors are: Health, Energy supply, Transport, Food and agriculture, National Security and Manufacturing (resources). Not all have equally weight within each section. For example, when considering mitigation of climate change, energy supply is the most significant sector, while consideration of adaptation inevitably weighs more heavily on agriculture than on national security.

## **International implications**

There has been considerable discussion of the likely impact of climate change on the UK, this review looks primarily at the international implications. Here too it helps to think in terms of understanding, mitigating and adapting to climate change.

We will need advances in science and technology to improve our understanding of the effects of climate change, to collect and analyse data. How can the UK contribute to the growing need for information on climate change itself?

What are the threats and opportunities to the UK of the impacts of climate change on other countries? For example, how should the UK, as a large importer of food, respond to agricultural changes elsewhere?

The Adaptation Sub-Committee of the Committee on Climate Change has said that “Approximately half the food consumed and two-thirds of the fuel used in the UK is imported. Producing and transporting food and other products uses considerable amounts of water and energy, often in places where water demand exceeds the supply – this indirect, international water demand accounts for two thirds of the UK’s total water demand. Water stress abroad would reduce the resilience of these supply chains.”<sup>2</sup>

The subcommittee points out that “Without adaptation, declining crop yields, especially in Africa, are likely to leave hundreds of millions without the ability to produce or purchase sufficient food. Even within the EU, countries around the Mediterranean basin are at risk of drastically reduced water supply and increased desertification.”

## **Opportunities**

As other countries strive to mitigate and adapt to climate change, opportunities will arise. For example, new markets will open for ‘clean technologies’ that can reduce emissions of greenhouse gases.

Further opportunities for the UK could arise from the initiative announced after the latest UN Climate Change Conference, COP16. The so-called Cancún Agreements included the creation of “a technology mechanism with a Technology Executive

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<sup>2</sup> *How well prepared is the UK for climate change?* Adaptation Sub-Committee of the Committee on Climate Change, 2010  
<http://www.theccc.org.uk/reports/adaptation>

Committee and Climate Technology Centre and Network to increase technology cooperation to support action on adaptation and mitigation”. The network will consist of national, regional, sectoral and international technology organisations and initiatives.

One objective of the Climate Technology Centre is to enhance “cooperation with national, regional and international technology centres and relevant national institutions”. Any measures to implement this agreement will provide opportunities for organisations in the UK.

There will also be opportunities for technologies that can help countries to adapt to the effects of climate change, through modifying and protecting their infrastructure, for example. The UK’s civil engineering, design and construction sector is a world leader and is well placed to develop the technologies and skills needed to protect civil structures such as bridges and ports from the effects of climate change.

Science and technology will aid in our response to climate change in many ways. To begin with science, aided by appropriate technologies to measure what is happening, will improve our understanding of climate change itself. Science and technology will also be important in investigating the likely effects of global warming on important activities such as agriculture. Science and technology will also assist in our efforts to reduce climate change, by studying and developing low-carbon energy production, for example. Science and technology will also play a part in helping us to adapt to climate change and in mitigating its effects, by making changes to those parts of our infrastructure that will feel the effects of climate change.

### **Priorities for the UK**

A better understanding of the global needs for science and technology, and what is happening internationally to research these issues, can help us to direct our own efforts and to fill any gaps. Even something like the science and technology underpinning mitigation, where the required actions depend very much on local circumstances, can draw on knowledge from elsewhere. For example, in its latest report, the Committee on Climate Change (CCC) , advises that it is “neither necessary nor affordable for the UK to seek to lead on every mitigation technology. There are technologies where the UK is better placed to support technology development and others where a focus on international collaboration and deployment is more appropriate.”<sup>3</sup> The remit of the CCC is to “review the adequacy of the UK’s research and innovation arrangements for delivering technologies required to meet the UK’s climate change objectives”. It is the CCC’s view that “The UK will be better placed to accelerate the development of new technologies where it has a particular advantage – for example where the UK has the full range of manufacturing and business R&D facilities.”

Knowing where the UK has strengths is a guide to where it is sensible to enter into collaborative ventures. As the CCC puts it, where the UK has strengths “UK based

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<sup>3</sup> *Building a low-carbon economy – the UK’s innovation challenge*, Committee on Climate Change, 2010  
<http://www.theccc.org.uk/reports/low-carbon-innovation>

companies will lead international collaborations and the technology will be significantly developed, demonstrated and deployed in the UK”.

Similarly, understanding where the UK has weaknesses in R&D can help to determine where to concentrate resources, and where to seek partnerships. In these circumstances, as the CCC says, “Where the UK appears to lack an advantage in production its influence on the development of technologies is likely to be much less. UK based suppliers may develop important components and may participate in international collaborations but the pace and scale of development will be determined overseas.”

### **Technology transfer**

Rapid and global deployment of technologies will be an essential component of any responses needed to climate change. Many countries will not be in a position to afford the most appropriate technologies without aid of some sort. This is why the IPCC considered technology transfer as long ago as 2000 when it produced a special report on *Methodological and Technological Issues in Technology Transfer*.<sup>4</sup>

The IPCC’s report defined technology transfer in the context of climate change as “as a broad set of processes covering the flows of know-how, experience and equipment for mitigating and adapting to climate change amongst different stakeholders such as governments, private sector entities, financial institutions, non-governmental organizations (NGOs) and research/education institutions”.

Technology transfer is also included in both the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. The topic of technology transfer has also received special attention through such activities as the Expert Group on Technology Transfer of the UNFCCC.

A paper from the Centre for Climate Change Economics and Policy (CCCEP) sums up the issues “environment-friendly technologies have been developed primarily in industrialised countries, but are urgently required to mitigate GHG emissions in fast-growing emerging economies. Ensuring their global diffusion thus entails considerable policy and economic challenges because developing countries are reluctant to bear the financial costs of catching up alone, while firms in industrialised countries are wary about giving away strategic intellectual assets.”<sup>5</sup>

Technology transfer itself hinges on a number of underlying issues. In its Technical Paper *Technologies, Policies Measures For Mitigating Climate Change*, the IPCC says that obstacles to technology transfer include “disagreements over intellectual property rights and a lack of available capital and hard currency”.<sup>6</sup> The report adds

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<sup>4</sup> *Methodological and Technological issues in Technology Transfer*, IPCC, 2000  
<http://www.grida.no/publications/other/ipcc%5Fsr/?src=/climate/ipcc/tectran/>

<sup>5</sup> *Invention and Transfer of Climate Change Mitigation Technologies on a Global Scale: A Study Drawing on Patent Data*, Centre for Climate Change Economics and Policy, 2010  
[http://www.cccep.ac.uk/Publications/Working%20Papers/Papers/WPapers%2010%20-%2019/Working\\_Paper19.pdf](http://www.cccep.ac.uk/Publications/Working%20Papers/Papers/WPapers%2010%20-%2019/Working_Paper19.pdf)

<sup>6</sup> *Technologies, Policies and Measures for Mitigating Climate Change*, IPCC, 1996  
<http://www.google.co.uk/url?sa=t&source=web&cd=3&ved=0CC4QFjAC&url=http%3A%2F>

that “Other barriers include a lack of capacity and basic environmental legislation, and institutional factors in the host countries.”

The UNFCCC created the Expert Group on Technology Transfer (EGTT) “to advance the technology transfer activities under the Convention”. The EGTT has established a framework to enhance technology transfer “by increasing and improving the transfer of and access to environmentally sound technologies and know-how”.

The EGTT’s technology transfer framework includes an “enabling environment component” which focuses on “governmental actions, such as fair trade policies, removal of technical, legal and administrative barriers to technology transfer, sound economic policy, regulatory frameworks and transparency”.<sup>7</sup>

The EGTT has also shown increasing interest in “technologies for adaptation to climate change”. The group’s work under this banner “aims to improve the current knowledge and understanding of adaptation to climate change, including the assessment of technologies for adaptation to climate change, the process of technology development and transfer as relevant to adaptation, and its implications for climate policy”.

As a part of this activity, the EGTT has established what is describes as “a technology transfer information clearing house”, TT:CLEAR<sup>8</sup>, which “acts as a gateway to technology information that enables users, including practitioners and private sector users, to find information on many issues related to technology transfer”.

A further factor in the transfer of technology is the regime governing intellectual property rights (IPR). A recent paper by Bronwyn H. Hall and Christian Helmers, *The role of patent protection in (clean/green) technology transfer*, set out to “review the existing evidence on the link between IPRs and the development and transfer of climate change-related technology”.<sup>9</sup> After discussing the factors involved, the paper concludes that “the existing evidence on the role of IPRs in promoting the development and diffusion of climate change-related technologies is surprisingly sparse and does not provide sufficient insight to reach any substantial conclusion”. The authors suggest that “This calls for additional efforts in investigating the relationship between IPRs and green technologies specifically in developing countries.”

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[http://www.ipcc.ch/pdf/technical-papers/paper-I-en.pdf&ei=62puTJfnIoKb4AbRnuyoCw&usq=AFQjCNHsih-z6YJ4kQzmrB\\_3Kj6AgaKftA&sig2=TLNJGY9fZ8xiYm0hThMI2g](http://www.ipcc.ch/pdf/technical-papers/paper-I-en.pdf&ei=62puTJfnIoKb4AbRnuyoCw&usq=AFQjCNHsih-z6YJ4kQzmrB_3Kj6AgaKftA&sig2=TLNJGY9fZ8xiYm0hThMI2g)

<sup>7</sup> *Expert Group On Technology Transfer – Five Years Of Work*, UNFCCC, 2007  
[http://unfccc.int/files/essential\\_background/background\\_publications\\_htmlpdf/application/pdf/egtt\\_en\\_070523.pdf](http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/egtt_en_070523.pdf)

<sup>8</sup> <http://unfccc.int/ttclear/jsp/index.jsp>

<sup>9</sup> *The role of patent protection in (clean/green) technology transfer*, UNU MERIT, 2007  
<http://www.merit.unu.edu/publications/wppdf/2010/wp2010-046.pdf>

## Science base

The UK remains at the forefront of research in many areas: it is in a strong position to contribute to the science and technology needed to understand and deal with the challenges of climate change. Many of these challenges are inherently international. Climate change is happening on a global scale. Understanding climate change requires interdisciplinary input from many parts of the research community. The Living with Environmental Change (LWEC) programme provides a focus for the research community, bringing together 20 UK organisations, including all of the Research Councils, governments departments, and such agencies at the Met Office and the Technology Strategy Board. LWEC is a 10-year programme, due to run from 2007 to 2017, which also brings in other organisations in individual projects. For example, the Wellcome Trust, The Ministry of Defence and the Health Protection Agency are a part of the LWEC Environment and Human Health Programme which “aims to build multi- and inter-disciplinary research capacity that can effectively tackle the ‘real-world’ multi-and inter-disciplinary problems that we face not only in the UK but also globally”<sup>10</sup>.

The UK’s scientific expertise starts at the beginning of the understanding process, with world class research into the processes that drive climate change. As the NERC puts it “The UK’s international pre-eminence in many of the relevant science disciplines makes it well placed to lead and partner others in this area, and to deliver outcomes that will enhance the quality of life in the UK and elsewhere.”<sup>11</sup>

With an annual spending of about £40m on the area, NERC is a focus for much of the UK’s research in climate change research. NERC operates internationally and runs a fleet of research ships and scientific aircraft. NERC is also at the forefront in developing the tools needed for innovative environmental science.

The UK has particular strengths in modelling the atmosphere, oceans, solar radiation and other processes that are involved in climate change. In particular, the Met Office has developed models that are used globally to understand what is happening in the climate at all scales, from global to local. Together, NERC and the Met Office launched the Joint Climate Research Programme which included a shared investment in super computing.

One output from the work of the Met Office Hadley Centre is the PRECIS (Providing Regional Climates for Impacts Studies) system. This tool for predictions can be applied in any region of the world and is made widely available to developing countries as an adaptation tool.

The UK’s research community makes extensive use of satellite observation to gather data for their work on climate change. Satellite observation is essentially an international activity. A report from the OECD points out the scale of the task, warning that “substantial investments in earth observation and meteorological

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<sup>10</sup> <http://www.nerc.ac.uk/research/programmes/humanhealth/background.asp>

<sup>11</sup> *Next Generation Science for Planet Earth – NERC Strategy 2007- 2012*, NERC  
<http://www.nerc.ac.uk/publications/strategicplan/documents/strategy07.pdf>

satellite systems will be needed over the next ten years or so, and considerable replacement and network expansion investments will be required thereafter (to 2025-30 and beyond)".<sup>12</sup> It suggests that "total investment needs for earth observation and meteorological space-based networks could be around US\$40 billion in the next 15-20 years.

The European Space Agency (ESA) is a focus for Europe's earth observation activities. ESA's Earthnet programme has operated from some 30 years. The agency operates through such satellites as CryoSat, Envisat and ERS-2.

The Natural Environment Research Council (NERC) manages the UK's contribution to ESA's Earth observation programmes. NERC also funds the UK contribution to the European Space Agency's Earth Explorer missions.

The UK also has strengths when it comes to understanding the impacts of climate change. Here too, researchers are globally active. For example, the UK has centres of excellence in the understanding of the tropical diseases that may well become locally relevant.

The UK Climate Impacts Programme (UKCIP) is a national agency set up in 1997 to help organisations "to adapt to inevitable climate change".<sup>13</sup> Funded primarily by the Department for Environment, Food and Rural Affairs, UKCIP's remit runs only to the UK. However, it also works with other national and international efforts "because we want to learn from impacts and adaptation work elsewhere, and to contribute to adaptation globally".

## Understanding climate change

There will be a continuing need to understand the mechanisms and progress of climate change. A recent study of experts in climate change hints at how much remains unknown.<sup>14</sup> According to this paper "Uncertainty about the response of the climate system to future changes in radiative forcing arises from incomplete forcing and climate response data, incomplete understanding of climate system processes, and the limitations of climate models."

The UK plays a major part in the global efforts to understand climate change. It is also active in research into mitigating the effects of climate change and into adapting to the changes that it is likely to bring about.

The reports of the Intergovernmental Panel on Climate Change detail much of the global research efforts. Countries are spending large amounts on research into understanding climate change and its likely effects. Since the early 1990s, the US

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<sup>12</sup> *Space Technologies and Climate Change*, OECD, 2008

<sup>13</sup> <http://www.ukcip.org.uk/index.php>

<sup>14</sup> "Expert judgments about transient climate response to alternative future trajectories of radiative forcing", Zickfeld et al., *PNAS*, vol. 107, pp 12451–12456  
<http://www.pnas.org/cgi/doi/10.1073/pnas.0908906107>

alone has invested more than \$20 billion through the U.S. Global Change Research Program (USGCRP).<sup>15</sup>

The UK makes its contribution through such activities as the Met Office's extensive research programme.<sup>16</sup> Among other internationally significant subjects, the Met Office is active in research into understanding the effects of climate change on the spread of diseases and its impact on fisheries. The Met Office also supports such research organisations as the Tyndall Centre for Climate Change Research which brings together six UK research institutions.<sup>17</sup>

The Met Office and the Hadley Centre have world class expertise in numerical modelling, an important aspect of any attempts to understand climate change. As well as its Unified Model, which underpins weather forecasts and climate prediction, the Met Office has several other modelling systems.

The UK is a leading player in many international ventures and organisation, such as the World Climate Programme, the International Council for Science, the World Meteorological Organization (WMO) Intergovernmental Oceanographic Commission and the International Group of Funding Agencies for Global Change Research. For example, the Natural Environment Research Council (NERC) represents the UK in the work of the International Group of Funding Agencies for Global Change Research (IGFA), which provides a forum "through which national agencies that fund Research on Global Change identify issues of mutual interest and ways to address these through national and when appropriate through coordinated international actions".<sup>18</sup>

The Met Office is also active in global agencies: it is the UK representative with the WMO, which operates the World Climate Programme whose goals are "to improve understanding of the climate system and to apply that understanding for the benefit of societies coping with climate variability and change".<sup>19</sup>

The Met Office is also involved in the Global Monitoring for Environment and Security (GMES), EU Framework Programmes, the Global Climate Observing System (GCOS) and the World Climate Research Programme (WCRP). It is also a partner in several international collaborative projects. For example, the Met Office has led the ENSEMBLES project into the likely effects of climate change on Europe. This five-year study, funded by the European Commission, involves 66 partners across Europe and beyond, is "the biggest ever integrated climate change research project".<sup>20</sup>

An important part of the scientific work of the Met Office takes place at the Hadley Centre, the UK's foremost research centre for climate change. Largely co-funded by

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<sup>15</sup> <http://www.globalchange.gov/>

<sup>16</sup> <http://www.metoffice.gov.uk/climatechange/science/explained/>

<sup>17</sup> <http://www.tyndall.ac.uk/>

<sup>18</sup> <http://www.igfaqcr.org/>

<sup>19</sup> [http://www.wmo.int/pages/prog/wcp/index\\_en.html](http://www.wmo.int/pages/prog/wcp/index_en.html)

<sup>20</sup> <http://www.metoffice.gov.uk/climatechange/science/projects/ensembles.html>

DEFRA, the Ministry of Defence (MOD) and Department of Energy and Climate Change (DECC), the Hadley Centre's researchers contribute to the Assessment Report of the IPCC. The centre's climate projections were also the basis for the Stern Review on the Economics of Climate Change.<sup>21</sup>

As a part of its modelling activity, the Met Office also runs ocean wave, dynamical and ecosystem models and analyses for short range forecast and climate applications. In this, it works with other groups in the UK, including the Plymouth Marine Laboratory (PML), a NERC Collaborative Centre. PML was part of the consortium that, during the 1990s, developed the European Regional Seas Ecosystem Model (ERSEM) to simulate carbon and nutrient cycling and ecosystem response in European shelf seas.

Through its services activity, the Met Office makes its expertise available to industry, government and the defence sectors.

## Impacts of climate change

A further challenge for science and technology is to understand the impacts of climate change on key sectors. Those that came out of the preliminary work for this foresight project were:

- Health
- Energy supply
- Transport
- Food and agriculture
- National Security
- Manufacturing (resources)

The following sections consider the impacts of climate change on each sector. Some sectors are more likely to suffer unique effects of climate change than others. For example, health, and food and agriculture may experience greater impacts from international developments than energy supply, transport and manufacturing.

### Health

The UK has a long history of research into health and medicine that is relevant beyond its own national interests. The Medical Research Council (MRC), for example, has studied malaria and other tropical details for many years. As climate change progresses, there could be increasing calls for this expertise, both internationally and nationally, if, as has been suggested, these diseases migrate to the UK. The MRC also supports research into new and emerging vector-borne infections that could become more important in a changing climate.

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<sup>21</sup> *Stern Review Report on the Economics of Climate Change*, H M Treasury, 2006  
[http://webarchive.nationalarchives.gov.uk/+http://www.hm-treasury.gov.uk/independent\\_reviews/stern\\_review\\_economics\\_climate\\_change/stern\\_review\\_report.cfm](http://webarchive.nationalarchives.gov.uk/+http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm)

The UK's research community has responded to the potential threats from climate change by setting up such initiatives as that on Environmental and Social Ecology of Human Infectious Diseases (ESEI). This joint initiative between the MRC, NERC, ESRC and BBSRC, as part of the Living With Environmental Change (LWEC) programme, sets out "to foster the development of a new paradigm, transcending discipline boundaries, and to build capability in this important area of research". ESEI covers national and international research priorities by investigating the changing patterns of diseases that could develop. As the research call described it "Environmental change will lead to vegetation change, and also changes in water quality and quantity, affecting vector habitats."<sup>22</sup>

The possible rise of malaria and other diseases requires the UK to carry out research to improve our understanding of how, and if, these diseases and their vectors could spread. Research in this area will include work on modelling methods and predictive modelling tools such as those developed in the Department of Animal and Plant Sciences at the University of Sheffield.<sup>23</sup> This research can also benefit those countries where these diseases are endemic.

In its "fact sheet" on Climate change and health, the WHO writes: "Many of the major killers such as diarrhoeal diseases, malnutrition, malaria and dengue are highly climate-sensitive and are expected to worsen as the climate changes."<sup>24</sup>

Changes to reduce the emissions of carbon dioxide could also have beneficial effects. For example, in its survey "The health benefits of tackling climate change", *The Lancet*, points to the health improvements that could arise from more efficient use of domestic energy for heating and cooking. A review of research priorities, the WHO adds: "The few relevant studies suggest that unmitigated climate change, in the coming several decades, will significantly increase financial costs to health services, for example through increased demands for prevention and treatment of diarrhoea, malaria and malnutrition."<sup>25</sup>

### **Credibility gap**

An important challenge facing health and climate change could be to persuade people that the two are connected. A recent article in *The Lancet* described the issue: "In the melee of discourse about climate change science, emissions targets and trading, differential responsibilities, and threats to livelihoods and residential security, we have not recognised the real issue. Nearly all the adverse environmental

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<sup>22</sup> <http://www.mrc.ac.uk/Fundingopportunities/Calls/ESEI/index.htm>

<sup>23</sup> "The interaction of seasonal forcing and immunity and the resonance dynamics of malaria", *J. R. Soc. Interface* (2010) vol. 7, Pages 309–319, July 2009

<sup>24</sup> <http://www.who.int/mediacentre/factsheets/fs266/en/index.html>

<sup>25</sup> *Protecting health from climate change: global research priorities*, WHO, 2009  
<http://www.who.int/globalchange/publications/9789241598187/en/index.html>

and social effects of climate change will ultimately threaten human health (physical, nutritional, microbiological, or mental).<sup>26</sup>

According to the authors, this points to a big gap “between understanding the type of risk posed by climate change to the foundations for health and the way that most disease causation is conventionally construed”. They argue that we need to think about the health implications of climate change in “population terms” and not just about traditional disease control. Our responses to climate change have to consider “primary, secondary and tertiary prevention”.

## **Geography of disease**

There is already evidence that climate change is influencing the distribution of diseases. According to the European Academies Science Advisory Council (EASAC) “Although the evidence base is fragmented and it is also important to take account of the other various determinants of changes in ecosystems and in human, animal and microbial behaviour, the fundamental influence of climate change on infectious diseases in Europe is beginning to be discerned.”<sup>27</sup>

The evidence, says EASAC, suggests that “In recent years, numerous vector-borne and other zoonotic diseases have emerged or re-emerged in Europe with major health and socio-economic consequences.”

Climate change is just one of a complex set of interacting factors that drive changes in disease patterns. However, EASAC asserts that “There is growing evidence that these new threats can be associated with global and local changes, resulting from climate influences (hotter summers, warmer winters, varying precipitation patterns).”

EASAC lists several diseases where climate change may already have had an impact on their distribution. For example, It points to evidence suggesting that there is “an increasing body of information in support of a correlation between climate change, tick activity and tick-borne disease in Europe”.

EASAC also warns that Climate change is likely to affect human migration as well as the mobility of animal hosts, vectors and pathogens.” Here too there is already evidence that human migration, albeit not itself a consequence of climate change, has affected the distribution of some diseases.

## **Food and agriculture**

Agriculture both contributes to and feels the effects of climate change. Like other sectors, agriculture consumes energy, which contributes to climate change through the emission of CO<sub>2</sub>. Activities such as deforestation also add to the planet’s carbon burden while removing carbon sinks.

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<sup>26</sup> “Climate change: a time of need and opportunity for the health sector”, *The Lancet*, Vol. 374 December 19/26, 2009, p 2123

[http://www.thelancet.com/journals/lancet/article/PIIS0140-6736\(09\)62031-6/fulltext](http://www.thelancet.com/journals/lancet/article/PIIS0140-6736(09)62031-6/fulltext)

<sup>27</sup> *Climate change and infectious diseases in Europe*, EASAC, 2010

<http://www.easac.eu/home/reports-and-statements/detail-view/article//climate-chan.html>

The OECD report, *Climate Change and Agriculture*, quotes estimates that agriculture “represents 10-12% of total global anthropogenic emissions of greenhouse gases”.<sup>28</sup> It warns, though, that scientific uncertainties mean that “this could be as high as 18-31%”.

The IDCC report on Physical Resources and Commodities and Climate Change, R3, identifies commodities in the agriculture sector as those “that are most likely to experience the greatest impacts from climate change”. The report also highlights “the fish and aquaculture commodity sector as particularly vulnerable to climate change”<sup>29</sup>.

A study by the International Food Policy Research Institute (IFPRI) has warned that in Africa alone, over the next four decades higher temperatures and more frequent droughts could depress wheat yields by over 30%, rice by 15% and maize by 10%.<sup>30</sup> In its report, the IFPRI warns that “Even without climate change, greater investments in agricultural science and technology are needed to meet the demands of a world population expected to reach 9 billion by 2050.”

The OECD-FAO *Agricultural Outlook 2010-2019* warns that “more frequent weather disturbances associated with climate change may render global yields much more variable, leading to greater instability in production and trade flows.”<sup>31</sup> The report also highlights “the continuing migration of production to areas of the world which suffer higher yield variability together” as a further factor that will influence the global pattern of agriculture.

In its previous review, *Agricultural Outlook 2009-2018*, the OECD-FAO highlighted a number of areas where we lack scientific understanding of the possible effects of climate change.<sup>32</sup> It warns, for example, that climate change is “an important variable in future production possibilities” that will “clearly add to the risks of water stress as well as the incidence and severity of floods, and likely shift production frontiers”.

Just as climate change could alter the geography of human diseases, it could influence diseases patterns in agriculture, an area of research where the UK has extensive experience. For example, in work that has global significance, researchers

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<sup>28</sup> *Climate Change and Agriculture: Impacts, Adaptation and Mitigation*, OECD, 2010  
<http://puck.sourceoecd.org/vl=9734306/cl=34/nw=1/rpsv/ij/oecdthemes/99980061/v2010n11/s1/p11>

<sup>29</sup> *IDCC Report R3: Physical Resources and Commodities and Climate Change*. Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

<sup>30</sup> *Climate Change – Impact on Agriculture and Costs of Adaptation*, International Food Policy Research Institute, Updated 2009, OECD, 2010  
<http://www.ifpri.org/sites/default/files/publications/pr21.pdf>

<sup>31</sup> *OECD-FAO Agricultural Outlook 2010-2019*, OECD-FAO, 2010  
[http://www.agri-outlook.org/pages/0,2987,en\\_36774715\\_36775671\\_1\\_1\\_1\\_1\\_1,00.html](http://www.agri-outlook.org/pages/0,2987,en_36774715_36775671_1_1_1_1_1,00.html)

<sup>32</sup> *OECD-FAO Agricultural Outlook 2009-2018*, OECD, 2009  
<http://puck.sourceoecd.org/vl=8080235/cl=45/nw=1/rpsv/cgi-bin/fulltextew.pl?prpsv=/ij/oecdthemes/9998010x/v2009n10/s1/p11.idx>

at Rothamsted Research, an Institute of the BBSRC, have used mathematical modelling to investigate disease patterns for wheat.

Animal husbandry may also see significant changes as result of climate change. The OECD report, *Climate Change And Agriculture: Impacts, Adaptation And Mitigation*, suggests that this is an area where the UK is working to fill a knowledge gap, with DEFRA “currently funding a number of projects focussing on impacts and adaptation on livestock sectors, which have been poorly represented in other research conducted by, for example, the EU”.<sup>33</sup>

## **Foresight project on Global Food and Farming Futures**

The Foresight Programme recently completed a wide reaching project on Global Food and Farming Futures that set out “to explore the pressures on the global food system between now and 2050 and identify the decisions that policy makers need to take today, and in the years ahead, to ensure that a global population rising to nine billion or more can be fed sustainably and equitably”. A major part of the study’s activity included consideration of the effects of climate change on food and agriculture, and of the effects of food and agriculture on the climate.

The project’s final report, *The Future of Food and Farming: Challenges and choices for global sustainability*<sup>34</sup> provides significant insights into the relationships between food and agriculture and climate. A key message from this work is that climate change and sustain ability are inextricably related. As the report puts it “Addressing climate change and achieving sustainability in the global food system need to be recognised as dual imperatives. Nothing less is required than a redesign of the whole food system to bring sustainability to the fore.”

The Foresight project investigated the challenges in science and technology that we need to address if we are to achieve this sustainability. It asserts that “Research on climate change adaptation and mitigation in the food system should be a priority.”

The project also produced a series of reports, several of which tackle aspect of science and technology, including State of science reviews. These cover many of the issues that are relevant to the IDCC project.

## **Benefits**

The underlying report of the IDCC project, *Physical Resources and Commodities and Climate Change*, points out that for agricultural commodities, climate change could also bring benefits<sup>35</sup>. Some plants can benefit from higher concentrations of atmospheric CO<sub>2</sub>. “Additional benefits include the expansion of areas suitable for

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<sup>33</sup> *Climate Change And Agriculture: Impacts, Adaptation And Mitigation*, OECD, 2010

<sup>34</sup> *Foresight. The Future of Food and Farming (2011) Final Project Report*. The Government Office for Science, London.  
<http://www.bis.gov.uk/foresight/our-work/projects/current-projects/global-food-and-farming-futures/reports-and-publications>

<sup>35</sup> *IDCC Report R3: Physical Resources and Commodities and Climate Change*. Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

crop production, longer growing seasons, and for some regions potential increases in rainfall.”

## **Fisheries**

Climate change will affect fisheries and aquaculture through ocean acidification, habitat damage and extreme weather, for example. It will affect fish populations and behaviour as well as the livelihoods of fishing communities. Climate change will alter the distribution and productivity of fisheries, as some species decline and others become more abundant. Research can help us to understand and adapt to these possible changes.

R7 of the IDCC project, Physical Resources and Commodities and Climate Change, points out that “the full extent of how fish stocks will respond to changes such as increasing acidification of the oceans and warming ocean temperatures is not known”<sup>35</sup>.

Climate change is likely to influence the distribution of fish species. For example, researchers have suggested that the invasive mosquitofish, *Gambusia holbrooki*, which is native to the United States and lives in Mediterranean rivers in Spain and France, could spread. This is because temperature affects the abundance of this species, its reproduction and other characteristics of its lifecycle. While this is not a food species, we could see changes in the distribution of economically valuable species that prefer warm water. Similarly, we may also see changes in the distribution and abundance of species that prefer colder waters.

The OECD-FAO *Agricultural Outlook 2009-2018* says that “Fish proteins accounted for 15% of total world animal protein supplies in 2003. Global fish production has increased about 8 times in volume since 1950 to reach some 145 million tonnes in 2006.”

With some 37% of fish production traded internationally in 2004, according to the OECD-FAO, fish and fish products “represent one of the most important commodity groups in the exports from developing countries”. That trade could well feel the effects of climate change, as well as pressure from growing affluence, and rising consumption, in developing countries. At the same time, Europe’s fisheries face pressure to reduce their fleets to conserve fish stocks.

Many countries believe that farmed fish could help to meet the future demand for high quality seafood. As a result aquaculture could be an area for research. The OECD-FAO warns that “aquaculture has economic, environmental and social implications which may be poorly evaluated or inadequately addressed within current policy frameworks”.

One recent paper asserts that “Climate effects on the structure and function of marine communities have received scant attention.”<sup>36</sup> We need more research if we

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<sup>36</sup> “Predicting the effects of climate variation and change on marine communities and the consequences for fisheries”, S. Jennings and K. Brander, *Journal of Marine Systems*, vol. 79, p 418-426  
[http://www.sciencedirect.com/science?\\_ob=ArticleURL&\\_udi=B6VF5-4VNK683-](http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VF5-4VNK683-)

are to understand the interaction between climate change and fisheries/aquaculture from economic, social and institutional perspectives. More locally, we will need research to understand the possible effects of climate change on local fish stocks if the European fisheries regime is to adapt successfully to a changing environment.

### **Food safety**

Climate change could also affect food safety. In its study, *Climate Change: Implications For Food Safety*, the Food and Agriculture Organization of the United Nations (FAO) warns that “Climate change affects the microbial population of the macro-environment (soil, air and water) and the population of pests or other vectors. It is therefore a contributing factor to the occurrence and gravity of biotic diseases attributable to (micro) organisms such as fungi, bacteria, viruses and insects.” The OECD-FAO *Agricultural Outlook 2010-2019* says that “Climate change may also increase food safety risks that might result from heat-related and water borne diseases with temperatures rising and more flooding.”

### **Beyond food – biofuels**

Agriculture also provides a number of non-food commodities, such as cotton. There are also moves towards the use of agricultural feedstocks for the production of polymers, for example. A further development is the conversion of crops into biofuels. Wheat, for example, is the feed material for biofuel production in the Ensus plant on Teesside.

Forestry is also likely to experience the effects of climate change. Forests are an important part of the carbon cycle, acting as sinks for CO<sub>2</sub>. Finland, for example, a sizeable exporter of forestry products, has a long tradition of research into the relation between climate change and forests. Estimates suggest that CO<sub>2</sub> emissions from deforestation exceed those from transport.<sup>37</sup>

A recent working paper on how climate change could affect its tree crops, *Finland's Forests in Changing Climate*, concludes that the main effects could include a longer growing season in the northern coniferous zone.<sup>38</sup> It also suggests that “forest growth may increase; wind damage will become more prevalent; and in the temperate zone insect pests are expected to spread northwards, possibly causing damage on a massive scale”.

The latest study for the Finnish Forest Research Institute says that “Good and timely forest management is the main way of improving the ability of forests to adapt to climate change”.

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<sup>37</sup> *Avoiding dangerous climate change*, Met Office Hadley Centre, 2008  
<http://www.metoffice.gov.uk/publications/brochures/cop14.pdf>

<sup>38</sup> *Finland's Forests in Changing Climate*, Finnish Forest Research Institute, 2010  
<http://www.metla.fi/julkaisut/workingpapers/2010/mwp159.htm>

Finland produced its first National Adaptation Strategy to climate change in 2004, compiled by the Ministry of Agriculture and Forestry in collaboration with other ministries, researchers and stakeholders. As research continues, this strategy will change. For example, according to the latest Finnish report “The compilation of the National strategy and programme to combat invasive alien species including forest species is under way in Finland and will be finalised before the end of 2010.”

As a part of this process, Finland has identified the need for further research in, for example, “the development of early warning and monitoring systems and in the increased cooperation between different administrative sectors”. There is also a need for research that “combines ecosystem functioning with economic and societal issues”.

When it comes to understanding the interaction between forests and the climate, the UK has a number of centres of excellence, including, for example, the NERC Earth Observation Centre of Excellence for Terrestrial Carbon Dynamics whose mission is “to provide the science basis for understanding the role of terrestrial systems in the carbon cycle, especially forest ecosystems”.<sup>39</sup>

## National security

Climate change is likely to change the operating environments for military activities. Climate change will also influence the roles and missions that the armed forces have to undertake.

In the latest, fourth, edition of *Global Strategic Trends – out to 2040*, the Development, Concepts and Doctrine Centre of the Ministry of Defence (MoD) writes: “Climate change will amplify existing social, political and resource stresses, shifting the tipping point at which conflict ignites, rather than directly causing it.”<sup>40</sup>

In the US, the Department of Defense (DoD), in its latest *Quadrennial Defense Review Report*, states that “Climate change and energy will play significant roles in the future security environment. The Department is developing policies and plans to manage the effects of climate change on its operating environment, missions, and facilities.”<sup>41</sup> This has implications for the DoD’s technology needs and procurement decisions. “We must continue incorporating geostrategic and operational energy considerations into force planning, requirements development, and acquisition processes. “

In the *Quadrennial Defense Review Report*, the DoD says that it will also continue to provide military installations as “a test bed to demonstrate and create a market for

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<sup>39</sup> NERC Earth Observation Centre of Excellence for Terrestrial Carbon Dynamics  
<http://ctcd.group.shef.ac.uk/ctcd.html>

<sup>40</sup> *Global Strategic Trends – out to 2040*, Ministry of Defence, 2010  
<http://www.mod.uk/DefenceInternet/MicroSite/DCDC/OurPublications/StrategicTrends+Programme/>

<sup>41</sup> *Quadrennial Defense Review Report*, US Department of Defense, 2010  
<http://www.defense.gov/qdr/>

innovative energy efficiency and renewable energy technologies coming out of the private sector and DoD and Department of Energy laboratories”.

National security and defence operate within a global environment. The tasks they are called upon to respond to will depend on international events and circumstances. In a statement to the US House Permanent Select Committee on Intelligence House Select Committee on Energy Independence and Global Warming in June 2008, Dr Thomas Fingar, Deputy Director of National Intelligence for Analysis and Chairman of the National Intelligence Council, said “the most significant impact [of global climate change] for the United States will be indirect and result from climate-driven effects on many other countries and their potential to seriously affect US national security interests. We assess that climate change alone is unlikely to trigger state failure in any state out to 2030, but the impacts will worsen existing problems—such as poverty, social tensions, environmental degradation, ineffectual leadership, and weak political institutions.”

The defence community in the US also support initiatives to improve its understanding of the processes of climate change. In the *Quadrennial Defense Review Report*, the DoD says that it “will leverage the Strategic Environmental Research and Development Program, a joint effort among DoD, the Department of Energy, and the Environmental Protection Agency, to develop climate change assessment tools”.

### **Natural disasters**

It is against this background that we have to consider the science and technology that the defence community will need to meet these challenges. For example, the armed forces are often called upon to provide humanitarian relief, in natural disasters. In Haiti’s earthquake in 2010, the US Marine Corps was the first to respond. In the UK, the Army played an important role in the floods in Cumbria in 2009.

Natural disasters may well be of a different nature as climate change takes hold. A study for the US Navy by the Committee on National Security Implications of Climate Change for U.S. Naval Forces suggests that “naval forces might be required to carry out more frequent humanitarian assistance and disaster relief (HA/DR) missions”.

Navies depend on coastal installations that may require modification to adapt them to the impacts of climate change. The report of the Committee on National Security Implications of Climate Change for U.S. Naval Forces warns that “The projected increased intensity of storms and storm surges also contributes to the anticipated increased vulnerability of naval coastal installations.”

Navies may also need to adapt their systems to accommodate the effect of changing thermal structure, ocean salinity and acidification. These changes could affect the performance of acoustical sensors and torpedoes, for example.

### **Energy supply and transport**

While energy supply and transport will feel the effects of climate change, their biggest influence is in the contributions to climate change. In any case, the effects on energy

supply and transport will often be local, with little international consequence in terms of science and technology. However, they are just a part of the bigger picture. The biggest effects of climate change on energy supply and transport may be in other domains, in economics and politics for example, rather than science and technology.

There is already a fair understanding of the effect that energy supply has on climate change. However, there has been less attention paid to the effects of climate change on energy supply. While many of these effects will be of a geopolitical nature – in threats to the security of supply as imports come under pressure, for example – energy supply will not be immune to the direct effects of climate change. For example, many of the UK's power stations are in coastal locations, where they could feel the influence of rising sea levels and extreme weather events. For this reason, the Department of Energy and Climate Change includes the possible effects of climate change in the planning process before the approval and construction of new nuclear power stations.

Climate change could also disrupt energy supply through more frequent flooding. The UK has already seen this phenomenon, with storms interrupting electricity supply.

The challenge for science and technology will be to understand how climate change could affect energy supply.

As with energy supply, transport will experience the effects of climate change, through disruptions caused by severe weather events, for example. In this, however, transport is much like other activities. There is, though, a continuing need for research to ensure that we understand all of the ways in which climate change could affect transport.

## **Reversing climate change – geoengineering**

One possible response to climate change is to try to intervene directly and, in effect, reverse the greenhouse effects by intercepting sunlight before it penetrates the earth's atmosphere. Any such approach would require a very detailed understanding of the scientific process involved in climate change.

A controversial approach to tackling climate change, geoengineering involves direct intervention in the atmosphere in an attempt to modify the climate. In its study, *Geoengineering the climate*, the Royal Society defined geoengineering as “the deliberate large-scale intervention in the Earth's climate system, in order to moderate global warming”.<sup>42</sup>

Techniques for geoengineering generally come in two forms, carbon dioxide removal (CDR) and solar radiation management (SRM). The labels describe what each sets out to do: ‘scrub’ CO<sub>2</sub> out of the atmosphere or repel the solar radiation that stokes the greenhouse effects.

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42 *Geoengineering the climate – Science, governance and uncertainty*, Royal Society, September 2009  
<http://royalsociety.org/Geoengineering-the-climate>

For SRM, geoengineering might deploy, for example, technologies to reflect sunlight back into space. This might be through extensive use of cloud creation to prevent solar radiation from reaching the lower atmosphere. Possible ways of achieving 'cloud albedo modification' as this approach is known "this could be to use of sulphate aerosols, fine clouds of sulphuric acid, or by spraying droplets of seawater into the atmosphere from specially designed ships to create clouds that acts as gigantic 'parasols'. Researchers have also suggested launching huge reflectors into orbit to intercept sunlight before it reaches the earth.

Geoengineering could also remove carbon dioxide from the atmosphere, perhaps by managing land use to create or improve 'land carbon sinks'. In its report, the Royal Society also mentions enhancing the ocean's uptake of CO<sub>2</sub>, "for example by fertilisation of the oceans with naturally scarce nutrients, or by increasing upwelling processes".

In its report, the Royal Society said that geoengineering is "very likely to be technically possible". However, it adds that "the technology to do so is barely formed, and there are major uncertainties regarding its effectiveness, costs, and environmental impacts".

## Research

In the UK, the Engineering and Physical Sciences Research Council (EPSRC) and the Natural Environment Research Council (NERC), fund research relevant to geoengineering. This is mostly to support modelling Earth and climate systems. However, there is, as yet, limited research under way into geoengineering in its own right.

Through their joint energy programme the UK's research councils have announced that they plan to support geoengineering research to "allow the UK to make informed and intelligent assessments about the development of climate geoengineering technologies".

The Royal Society is one of many organisations that have called for international collaboration. "Relevant international scientific organisations should coordinate an international programme of research on geoengineering methods with the aim of providing an adequate evidence base with which to assess their technical feasibility and risks, and reducing uncertainties within ten years." In 2009, the House of Commons Innovation, Universities, Science and Skills Committee, called for "a publicly-funded programme of geoengineering research".<sup>43</sup>

## Controversy and policy

Geoengineering is controversial. Does it really make sense to embark on massive interference in the planet's geophysics is an attempt to compensate for our own accidental interference? Will we be able to anticipate, and avoid, any unwanted

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<sup>43</sup> *Engineering: turning ideas into reality*, House of Commons Innovation, Universities, Science and Skills Committee, 2009  
<http://www.publications.parliament.uk/pa/cm200809/cmselect/cmdius/759/75902.htm>

environmental effects of geoengineering? Geoengineering could suffer from the same criticism that has affected genetically modified foods, with the suggestion that “emerging laboratory-based development of SRM technologies raises the prospect that national or corporate interests might try (or appear to try) to control or profit from these schemes”.<sup>44</sup>

In its report, the Royal Society pointed out that geoengineering has significant implications for international governance. It recommended that: “The governance challenges posed by geoengineering should be explored in more detail by an international body such as the UN Commission for Sustainable Development, and processes established for the development of policy mechanisms to resolve them.”

Several initiatives are under way to investigate the policy implications of, and public response to, geoengineering. The NERC, for example, is conducting a public dialogue on geoengineering “to assess public opinion on how future research relating to the subject should be directed, conducted and communicated”.<sup>45</sup>

In 2009, the Science and Technology committees of the U.S. House of Representatives and the U.K. House of Commons initiated a joint inquiry on geoengineering that would allow them to coordinate their work on “an emerging science and technology subject with important international implications”.<sup>46</sup>

In its report *The Regulation of Geoengineering* House of Commons Science and Technology Committee called for “the groundwork for regulatory arrangements to begin”.<sup>47</sup> The committee then suggests that any controls on geoengineering should be based on “a set of principles that command widespread agreement—for example, the disclosure of geoengineering research and open publication of results and the development of governance arrangements before the deployment of geoengineering techniques”.

Geoengineering clearly has significant international dimensions. The Science and Technology Committee’s report, which fed into the work of the US House of Representatives Committee, suggests that it will be for the UN to bring about any regulatory regime.

The nature of the research involved, especially its scale, suggests that here too there will also be considerable international collaboration. There may also be a need for international agreement on the conduct of research into geoengineering. As Blackstock and Long write in *Science*, “If conducted without international approval, a

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<sup>44</sup> “The Politics of Geoengineering”, Jason J. Blackstock and Jane C. S. Long, *Science*, vol. 326, p 527, January 2010

<sup>45</sup> <http://www.nerc.ac.uk/about/consult/geoengineering.asp>

<sup>46</sup> *Collaboration and Coordination on Geoengineering*, U.S. House of Representatives Committee on Science and Technology, House of Commons Select Committee on Science and Technology

<sup>47</sup> *The Regulation of Geoengineering*, House of Commons Science and Technology Committee, 2010  
<http://www.publications.parliament.uk/pa/cm200910/cmselect/cmsctech/221/22102.htm>

test perceived (even just politically) to present transboundary risks could spark international tensions, creating a global ‘crisis of legitimacy’.”

The Royal Society anticipates the need for international acceptability and agreement when it says in its report: “The Royal Society in collaboration with international science partners should develop a code of practice for geoengineering research and provide recommendations to the international scientific community for a voluntary research governance framework.”

Any research into geoengineering will be global in nature. The UK will play its part through such activities as the Research Councils Energy programme which “intends to provide support to research within the Climate Geoengineering remit” and aims “to fund research which will allow informed and intelligent assessments about the development of Climate Geoengineering technologies”.<sup>48</sup>

## Mitigating climate change

Understanding the effects of climate change is an important precursor to the development of the science and technology that we will need to reduce, or mitigate, our impact on the climate. In essence, mitigation means developing technologies that reduce emissions of carbon dioxide and other greenhouse gases. Mitigation also includes measures that enhance the sinks for greenhouse gases.

As in the case of understanding climate change, it helps to consider the special circumstances of important sectors:

- Health
- Energy supply
- Transport
- Food and agriculture
- National Security
- Manufacturing (resources)

Also in common with understanding climate change, some sectors will be more important than others. Energy supply, for example, is the focus of most attention, as the main source of the greenhouses gases that lead to climate change. A secondary effect of the need to decarbonise energy use is that transport needs to find new technologies that do not rely on carbon fuels.

Some sectors, such as health and national security, will not in themselves be major players in mitigating the effects of climate change, beyond the need to reduce the own carbon footprint. In many cases, the solutions will be the same as those deployed in other sectors. For example, if transport in general moves over to biofuels, the defence sector could follow. The US military has already begun to test and adopt technologies that will reduce that dependence, with projects on solar powered water purification systems in Afghanistan and a Navy jet fuelled partly by biofuels.

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<sup>48</sup> <http://www.epsrc.ac.uk/funding/calls/2009/Pages/geoengineeringscoping.aspx>

## Energy supply

We need to consider energy as a two-sided process, generation and consumption. Science and technology will come into play on both sides, in finding low-carbon ways to supply the energy we need, and to reduce the carbon intensity of consumption. In terms of consumption, the nature of the science and technology will differ, depending on the sector. This section will focus on the supply of energy, later sections will consider the consumption side of the process.

Climate change is one of a number of drivers of change in the move towards sustainable energy, alongside energy insecurity, fossil fuel depletion and the development of new technologies. The timescale for the development and deployment of new energy technologies makes it difficult to have much impact on the emissions of climate gases before 2050. Incremental improvements can improve the efficiency of existing technologies, particularly renewable energy technologies. In the longer term, nuclear fusion holds out the prospect of a replacement for nuclear fission.

Nuclear fission is, though, likely to be the mainstay of low-carbon electricity generation. The Committee on Climate Change has pointed out that the UK “will need to rely on overseas based suppliers offering standardised designs.”<sup>49</sup>

It will take money as well as time to bring about any move towards a sustainable energy system. While the recent financial crisis has acted as a brake on investment, the United Nations Environment Programme (UNEP) reports that “Sustainable energy – helped by sky-high oil prices – resisted the financial crisis more successfully than many other sectors for much of 2008, only feeling the impact from September onwards and continuing into 2009.”<sup>50</sup>

According to UNEP, 2008 “was another milestone for investment in sustainable energy, especially in view of the difficult overall investment climate. A total of \$155 billion was invested in companies and projects globally, a more than four-fold increase on 2004”. However, at just 5%, the growth in 2008 was much less than the 50% growth rates of previous years.

## Solar power

While the UK is unlikely to develop solar power to the same extent as it is rolling out wind energy, there are both national and international opportunities for various technologies. The International Energy Agency (IEA) gives some idea of how long it will take for carbon free energy sources to have an impact. In its report, *Technology Roadmap – Solar photovoltaic energy*, the IEA describes solar photovoltaic (PV) power as “a commercially available and reliable technology with a significant potential for long-term growth in nearly all world regions”. However, it will take time to

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<sup>49</sup> *Building a low-carbon economy – the UK’s innovation challenge*, Committee on Climate Change, 2010

<http://www.theccc.org.uk/reports/low-carbon-innovation>

<sup>50</sup> *Global Trends in Sustainable Energy Investment 2009*, UNEP, 2009

<http://sefi.unep.org/english/globaltrends2009.html>

have that impact. The IEA estimates that “by 2050, PV will provide around 11% of global electricity production and avoid 2.3 gigatonnes (Gt) of CO<sub>2</sub> emissions per year”.<sup>51</sup>

The UK conducts research into the underlying science and technology of photovoltaic solar cells. A promising area of science is in the development of ‘organic solar cells’. Research at the Cavendish Laboratory in Cambridge University includes solar cells in its portfolio of work on electronic materials that build on polymer science. Success in this work would open the way to using conventional manufacturing and printing techniques from the polymer industry in the manufacture of inexpensive solar cells. While organic solar cells are currently less efficient than conventional inorganic silicon solar cells, the research is making steady progress, with support from the Carbon Trust. Success in this area could lead to major export opportunities for the UK as well as domestic use of the technology.

While PV solar is amenable to widespread implementation in units of any size, concentrating solar power (CSP) is more suited to large scale deployment in countries that have strong sunlight and clear skies. In its roadmap of CSP, the IEA finds that “with appropriate support”, by 2050, the technology “could provide 11.3 % of global electricity, with 9.6% from solar power and .7% from backup fuels (fossil fuels or biomass)”. The potential is such that “CSP can be expected to become a competitive source of bulk power in peak and intermediate loads by 2020, and of base-load power by 2025 to 2030”.

### **Smart grids**

Any new technology that requires the long distance transmission of electricity will need an electricity ‘grid’ that is in keeping with moves to decarbonise energy production. As the report *Roadmap 2010-18 and Detailed Implementation Plan 2010-12*, prepared for the European Electricity Grid Initiative (EEGI) puts it: “A single, stronger and smarter European electricity grid will have a central role to accommodate the resulting massive deployment of renewable and decentralised energy sources.”

The UK is already connected to the electricity networks in France and Ireland. In 2008, the UK exported 1,272 GWh of electricity and imported 12,294 GWh, which accounted for 3% of the electricity supplied.<sup>52</sup> In comparison, around 5.5% of the UK’s electricity comes from renewable energy sources. The UK’s imports of electricity were valued at nearly £500 million in 2008.<sup>53</sup>

Connection to the international grid means that the UK benefits from low-carbon electricity generation at nuclear power stations in France. With the UK’s potential to

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<sup>51</sup> *Technology Roadmap – Solar photovoltaic energy*, IEA, 2010  
[http://www.iea.org/papers/2010/pv\\_roadmap.pdf](http://www.iea.org/papers/2010/pv_roadmap.pdf)

<sup>52</sup> Association of Electricity Producers  
<http://www.aepuk.com/about-electricity/how-electricity-is-generated/>

<sup>53</sup> Annex G Foreign trade, *Digest of United Kingdom Energy Statistics 2009*, DECC, 2009  
[http://www.decc.gov.uk/media/viewfile.ashx?filepath=statistics/publications/dukes/1\\_20090923115943\\_e\\_@@\\_dukes09annexg.pdf&filetype=4](http://www.decc.gov.uk/media/viewfile.ashx?filepath=statistics/publications/dukes/1_20090923115943_e_@@_dukes09annexg.pdf&filetype=4)

be one of Europe's biggest generators of electricity from wind turbines, there could be opportunities to redress the balance between the country's imports and exports of electricity.

The EEGI's report describes a nine-year "European research, development and demonstration (RD&D) programme initiated by electricity transmission and distribution network operators to accelerate innovation and the development of the electricity networks of the future in Europe".<sup>54</sup> One benefits of the 'smart grid', according to the report, will be the "integration of national networks into a market-based, truly pan-European network" as well "Increased hosting capacity for renewable and distributed sources of electricity".

Such a development could pave the way for a wider international trade in energy based on renewable sources. For example, while the UK is not, under current climate conditions, likely to be in a position to exploit CSP, if the technology does prove commercially viable, it could import electricity from further afar from, say, the Sahara to the UK. There is also a proposal to connect Europe's northern states with an undersea 'supergrid' to carry electricity from renewable energy sources that tap wind and wave power.<sup>55</sup>

At the end of 2010, ministers from 10 European countries, including the UK, signed the North Seas Memorandum of Understanding agreeing the Ten Year Network Development Plans of the European Network of Transmission System Operators for Electricity (ENTSO-E). Under the agreement, the countries have agreed to "identify and tackle barriers to grid development at both national, regional and EU-level, in particular regulatory, legal, market, planning, authorisation and technical issues".

Until recently, long distance electricity transmission has been over ageing networks, with little incentive, or need, to develop new technologies. The decarbonisation of energy could encourage the development of 'smart grids'. Networks were essentially designed for the flow of electricity in one direction from large centralised power stations to customers. In future, the need will be for electricity to travel in different directions from a complex and changing mix of sources. For example, off-shore wind power will deliver varying amounts of electricity as the weather changes. "The goal is that by 2020, 50% of networks in Europe would enable the seamless integration of renewables and operate along 'smart' principles, effectively matching supply and demand and supporting the internal market for the benefit of citizens."<sup>56</sup>

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<sup>54</sup> *European Electricity Grid Initiative (EEGI) Roadmap 2010-18 and Detailed Implementation Plan 2010-12*, European Network of Transmission System Operators for Electricity and European DSO Association for Smart Grids, May 2010  
[http://www.smartgrids.eu/documents/EEGI/EEGI\\_Implementation\\_plan\\_May%202010.pdf](http://www.smartgrids.eu/documents/EEGI/EEGI_Implementation_plan_May%202010.pdf)

<sup>55</sup> "Energy: Supergrid," *Nature*, vol. 468, p 624,  
<http://www.nature.com/news/2010/101130/full/468624a.html>

<sup>56</sup> *Investing in the Development of Low Carbon Technologies (SET-Plan)*, Commission Of The European Communities, October 2009  
[http://ec.europa.eu/energy/technology/set\\_plan/doc/2009\\_comm\\_investing\\_development\\_low\\_carbon\\_technologies\\_en.pdf](http://ec.europa.eu/energy/technology/set_plan/doc/2009_comm_investing_development_low_carbon_technologies_en.pdf)

The CCC sees wind power as an area where the UK has particular strengths. “With significant capability already established, the UK is uniquely placed to accelerate development and deployment of offshore wind power.”

Europe’s Strategic Energy Technology Plan (SET Plan) highlights electricity networks as an area that needs attention, including “a strongly integrated research and demonstration programme”. Europe will have to invest €2 bn over the next 10 years.

Smart grids could develop in many regions, raising the issue of international agreements. Just as the European grid will require “appropriate cross-border coordination of planning and operations” other grids that cross national boundaries will require similar agreements between governments.

## **Biofuels**

Biofuels offer an important opportunity to remove fossil carbon from energy supply. Researchers in the UK are working on various approaches to the science and technology of biofuels. That research addresses the complete “food chain” for biofuel, from work on ‘feedstocks’, including crops and algae, through to processing technologies and on to the changes needed so that existing users of fossil fuelled devices, such as cars and aircraft, can work with biofuel. The UK is also home to early commercialisation activities.

At the beginning of the fuel chain, the BBSRC supports basic research that underpins bioenergy, including work on photosynthesis and light harvesting. This includes studies of genetic manipulation of light harvesting in plants.

Much of the bioenergy research conducted in the UK is part of a collective effort through various initiatives. For example, EPSRC funds work on biomass and bioenergy within its SUPERGEN Bioenergy Consortium. The consortium is a subset of the EPSRC’s wider SUPERGEN initiative which is the primary delivery mechanism for sustainable energy research funded by EPSRC as part of the Research Councils’ Energy Programme.

The SUPERGEN Bioenergy Consortium is led by Aston University and the University of Leeds, with a number of research partners and industrial members, including AMEC, Alstom Power UK, E.ON UK plc and BP. Its activities also include work on combustion and energy conversion. “We are studying the production of different types of biomass and investigating their behaviour in thermal conversion processes, with particular emphasis on the interaction and interface between production and conversion.”<sup>57</sup> The work of the consortium includes research at Rothamsted Research into the quality improvement of crops for power generation.

The BBSRC supports another collective venture in the Sustainable Bioenergy Centre. Established in January 2009, this ‘virtual centre’, a £26 million investment,

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<sup>57</sup> [http://www.supergen-bioenergy.net/?\\_id=1](http://www.supergen-bioenergy.net/?_id=1)

integrates the work of six research programmes that bring together 12 universities and institutes, including Rothamsted Research, with 14 industrial partners.<sup>58</sup>

The BBSRC also supports the Integrated Biorefining Research and Technology Club (IBTI Club), a £6M partnership between BBSRC, the EPSRC, a consortium of leading companies, and the Bioscience for Business Knowledge Transfer Network.

In its work, the BBSRC supports researchers who have active links with many countries including across the EU, USA, Brazil and China. “Research proposals involving overseas collaborations, particularly in developing countries, require careful consideration of the various local applications and implications,” the council states.<sup>59</sup> It funds collaborations with the USA on enhancing the efficiency of photosynthesis that could lead to transformative technologies in bioenergy production. “We are also exploring other opportunities through European research collaborations.”

A number of specialist labs in universities in the UK are addressing particular aspects of biofuels. For example, the Royal Society-Wolfson Advanced Biofuels and Bioenergy Laboratory at Aston University focuses on biomass conversion technologies – the process of transforming plant materials, oils and municipal and agricultural waste into useful and valuable forms of renewable energy.

Like many areas of science and technology, advances in biofuels depend on interdisciplinary teams. One example of this in action is the work on the use algae to produce bioenergy. In Cambridge, for example, the Algal Bioenergy Consortium (ABC) involves a large multidisciplinary group of scientists who aim to use algae for different applications in the bioenergy industry. This consortium brings together molecular biologists, physiologists, engineers and chemical engineers to facilitate the development of future Bioenergy solutions.

The teams in the ABC consortium collaborate with industrial partners to test their ideas. This is an important part of the innovation chain. The commercialisation of algae and other microbial approach to creating biofuels will depend on developing economically competitive industrial processes.

Companies are already working in the UK to commercialise biofuels. Ensus has built a processing plant on Teesside, processing wheat to produce bioethanol and high-protein ingredients for animal feed. The company’s new £250 million biorefinery shipped its first tanker of sustainably produced bioethanol at the beginning of 2010.

Another company, Renewable Energy Crops Ltd, supplies a range of products based on Elephant Grass, *Miscanthus*, to end-users like RWE Npower. Renewable Energy Crops has subsidiaries in the USA and Canada. It also has extensive plantings across Europe, in countries including Ireland, France, Spain, Italy, Germany, Austria, Portugal, Poland and Hungary.<sup>60</sup>

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<sup>58</sup> <http://www.bsbec.bbsrc.ac.uk/>

<sup>59</sup> Bioenergy Research, BBSRC, 2009  
<http://www.bsbec.bbsrc.ac.uk/assets/pdfs/bbsrc-bioenergy-position-statement.pdf>

<sup>60</sup> <http://www.recrops.com/>

British companies have also started operations that depend on setting up managed plantations abroad.

Work on biofuels is of international significance. The UK's scientific expertise can support work in many countries; it also supports indigenous industries to develop exportable technologies. The UK may want to import feedstocks for biofuels, and could export processed materials.

### **Carbon capture and storage**

The world will continue to rely on fossil fuels for electricity generation for many years. If we want to reduce the CO<sub>2</sub> burden that this imposes on the atmosphere, then there is a clear need for science and technology that can decarbonise electricity production. One approach to this is carbon capture and storage (CCS).

CCS technology is intended to capture CO<sub>2</sub> produced in the combustion of fossil fuels before the gas can enter the atmosphere, and then to store the carbon in some way. In its analysis of CCS, the IEA suggests that "without CCS, overall costs to reduce emissions to 2005 levels by 2050 increase by 70%".<sup>61</sup>

CCS requires technologies at three stages: to capture CO<sub>2</sub> at power stations; pipeline to transfer that CO<sub>2</sub> to repositories for ultimate incarceration; and long term storage. While much of the technology for CCS will be transferable, allowing the UK to benefit from developments elsewhere, there are local issues, such as the development of repositories for captured carbon.

In its *Technology Annex – Energy and Low Carbon*, the Technology and Innovation Futures project of the Horizon Scanning Centre says that "Whilst not considered a world leader, the UK has strong capabilities in systems integration, design and engineering and has some of the most advanced CCS demonstrators. There is also [an] opportunity for the UK to develop and export CCS technology."<sup>62</sup>

The technology of CCS is still at an early stage. In its roadmap for CCS, the IEA estimated that it will take a quarter of a century to develop and begin to deploy commercial systems. This long and expensive process "envisions 100 projects globally by 2020 and over 3000 projects in 2050". Over the period of the roadmap, from 2010 to 2050, it "requires an additional investment of over US\$2.5-3 trillion". This is "about 6% of the overall investment needed to achieve a 50% reduction in GHG emissions by 2050".

The UK expects to have CCS projects commissioned on a shorter timescale. In the report, *CO<sub>2</sub> Storage in the UK - Industry Potential*, prepared for the Department of Energy and Climate Change (DECC), Senior CCS Solutions Ltd says that the

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<sup>61</sup> *Technology Roadmap – Carbon capture and storage*, IEA, 2010  
[http://www.iea.org/roadmaps/ccs\\_power.asp](http://www.iea.org/roadmaps/ccs_power.asp)

<sup>62</sup> Foresight Horizon Scanning Centre (2010), *Technology and Innovation Futures: Technology Annex*. URN: 10/1252.  
<http://www.bis.gov.uk/assets/bispartners/foresight/docs/general-publications/10-1252an-technology-and-innovation-futures-annex.pdf>

“Government’s timeline for CCS in the UK envisages commercial deployment in the period 2020-2025, after a demonstration programme of four projects. The first integrated CCS projects are expected to be UK based projects.”<sup>63</sup>

The report for DECC draws attention to the need for the UK to develop repositories for captured CO<sub>2</sub>. The UK does have good candidates for carbon storage in depleted North Sea gas fields. “Storage in depleted gas fields is the most important storage type for the UK, with low risk, potentially enough storage capacity to meet national CCS deployment requirements and wide regional distribution.” However, the report adds that “A key issue for CCS and for government is that developing storage sites may be an uncertain, time-consuming, costly and risky business opportunity.”

The Energy Technologies Institute (ETI), a joint venture that brings together companies that are engaged in energy activities, government departments and the EPSRC in a private-public partnership, funded equally by member companies and the UK Government, has set out to investigate this issue. (Members of the ETI include Rolls-Royce and Caterpillar, international companies that are in a position to develop the export potential of any new technologies that arise from any projects that the organisation initiates.) The ETI has embarked upon a detailed study of the availability and distribution of suitable minerals across the UK and technologies that could be economically viable for CCS. The project will also identify the technologies that could be developed to meet the UK’s requirements.

The ETI’s project is part of the organisation’s wider programme of R&D into CCS. The institute is also planning a demonstration project. The size of the task is such that developing CCS technology will require international collaboration, especially if developed countries are to assist the take up in less wealthy countries. In its roadmap, the IEA asserts that this will require “expanded international collaboration and financing for CCS demonstration in developing countries at an average annual level of US\$1.5 to 2.5 billion from 2010 to 2020.

The EU supports the development of CCS for coal-fired power plants, with the aim of making the technology commercially feasible by 2020.

Proving the technology of CCS is one thing, turning that into successful business takes further action. One indicator of the need to create new business models is the recent initiative that brings together Arup, the law firm Martineau, and Yellow Wood Energy. The three have set up an alliance that, according to Steve Argent of Arup, hopes to create a “single source that can cover all the bases”.<sup>64</sup> Such activities will prepare these businesses to exploit what could be a growing global market for CCS technology and associated services.

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<sup>63</sup> *CO<sub>2</sub> Storage in the UK - Industry Potential*, DECC, 2010  
[http://www.decc.gov.uk/Media/viewfile.ashx?FilePath=What%20we%20do\UK%20energy%20supply\Energy%20mix\Carbon%20capture%20and%20storage\1\\_20100317090053\\_e@@\\_UKStorageIndustryPotentialSeniorCCS.pdf&filetype=4](http://www.decc.gov.uk/Media/viewfile.ashx?FilePath=What%20we%20do\UK%20energy%20supply\Energy%20mix\Carbon%20capture%20and%20storage\1_20100317090053_e@@_UKStorageIndustryPotentialSeniorCCS.pdf&filetype=4)

<sup>64</sup> Arup press release, June 2010  
[http://www.arup.com/News/2010\\_06\\_June/01\\_Jun\\_2010\\_Carbon\\_Capture\\_Storage\\_partnership.aspx](http://www.arup.com/News/2010_06_June/01_Jun_2010_Carbon_Capture_Storage_partnership.aspx)

## International dimensions

For the UK, a major goal of energy policy is to achieve secure energy supplies that are not liable to interruption by events beyond our control. Imports from politically sensitive regions are all too easily disrupted. The policy has been to take a two pronged approach that delivers energy that is both secure and environmentally sustainable.

The challenges we face in developing low-carbon energy production have prompted growing international collaboration on R&D. For example, in October 2009 ministers from the 28 countries within the IEA agreed to accelerate the development and deployment of cleaner energy technologies.<sup>65</sup> They also endorsed the development of an international low-carbon energy technology platform which, according to Nobuo Tanaka, Executive Director of the IEA, “provides an international forum that enables countries to work together with industry and other international organisations to create country-specific, strategic energy technology plans drawing on the work of the IEA, the IEA global energy technology network and other ongoing initiatives.”

The IEA supports international collaboration through its Committee on Energy Research and Technology (CERT). The IEA set up CERT in 1975, in response to another energy crisis, “to examine and report on co-operative action in the conservation of energy”. CERT’s current mission is to “maximise energy technology’s impact by optimising international collaborative RD &D and deployment, by initiating timely technology assessment, analysis and scenarios, by engaging IEA non-member countries and, crucially, by delivering policy guidance that will make a difference.”

The EU continues to play a central role in coordinating energy R&D within Europe. However, it too realises that member countries cannot act alone. As the Commission says in the report *International cooperation in EU energy research* “The SET Plan recognises that now, more than ever, energy research must be a global endeavour, with international research cooperation leading to more effective results.”<sup>66</sup>

In this document, the EU lists what it hopes to achieve through cooperating with international partners on energy research. The EU hopes to:

- make Europe more competitive by forming strategic partnerships with other countries;
- address specific issues that other countries face as well as problems that are global in nature;
- use energy research cooperation to strengthen the EU’s relations with other countries and support the EU’s work in other areas, such as combating

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<sup>65</sup> *Energy Technology Initiatives – Implementation through Multilateral Co-operation*, IEA, 2010

<sup>66</sup> *International cooperation in EU energy research*, European Commission, 2010  
[http://bookshop.europa.eu/is-bin/INTERSHOP.enfinity/WFS/EU-Bookshop-Site/en\\_GB/-/EUR/ViewPDFFile-OpenPDFFile?FileName=KI3209191END\\_002.pdf&SKU=KI3209191END\\_PDF](http://bookshop.europa.eu/is-bin/INTERSHOP.enfinity/WFS/EU-Bookshop-Site/en_GB/-/EUR/ViewPDFFile-OpenPDFFile?FileName=KI3209191END_002.pdf&SKU=KI3209191END_PDF)

climate change, ensuring the security of energy supply and supporting developing countries.

Europe's Strategic Energy Technology Plan (SET-plan) includes initiatives in various low-carbon energy technologies:

- European Industrial Bioenergy Initiative – €9 billion over 10 years.
- European CO<sub>2</sub> Capture, Transport and Storage Initiative – some €13 billion over 10 years, depending mainly on the number and size of demonstration plants built.
- European Electricity Grid Initiative – €2 billion over 10 years excluding the costs of generic assets used in the demonstration
- Fuel Cells and Hydrogen (FCH) Joint Technology Initiative – €1 billion for the years 2008-2013 financed in equal parts by the European Commission and the industry.
- Sustainable Nuclear Initiative – €7-10 billion over 10 years.
- Energy Efficiency – The Smart Cities Initiative
- Solar Europe Initiative – around €16 billion over ten years
- European Wind Initiative – estimated cost, €6 billion over 10 years

These initiatives include industrial sized demonstration projects or 'first of a kind' plants.<sup>67</sup> Europe's geographical spread means that these plants can take advantage of different geographical, social and climatic conditions.

The EU works with international partners through multilateral agreements, including agreements made through such agencies as the IEA, the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) and the Carbon Sequestration Leadership Forum (CSLF). The UK provides a vice chair for the CSLF's Policy Group and operates a number of "recognised projects". While these groupings do not commission or conduct research, they can play a part in the wider collaboration on issues that are important in the development of the science and technology needed to tackle climate change.

Among other multilateral agreements, the EU and Russia have launched joint research projects in the fields of electricity network management and power generation from biomass. Research cooperation with China focuses largely on 'near-zero-emissions coal technology'.

One challenge that the UK and other countries face is in finding ways to support the development and testing of new energy technologies. This is an area where government procurement and support can play an important role. For example, the US Department of Defence (DoD), the country's largest government user of energy, already supports a number of renewable energy initiatives. A report from the United

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<sup>67</sup> *The European Strategic Energy Technology Plan – Towards a low-carbon future*, European Union, 2010  
[http://ec.europa.eu/energy/publications/doc/2010\\_setplan\\_brochure.pdf](http://ec.europa.eu/energy/publications/doc/2010_setplan_brochure.pdf)

States Government Accountability Office said that “As of April 22, 2010, DoD reported to us that it has 454 renewable energy initiatives currently producing energy or under development.”<sup>68</sup>

These initiatives encompass a variety of carbon-free power sources at military installations, in the US and overseas. The technologies include solar, wind, geothermal and biomass energy at different scales. Around a half of these initiatives are solar photovoltaic. One project involves solar-powered street lights that illuminate an installation road while larger initiatives include a wind turbine and a waste-to-energy conversion project.

## Transport

Transport is perhaps the most visible and controversial source of CO<sub>2</sub> emissions. In his review of the transport in the UK, Sir Rod Eddington said that as “transport contributes around a quarter of UK emissions and is the fastest rising source of carbon emissions within the economy in the near term, addressing the challenge of climate change has important implications for any long-term transport strategy”.<sup>69</sup>

In some countries, emissions are much higher. For example, in the US, road transport accounts for 33% of total emissions. Transport’s share of CO<sub>2</sub> emissions is also increasing in all regions of the world. According to the report of the European Conference of Ministers of Transport, *Cutting Transport CO<sub>2</sub> Emissions: What Progress?*, transport’s share of world emissions increased from 22% in 1990 to 24% in 2003.<sup>70</sup>

Major initiatives are already under way to ‘decarbonise’ transport. Most car makers, for example, plan to market electric vehicles in the near future. The aviation sector is investigating the possible use of biofuels.

While these plans try to allow a ‘business as usual’ approach to transport and mobility, other technologies could have greater impacts. One area where we have barely started to develop the technologies is in intelligent transport systems (ITS). This brings the power of modern information and communications technologies to transport.

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<sup>68</sup> *Defense Infrastructure: Department of Defense’s Renewable Energy Initiatives*, April 2010  
<http://www.gao.gov/new.items/d10681r.pdf>

<sup>69</sup> *The Eddington Transport Study*, HMSO, 2006  
<http://webarchive.nationalarchives.gov.uk/+/http://www.dft.gov.uk/about/strategy/transportstrategy/eddingonstudy/>

<sup>70</sup> *Cutting Transport CO<sub>2</sub> Emissions: What Progress?*, OECD, 2007  
<http://titania.sourceoecd.org/vl=1604428/cl=21/nw=1/rpsv/~6687/v2007n1/s1/p11>

The Foresight Project Intelligent Infrastructure Systems (IIS) describes many of the opportunities and technologies that ITS can offer. These include not only reducing energy use but also by providing alternatives to travel.<sup>71</sup>

In its report *ITS (UK) Strategy to support carbon reduction and to address climate change issues*, The Carbon Working Group of ITS UK suggests several ways in which the technology can help us to cope with the effects of climate change. For example, “ITS can assist with adaptation to the effects of climate change by reducing the disruptions to travel as a result of weather events.”

ITS can also promote “eco driving”, encouraging motorists to drive in a more energy efficient way. As its strategy report puts it “Technology could be used to encourage particular driving styles using in-vehicle and infrastructure-to-vehicle systems.”

The need to build a new infrastructure to recharge electric vehicles could also benefit from developments in ICT. For example, the consultants Frost & Sullivan suggest that vehicle telematics, the integration of vehicle monitoring and location and communications, could be a solution to “range anxiety”, the fear that a vehicle’s battery is inadequate to complete their journey, thus discouraging the adoption of the technology. Telematics can reduce range anxiety by helping drivers to drive in an energy efficient way and to locate and book charging stations. It could be a part of wider move to a new business model, with drivers leasing electric vehicles as a way of avoiding higher capital costs.

## Food and agriculture

The food and agriculture sector is also a significant contributor to climate change. It is, therefore, in need of science and technology to reduce its impact.

Agriculture creates CO<sub>2</sub> emissions through its use of energy, from such activities as the use of machinery, consumption of gas and electricity in buildings and so on. Livestock production also creates emissions of methane, another greenhouse gas.

Some energy consumption is unique to agriculture. For example, the production and use of nitrogen fertiliser are major sources of CO<sub>2</sub>. The use of nitrogen fertilisers is falling in Europe: the report *European Food Systems in a Changing World* says that the “amount of mineral nitrogen fertiliser consumption in the EU-15 has decreased by ca. 15% between 1995 and 2005”.<sup>72</sup> In the UK, the use of nitrogen fertiliser fell by 10% between 1990 and 1998.<sup>73</sup> However, globally production of fertilisers continues

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<sup>71</sup> *Intelligent Infrastructure Futures Project Overview*, Office of Science and Technology, 2006  
[http://www.foresight.gov.uk/Intelligent%20Infrastructure%20Systems/Project\\_Overview.pdf](http://www.foresight.gov.uk/Intelligent%20Infrastructure%20Systems/Project_Overview.pdf)

<sup>72</sup> *European Food Systems in a Changing World*, European Science Foundation, 2009  
[http://www.esf.org/index.php?eID=tx\\_ccdamdl\\_file&p\[file\]=25400&p\[dI\]=1&p\[pid\]=4050&p\[site\]=European%20Science%20Foundation&p\[t\]=1277714257&hash=5972abc04bc5a451e7d2ae9d1e32112a&l=en](http://www.esf.org/index.php?eID=tx_ccdamdl_file&p[file]=25400&p[dI]=1&p[pid]=4050&p[site]=European%20Science%20Foundation&p[t]=1277714257&hash=5972abc04bc5a451e7d2ae9d1e32112a&l=en)

<sup>73</sup> *Climate Change – The UK Programme*, HMSO, 2000  
[http://decc.gov.uk/en/content/cms/what\\_we\\_do/change\\_energy/tackling\\_clima/programme/programme.aspx](http://decc.gov.uk/en/content/cms/what_we_do/change_energy/tackling_clima/programme/programme.aspx)

to increase.<sup>74</sup> There is, therefore, the opportunity for research that helps to reduce the consumption of fertilisers without harming agricultural production.

According to the *OECD-FAO Agricultural Outlook 2010-2019* “In 2005, agriculture contributed about 10-12% of greenhouse gas emissions (GHGs). Agriculture accounts for about 50% of global methane and about 60% of global N<sub>2</sub>O emissions.”<sup>75</sup> Livestock farming makes up around 80% of those emissions, including methane, which is more potent than carbon dioxide as a greenhouse gas.<sup>76</sup>

The OECD-FAO also highlights the importance of science and technology. “Public and private agricultural research capital and public agricultural extension can introduce new technologies that can enhance agricultural productivity.” It takes time for science to improve agricultural productivity, so, as the OECD-FAO puts it “the foundations for new agricultural technologies of 2018 are being laid today”. By investing less in research today, we run the risk that a decade from now the upward increase in agricultural productivity will falter.

## **Manufacturing (resources)**

The IDCC report on “Physical resources and commodities and climate change”, R3, has indicated the commodities and resources that are most likely to be affected<sup>77</sup>. This shows that ‘manufacturing’ is by far the largest category of imported ‘resources’ that are likely to be affected by climate change. The report says that “Climate change will affect manufacturing in a number of ways, but it is assumed here that the dominant effects will be from impacts on regional energy supply, transportation and water availability.”

R3 warns that manufacturing “is a particularly difficult sector to assess from a climate change perspective”. This is primarily because manufacturing encompasses a huge range of goods and processes. The biggest threats to manufacturing and the trade of manufactured goods are likely to arise from problems with electricity or water supply, or the transportation of raw materials and manufactured goods.

## **Mining and minerals**

The UK also relies on large imports that can be classified as ‘mining and quarrying’. While there are also significant imports of agricultural and other food products, we have discussed this elsewhere.

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<sup>74</sup> *Fertilizer Outlook 2009-2013*, International Fertilizer Industry Association, 2009  
<http://www.fertilizer.org/ifa/Home-Page/LIBRARY/Publication-database.html/Fertilizer-Outlook-2009-2013.html>

<sup>75</sup> *OECD-FAO Agricultural Outlook 2009-2018*, OECD, 2009  
<http://puck.sourceoecd.org/vl=8080235/cl=45/nw=1/rpsv/cgi-bin/fulltextew.pl?prpsv=/ij/ocdthemes/9998010x/v2009n10/s1/p1l.idx>

<sup>76</sup> *OECD-FAO Agricultural Outlook 2010-2019*, OECD, 2010  
[http://www.agri-outlook.org/pages/0,2987,en\\_36774715\\_36775671\\_1\\_1\\_1\\_1\\_1,00.html](http://www.agri-outlook.org/pages/0,2987,en_36774715_36775671_1_1_1_1_1,00.html)

<sup>77</sup> *IDCC Report R3: Physical Resources and Commodities and Climate Change*. Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

Report 3, Physical Resources and Commodities and Climate Change, suggests that for some regions of the world, “changes to the climate such as increases in temperature, changes in precipitation, sea level rise and reductions in the availability and reliability of water resources could make mining and extraction a more difficult and expensive process”<sup>78</sup>. The report adds that there could then be a demand for “engineering solutions to problems such as water extraction and desalination, temperature control, and flood management”. The UK has companies that are active in these sectors as well as established research expertise that could address these challenges.

The report does point out that mining activities are often already in environmentally inhospitable places, where weather and climate are just one of the physical challenges faced in extraction. “However, it is true that most of the current practices and equipment designs are developed for current climatic conditions, so any changes to those conditions that are not adequately planned for, will represent an additional cost.”

### **Energy and water**

Manufacturing relies on energy and water. Both of these ‘resources’ are themselves prone to the influence of climate change. When it comes to its energy consumption, manufacturing faces the same challenges as other activities. However, some aspects of the need for low-carbon energy are particular to manufacturing.

The IEA has recently studied the energy requirements on industry, *Energy Technology Transitions For Industry: Strategies for the Next Industrial Revolution*. This report points out that “Nearly one-third of global energy demand and almost 40% of worldwide CO<sub>2</sub> emissions are attributable to industrial activities.”<sup>79</sup> In recent years the energy efficiency of manufacturing has improved; CO<sub>2</sub> intensity has declined substantially in many sectors. However, rising production mean that the CO<sub>2</sub> emissions from industry continue to increase.

The IEA is of the view that “Making substantial cuts in industrial CO<sub>2</sub> emissions will require the widespread adoption of current best available technology (BAT), and the development and deployment of a range of new technologies.” Furthermore, the IEA makes the case that we need urgent action and that “industrial emissions must peak in the coming decade if the worse impacts of climate change are to be avoided”. Any action has to be global. While OECD countries now account for a third of current global industrial CO<sub>2</sub> emissions, increasing production by non-OECD countries means that “by 2050, in the absence of any further action, they will account for 80% of global industrial CO<sub>2</sub> emissions”.

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<sup>78</sup> *IDCC Report R3: Physical Resources and Commodities and Climate Change*. Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

<sup>79</sup> *Energy Technology Transitions For Industry: Strategies for the Next Industrial Revolution*, IEA, 2009  
[http://www.iea.org/publications/free\\_new\\_Desc.asp?PUBS\\_ID=2104](http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=2104)

Adopting today's BAT could reduce industrial energy use by up to between 20% and 30%. The IEA's analysis of different scenarios for growth and energy use suggests that "Energy efficiency gains will need to increase to 1.3% per year, double the rate seen in the Baseline scenarios." This will require the development of new energy-efficient technologies to maintain significant reductions in CO<sub>2</sub> emissions into the second half of the century and the development of carbon-free production processes.

The IEA highlights the production of the iron and steel and cement as sectors that will require deep reductions in emissions. Other energy intensive sectors that need to reduce their emissions include chemicals and petrochemicals, pulp and paper, and aluminium. In all, these five sectors account for 75% of total direct CO<sub>2</sub> emissions.

One option open to industry is to make greater use of biomass and biomass waste. Industry would, though, have to compete with other sectors for what will be a limited resource. The IEA's report warns that "Such competition will put significant pressure on the price of biomass and could create economic barriers that could limit its potential use in industry."

A global move towards low carbon energy production will affect the demand for materials. While the IEA expects that there will be a small impact on the overall demand for most major commodities, "constraints on the availability of certain specialty materials could reduce the penetration levels of some low-carbon technologies". Removing carbon from energy production will actually increase the demand for some materials but the energy sector has a relatively modest need for materials so it will have a limited impact on total demand.

Several materials could come under pressure in a move to low carbon energy production. Lithium, for example, could see rising demand for batteries in electric vehicles. Batteries for electric vehicles also contain the rare earth element lanthanum. Another rare earth mineral, neodymium, is a component of the lightweight magnets that are a part of the electric motors used in hybrid and electric vehicles.

The concern with the rare earth elements is that there are currently few sources. Some 97 per cent of the world's supply of rare earth elements comes from China, predominantly one mine in Inner Mongolia. China has already caused concern by limiting exports of these essential materials, a move that has prompted plans to revive production in the USA.

The need to reduce dependence on imports of rare earths is already driving research into alternative materials. It is also an incentive to increase the recycling of such materials and, indeed, of all resources.

### **Roadmaps of the future**

To prepare for the development and implementation of new technologies for manufacturing, the IEA advocates the use of roadmaps that "include all the technical, policy, legal, financial, market and organisational requirements that are necessary to deliver an earlier uptake of more efficient and low carbon technologies into the market".

Any development of new technology will need government backing for the early stages of research, development and demonstration (RD&D). This is against a trend of declining government investment in RD&D. In energy RD&D alone, its share of total RD&D in OECD countries declined from 11% in 1985 to 3% in 2005.

The IEA highlights a number of priority areas where there is a need for more RD&D. These include the development of technologies for carbon capture and storage (CCS) for several processes in the manufacture of iron and steel, cement, chemicals and pulp and paper. These key technologies also include the use of hydrogen in the chemicals, pulp and paper, and aluminium sectors.

The development of these technologies will rest not with the producers of iron and steel and cement, for example. These industries buy their process equipment from specialised suppliers. The IEA's report points out that "While the industry has come together to promote collaborative R&D in iron and steel, and more recently in cement, this is not the case in the aluminium industry."

The report also states that "Investment is also needed in research to help identify new, potentially breakthrough technologies, which may have the capacity to overturn the limitations of current knowledge." It spells out some near-term priorities for RD&D. These include "Achieving long-term and substantial reductions in CO<sub>2</sub> emissions from industry is dependent on a wide range of innovative industrial technology developments, including materials and product efficiency, process innovation, energy and feedstock substitution, and CCS."

The IEA's report suggests that technology transfer is an issue that needs addressing. New technology often needs to be adapted to local conditions. For small and medium-sized enterprises, "access to new technology and intellectual property rights (IPR) pose an issue". While finance is a barrier to the transfer of technology, it is but one issue that needs to be addressed. As the IEA puts it "Achieving deep reductions in industrial CO<sub>2</sub> emissions will need to include mechanisms that can address all the relevant barriers and so facilitate the transfer and deployment of low-carbon technologies in developing countries."

Despite recent increases in the manufacturing output of China and other countries, Europe remains a major supplier of manufactured goods and a leader in developing new manufacturing technologies. This is in part due to continued R&D in this sector. Here too there is a European dimension through such activities as the work of the European Commission and its Factories of the Future Public-Private Partnership (FoF PPP). This is a "€1.2 billion programme in which the European Commission and industry will support the development of new enabling technologies for EU manufacturing which have cross-sectoral benefits and contribute to greener production".<sup>80</sup>

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<sup>80</sup> *New public-private partnerships for research in the manufacturing, construction and automotive sectors*, European Commission, 2009  
[http://ec.europa.eu/research/industrial\\_technologies/pdf/brochure-ppp-090622\\_en.pdf](http://ec.europa.eu/research/industrial_technologies/pdf/brochure-ppp-090622_en.pdf)

The 'roadmap for the FoF PPP states that "Environmental challenges such as climate change and resource scarcity are the source of both constraints and opportunities for technological development."<sup>81</sup>

## Health

While it has few unique impacts on climate change, the health sector shares the need to reduce its carbon footprint. However, remediation brings with it several health issues. For example, reducing the emissions of carbon dioxide could have beneficial effects. In its survey "*The health benefits of tackling climate change*", *The Lancet* points to the health improvements that could arise from more efficient use of domestic energy for heating and cooking.

Potential health benefits from tackling climate change could arise mostly through the improvements in air quality that would follow the introduction of cleaner ways of using energy. While this might yield minor health improvements in the UK, in other countries the gains would be more dramatic.

For example, better ways of cooking food would bring substantial benefits in India. In its review, *The Lancet* points out that "Indoor air pollution from inefficient cookstoves increases the risk of acute respiratory tract infections in children younger than 5 years and chronic respiratory and heart disease in adults older than 30 years. Globally, almost 1 million children are currently dying every year of respiratory infections induced or exacerbated by the inefficient burning of solid fuels."

These may not be introduced simply to reduce climate change as to improve the efficiency of energy consumption, but the benefits would be there all the same. Recognising, and publicising, such incidental benefits could support attempts to "sell" new technologies that set out to address climate change.

Changes in transport that set out to address climate change could also yield secondary benefits such as changes in health patterns. In its survey, *The Lancet* points to health benefits that could arise from walking and cycling. Not only would this reduce emissions of greenhouse gases, in London, for example, "more active travel would bring substantial health gains. Heart disease and stroke could fall by 10–20%, with reductions in breast cancer (12–13%), dementia (8%), and depression (5%)."

The WHO also points to health benefits that could arise from action taken to reduce our impact on the climate: "Many policies and individual choices have the potential to reduce greenhouse gas emissions and produce major health co-benefits. For example, promoting the safe use of public transportation and active movement – such as cycling or walking as alternatives to using private vehicles – could reduce carbon dioxide emissions and improve health."

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<sup>81</sup> *Factories Of The Future PPP – Strategic Multi-Annual Roadmap*, European Commission, 2009  
[http://ec.europa.eu/research/industrial\\_technologies/pdf/ppp-factories-of-the-future-strategic-multiannual-roadmap-info-day\\_en.pdf](http://ec.europa.eu/research/industrial_technologies/pdf/ppp-factories-of-the-future-strategic-multiannual-roadmap-info-day_en.pdf)

Energy technologies with lower emissions of carbon dioxide will also affect health. For example, as coal consumption declines so will the emissions of potentially harmful particles. This could result in lower incidences of cardiopulmonary disease and lung cancer. These effects will be particularly significant in China and India.

The main focus of efforts to reduce climate change is on long-lived greenhouse gases, particularly CO<sub>2</sub>. However, *The Lancet* points out in its survey that measures that reduce long lasting emissions will also affect short-lived pollutants that also contribute, directly or indirectly, to global warming. These more ephemeral pollutants include sulphate, organic and carbon particles, carbon monoxide, volatile organic compounds and other gases that are responsible for ozone creation, such as methane and nitrogen oxides.

These emissions of short-lived pollutants are important because they cause most of the direct damage to human health from energy. "Breathing air laden with particles from fuel combustion is associated with increased morbidity and mortality. WHO has estimated that in 2000 this caused well over 2 million premature deaths".

Moves to reduce emissions of greenhouse gases may lead to beneficial health effects, but there is also the possibility that alternative approaches to the production and use of energy will themselves bring harmful health effects. For example, some types of biofuel have health implications, ranging from relatively trivial issues such as the odours that emanate from processing facilities to more significant concerns.

Health concerns can also overlap with others areas where science and technology is a factor. For example, climate change can affect food safety (see below).

## **Adapting to climate change**

Adaption refers to taking measures to reduce our vulnerability to the effects of climate change, by modifying and protecting infrastructure, for example, so that it can withstand changes in weather patterns, rising sea levels and increased frequency and intensity of extreme weather. The IPCC defines adaptation as having three objectives: to reduce exposure to the risk of damage; to develop the capacity to cope with unavoidable damages; and to take advantage of new opportunities.

In its report, *Adapting to Climate Change*, the House of Commons Environmental Audit Committee warned that "The need to adapt to climate change is poorly understood by the public, much of business and many in the public sector."<sup>82</sup>

The Royal Commission on Environmental Pollution (RCEP), in the report, *Adapting Institutions to Climate Change*, avers that "Mitigation and adaptation are not alternatives."<sup>83</sup> The 'locked in' change to the environment due to the current burden of

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<sup>82</sup> *Adapting to Climate Change*, House of Commons Environmental Audit Committee, 2010 <http://www.publications.parliament.uk/pa/cm200910/cmselect/cmenvaud/113/11302.htm>

<sup>83</sup> *Adapting Institutions to Climate Change*, Royal Commission on Environmental Pollution, 2010 <http://www.rcep.org.uk/reports/28-adaptation/28-adaptation.htm>

CO2 is such that “we face the challenge of having to adapt even if mitigation is successful”.

The RCEP goes on to say that “adaptation is primarily local: the effects of weather are felt in particular places. Whilst we shall feel the effect of certain climate impacts elsewhere in the world, adaptation measures need to be adopted within domestic policies and programmes and will be specific to UK circumstances. ”

In this way, the international dimensions of adaptation are unlike those for other aspects of climate change. While the UK has international obligations to reduce its emissions of CO2, mitigation is essentially a domestic concern.

## European dimensions

As in other aspects of climate change, the UK’s own responses will be a part of a wider approach within the EU. While the EU also sees adaptation as primarily an issue that will require measures at “national, regional or local level” its White Paper on adaptation states that “these measures can be supported and strengthened by an integrated and coordinated approach at EU level”.<sup>84</sup>

The Commission’s White Paper states that “Adaptation will require solidarity among EU Member States to ensure that disadvantaged regions and regions most affected by climate change will be capable of taking the measures needed to adapt. Moreover, coordinated EU action will be necessary in certain sectors (e.g. agriculture, water, biodiversity, fisheries, and energy networks) that are closely integrated at EU level through the single market and common policies.”

The White Paper also suggests that the EU “is well placed to facilitate coordination and the exchange of best practices between Member States on climate”. To assist in this coordination, the Commission suggests that “An effective way to improve knowledge management would be to establish a Clearing House Mechanism as an IT tool and database on climate change impact, vulnerability and best practices on adaptation.”

The EU has started this process in the creation of a Knowledge and Innovation Community (KIC) on climate as a part of the European Institute of Innovation and Technology (EIT). The Climate-KIC sets out to “drive innovation in the area of climate change adaptation and mitigation through integrated and creative partnerships between business, academic and public institutions”.<sup>85</sup>

As in other areas, the EU can also be a focus for international discussions of climate change and adaptation. A Commission Staff Working Document suggests that “At the international level, closer cooperation with key third countries should be pursued, by exploring possibilities provided by existing Science & Technology agreements and focusing on important, mutually agreed, research questions and topics. Special

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<sup>84</sup> *Adapting to climate change : towards a European framework for action*, Commission of the European Communities, 2009  
<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52009DC0147:EN:NOT>

<sup>85</sup> <http://www.climate-kic.org/>

attention will be given to regions/countries that are particularly vulnerable to climate change.”<sup>86</sup>

### **Adaptation for development**

The UK will also depend on adaptation that other countries implement to protect essential infrastructure, especially the ports that are so important in the international trade in energy, agricultural products and manufactured goods. However, in the context of the IDCC project, perhaps the most significant issues surrounding adaptation is in the opportunities that it opens up for British companies. For example, as a major player in construction and civil engineering, the UK is well placed to help countries to adapt their own essential infrastructure. The UK can also help countries to understand how climate change could affect them and to prepare their adaptation strategies.

Support for international responses to climate change could also become increasingly important in the UK’s support for developing countries, many of which could be especially hard hit by the effects of climate change. The report, a joint paper produced under the auspices of leading international and national organisations, *Poverty and Climate Change – Reducing the Vulnerability of the Poor through Adaptation* states that “Adaptation is necessary and there is a need to integrate responses to climate change and adaptation measures into strategies for poverty reduction to ensure sustainable development.” The international community has an important part to play here, for as the report says “the task ahead is to increase the adaptive capacity of affected poor communities and countries”.

The Adaptation Sub-Committee of the Committee on Climate Change has also considered the role that the UK can play in the global adaptation process. In its report *How well prepared is the UK for climate change?*, the sub-committee recommends that the UK government “could focus more effort on understanding the international implications of climate change on the UK. This should include sharing good practice with other countries that are also going through the process of setting adaptation outcomes.”<sup>87</sup>

### **Sector challenges**

Adaptation is a complex challenge that will require all sectors to respond to the likely impacts of climate change. However, as is the case with mitigating climate change, some sectors deserve particular attention.

For example, while energy supply will have to adapt to rising sea levels and the possibility of more frequent flooding, it does not require unique science and technology in to the same extent as agriculture. Many of the challenges facing

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<sup>86</sup> *Integrated climate change research following the release of the 4<sup>th</sup> Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) and most recent research developments*, European Commission Staff Working Document, 2008  
[http://ec.europa.eu/research/environment/pdf/commission\\_working\\_doc.pdf](http://ec.europa.eu/research/environment/pdf/commission_working_doc.pdf)

<sup>87</sup> *How well prepared is the UK for climate change?* Adaptation Sub-Committee of the Committee on Climate Change, 2010  
<http://www.theccc.org.uk/reports/adaptation>

energy supply and transport are local, while our heavy dependence on imported food means that the UK has to concern itself with the global picture. However, the UK's reliance on imports is such that adaptive measurements taken by exporters will affect our ability to maintain energy imports.

The UNFCCC has paid increasing attention to the challenge of adaptation in the work of its Expert Group on Technology Transfer and analysed the situation in several developing regions, Africa, Asia, Latin America and Small Island developing states.<sup>88</sup>

## **Food and agriculture**

We have already seen how climate change could affect agriculture and food production and the measures that might be necessary to mitigate their impact on the climate. Agriculture will also require advances in science and technology if it is to adapt to climate change.

Increased agricultural productivity is a priority. As the Royal Society said in its report, *Reaping the benefits – Science and the sustainable intensification of global agriculture* “There is a pressing need for the ‘sustainable intensification’ of global agriculture in which yields are increased without adverse environmental impact and without the cultivation of more land.”

While not driven primarily by climate change, productivity is essential if we are to be in a position to feed a population that is affected by global warming. The IFPRI calls for investments in agricultural productivity. “Crop and livestock productivity-enhancing research, including biotechnology, will be essential to help overcome stresses due to climate change.”

Water and agriculture are inextricably tied together. Even without climate change, there is competition for water. Irrigation is one area where advances in science and technology can help us to adapt to the possible effects of climate change. As the OECD-FAO puts it: “Future gains in irrigated agriculture will come from improved performances of existing irrigation in all irrigated regions of the world, in order to meet the projected global increase in agricultural commodity production.”

## **Plant breeding**

The OECD-FAO *Agricultural Outlook 2010-2019* states that “Plant breeding is a major factor contributing to increased food security whilst reducing input costs, greenhouse gas emissions and deforestation.” It then warns that “Concerns have been expressed that global plant breeding capacity has been declining.”

The UK has traditionally been strong in some areas of agricultural research, such as plant breeding and plant diseases that we will need to meet the challenges of climate change. The Royal Society warns that “UK scientists and agronomists have in the past played a leading role in disciplines relevant to agriculture, but training in

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<sup>88</sup> *Climate Change: Impacts, Vulnerabilities And Adaptation In Developing Countries*, UNFCCC, 2007

agricultural sciences and related topics has recently suffered from a lack of policy attention and support.”

In the UK, the Biotechnology and Biological Sciences Research Council (BBSRC) has a long track record of supporting research in plant breeding. However, it is seeking to address what it has identified as “a severe lack of trained plant breeders in the UK”.

The BBSRC supports several research institutes working in plant science. It brings this expertise to the Sustainable Agriculture and Food Innovation Platform which the Technology Strategy Board launched in 2009 in partnership with DEFRA and the BBSRC.<sup>89</sup> Over the next five years there will be an investment of up to £90 million in projects to develop new technologies. The partners in this initiative believe that developing solutions to major societal challenges “presents at the same time a market opportunity for UK businesses throughout the food supply chain”.

The UK, along with other European countries, works with a handicap in that public hostility means that the agricultural sector cannot employ genetic modification (GM) to create improved crop varieties. However, the research community’s inability to develop the science and technology for use in its own backyard has not prevented it from taking field forward. Even if the UK cannot use the techniques, it is well placed to export them to regions where GM crops are not only accepted but welcome.

In 2008, 13 million farmers in 25 countries planted 125 million hectares of GM crops globally.<sup>90</sup> Within this, the EU accounted for about 65,000 ha. No commercial GM crops are grown in the UK.

In the Technology Annex of the Technology and Innovation Futures report<sup>91</sup>, the Foresight Horizon Scanning Centre (HSC) refers to the possibility of developing second or third generation GM products. Second generation GM would include crop traits aimed at pests, diseases and weeds, as well as crops that with commercially viable yields of desirable products such as oils and starches. Third generation products are those furthest from commercialisation and include plants that have the ability to withstand environmental stresses.

The HSC’s report points out that the focus of much of the research into these traits “has concentrated on crops not typically grown in the UK, notably maize, soybeans and cotton”. However it adds that “some commercial applications are being explored in crops that are relevant to the UK, such as oilseed rape, forage maize, potatoes and sugar beet. Also, some “pipeline” traits could apply to crops such as wheat and sugar beet. These pipeline developments could improve the profitability and

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<sup>89</sup> *Sustainable Agriculture and Food Innovation Platform*, Technology Strategy Board, 2009

<sup>90</sup> *Technology and Innovation Futures Technology Annex – Energy and Low Carbon*, Foresight Horizon Scanning Centre, 2010

<sup>91</sup> Foresight Horizon Scanning Centre (2010), *Technology and Innovation Futures: Technology Annex*. URN: 10/1252.  
<http://www.bis.gov.uk/assets/bispartners/foresight/docs/general-publications/10-1252an-technology-and-innovation-futures-annex.pdf>

competitiveness of the UK's agricultural sector through lower costs and higher productivity if the technology becomes acceptable.”

Work on GM crops is underpinned by the UK's world leading position in genetics generally. That knowledge also supports more traditional techniques for improving crops. The Royal Society described this in its report when it said, “In genetic improvement strategies these genes can be targeted in breeding programmes or they can be transferred into crops by GM... However, it should be stressed that the information from genomic studies is also important for the science that underpins changes in crop management. The information about genes, proteins and metabolites in crop plants allows strategies for crop management to be developed that maximise agronomic performance of crops in a sustainable way.”<sup>92</sup>

### **Drought resistant crops**

One area where research in the UK could deliver both local and global benefits is in the understanding of how crops respond to drought conditions. Concerns about water supply underpin much of the concern about the impacts of climate change on agriculture. Within OECD countries, agriculture accounted for 44% of total water use in 2002-04 – over 60% in some countries.

Strategies for dealing with drought include the development of new varieties, using both GM and traditional approaches to plant breeding. Plant breeding has produced drought-resistant varieties of oilseed rape, sugar-beet suitable for UK climates, and pearl millet – a crop that assures food security for half a billion people across Africa and Asia. Breeding has also created shorter varieties of wheat that produce more edible grain and less inedible stem. Scientists are now breeding ‘dwarf’ varieties of the world's other staple crops, such as sorghum, rice and maize.

A number of institutes in the UK conduct research into new crops. Rothamsted Research, for example, has an international reputation as a centre of excellence for science in support of sustainable land management and its environmental impact. Rothamsted's Centre for Bioenergy and Climate Change focuses on climate change. Its mission statement is “To understand and predict the impacts of climate change on biotic and abiotic components of agro-ecosystems and provide land-based solutions for mitigation and adaptation through carbon-neutral renewable bioenergy crops and sustainable management strategies that retain ecosystem services and reduce greenhouse gas emissions.”<sup>93</sup> Its research is of global significance.

### **Health**

The spread of disease, however it comes about, is an international concern. EASAC highlights areas where further research will help us in “identifying and supporting the necessary adaptation responses to what is unavoidable in climate change”. The areas of concern include: better surveillance, “based on trans-European early

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<sup>92</sup> *Reaping the benefits – Science and the sustainable intensification of global agriculture*, Royal Society, 2009

<sup>93</sup> <http://www.rothamsted.bbsrc.ac.uk/Research/Centres/index.php?Centre=BCC>

warning systems that have the capability to integrate epidemiological and environmental data” and integration of data collection and analysis for human and veterinary health.

The WHO warns that “Research in this field is increasing, but it is still comparatively weak in relation to the complexity of the issue and the magnitude of the health risks that may arise from inadequate or inappropriate responses.”

The WHO adds to the portfolio of research needs: “Applied research on surveillance and other decision-support tools is necessary to enhance operational effectiveness and early warning.”<sup>94</sup> The report also asserts that “Improved economic assessments of the costs associated with the health impacts of climate change can help support investment in health adaptation programmes, and support mitigation policies that enhance health.”

Health is a global issue. As EASAC points out, the research goals for the EU cannot be considered in isolation from the rest of the world. The WHO warns that “While some research donors, such as the European Community, support both international and interdisciplinary collaboration around this issue, the global research effort linking climate and health disciplines is relatively small.”

## **Food safety**

We have already seen that climate change could affect food safety. Here too science and technology can play a part in adapting to those threats. In its report, *Climate Change: Implications For Food Safety*, the FAO highlights a number of scientific and technological innovations “that are expected to play a major role in helping us to understand and to deal with the food safety challenges posed by climate change”.<sup>95</sup> The FAO’s report mentions a number of possibilities:

*“new filtration devices based on developments in nanotechnologies that can remove a range of chemical and microbiological contaminants from water and even from soils; rapid pathogen and contaminant detection using novel techniques (including nanotechnologies); new molecular biological methods such as nucleic acid sequence comparisons and genomics-based approaches to characterise complex microbial communities and their interactions; genetically modified crops that are suitable for growth in marginalised lands, etc.”*

The FAO’s report says that “The food safety challenges raised by climate related changes highlight the need for continued emphasis on food safety capacity building to developing countries.”

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<sup>94</sup> “Protecting health from climate change: Global research priorities”, WHO, 2009  
<http://www.who.int/globalchange/publications/9789241598187/en/index.html>

<sup>95</sup> *Climate Change: Implications For Food Safety*, FAO,  
[http://www.fao.org/ag/agn/agns/files/HLC1\\_Climate\\_Change\\_and\\_Food\\_Safety.pdf](http://www.fao.org/ag/agn/agns/files/HLC1_Climate_Change_and_Food_Safety.pdf)

## Infrastructure

An important aspect of climate change that crosses all sectors is that of the infrastructure on which society depends. The IDCC report on The Impacts of Climate Change on Overseas Infrastructure, R6.2, sums up the issue: “The importance of infrastructure around the world has grown quickly over the last 50 years and with the latest wave of globalisation and leaps in telecommunications, dependence on modern infrastructures has intensified exponentially over the last two decades in particular.”<sup>96</sup>

Buildings, transport links, energy generation and distribution and other essential services, such as water and waste management, make up the essential infrastructure that underpins society. In its review of the UK’s infrastructure, the Council for Science and Technology warned that “Resilience against climate change is the most significant and complex longer-term challenge.”<sup>97</sup>

Climate change will affect existing infrastructure, while new infrastructure will have to fit in with the need to minimise its impact on the climate. Meeting both challenges will require the development and use of appropriate technologies by the construction and civil engineering sector in the UK. There will also be a role for the use of information and communications technologies in developing ‘smart infrastructure’.

It is also important to consider the various components of infrastructure collectively. In its review, the OECD points out that the ‘infrastructures’ for energy, telecom, water and transport do not exist in isolation. “Relationships with other infrastructures will have to be managed from a systems perspective”.<sup>98</sup>

The IDCC report on overseas infrastructure underlines the interdependence of transport, and communications infrastructure<sup>99</sup>. The study points to an infrastructure “investment crisis”, with the World Bank suggesting the needs for global investment in infrastructure of US\$ 35 trillion over the next 20 years.

Climate change can affect infrastructure in many ways. Extremes of weather can create more severe freeze/thaw cycles. Floods, landslides and more frequent tropical storms are just some of the events that could occur if weather conditions become more variable.

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<sup>96</sup> *IDCC Report R6.2: The Impacts of Climate Change on Overseas Infrastructure*. Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

<sup>97</sup> *A national infrastructure for the 21<sup>st</sup> century*, Council for Science and Technology, 2009 <http://www.cst.gov.uk/reports/#Infrastructure>

<sup>98</sup> *Infrastructure to 2030 – Telecom, Land Transport, Water And Electricity*, OECD, 2006 <http://oberon.sourceoecd.org/vl=1096140/cl=14/nw=1/rpsv/~6687/v2006n9/s1/p11>

<sup>99</sup> *IDCC Report R6.1: The Implications on the UK of the Impacts of Climate Change and Sea-Level Rise on Critical Coastal Infrastructure Overseas, 2010 to 2100*. Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

The UK has already established itself as a leader in understanding how climate change could influence our lives. It had done this through, for example, detailed studies of how the changed flood regime that could develop as weather patterns change might affect important infrastructure. With this understanding, a world leading civil engineering and construction sector, the UK is, therefore, well placed to develop the technologies needed to adapt our infrastructure to withstand the effects of climate change. That expertise is also a valuable exportable commodity.

## **Construction**

The physical infrastructure is a part of the broader construction sector, with buildings responsible between 40% and 50% of the UK's energy consumption.<sup>100</sup> The output of the UK's construction industry, worth over £100 bn a year, accounts for 8% of GDP and employs around 3 million workers.<sup>101</sup>

The effects of climate change on infrastructure are already apparent, with rising sea levels and increased storm frequency affecting coastal areas. Countering these impacts will increase the demand for expertise in civil engineering and construction. The UK has considerable strengths in this sector, putting it in a good position to export that expertise and support the response to the effects of climate change on infrastructure.

As well as meeting the challenge of responding to climate change, we will also need to develop low-carbon infrastructure. This will include a need for materials that are less energy intensive in their production and use. Cement production, for example, accounts for "about 5% of anthropogenic global CO<sub>2</sub> emissions".<sup>102</sup> The UK supports materials research that could remove carbon from this sector. Novacem, a spin-out company from Imperial College London, has developed a magnesium oxide-based, construction-quality 'carbon negative' cement based on processes that actually remove CO<sub>2</sub> from the atmosphere.<sup>103</sup> The researchers behind Novacem received funding from the EPSRC for developing both the cement and the manufacturing processes that will be required for commercialisation.

The UK's expertise in infrastructure and construction puts it in a good position to contribute to the development of renewable energy sources. As the Low Carbon Construction Innovation & Growth Team puts it: "The UK has competitive advantages relating to off-shore wind and coastal/estuarial power"<sup>104</sup>.

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<sup>100</sup> Low Carbon Construction Innovation & Growth Team – Emerging Findings  
<http://www.bis.gov.uk/assets/biscore/business-sectors/docs/10-671-construction-igt-emerging-findings.pdf>

<sup>101</sup> *Strategy For Sustainable Construction*, June 2008  
<http://www.bis.gov.uk/files/file46535.pdf>

<sup>102</sup> *Cement Technology Roadmap 2009*, World Business Council for Sustainable Development and International Energy Agency, 2009

<sup>103</sup> <http://novacem.com/>

<sup>104</sup> Low Carbon Construction Innovation & Growth Team – Emerging Findings,  
<http://www.bis.gov.uk/assets/biscore/business-sectors/docs/10-671-construction-igt-emerging-findings.pdf>

The UK also has considerable expertise in researching and modelling the effects of climate change on infrastructure. For example, the Foresight Project Flood and Coastal Defence paved the way for studies of flood threats in China.

As a leading player in the insurance sector, the UK has considerable experience of the likely effects of climate change. Insurance or reinsurance companies based in the UK have sophisticated flood models for different parts of the world, as well as London.

### **Intelligent infrastructure**

Information and communications technologies can also contribute to more efficient use of energy in buildings. Improved controls and fault detection could save 10 to 20% on top of the gains that could come from more conventional measures.

The application of ICT to buildings will also be an essential component of the technology of smart grids for energy distribution. One idea is that the grid itself will be able to control energy use in building. For that to be possible, the buildings themselves have to incorporate the appropriate technology.

As a recent article in *Science* put it “a grid cannot be smart if it is connected to dumb devices”.<sup>105</sup> “Intelligent infrastructure extends ‘smart grid’ initiatives that seek to save energy by allowing utilities to manage loads, such as turning off air conditioners during peak demand.”

The authors of this article suggest that we should develop an ‘intelligent infrastructure for energy efficiency’ that connects buildings in the same way that we now network computers in the internet. “Many of the candidate standards for smart building systems are recreating rather than extending the development of the Internet.” Just as the internet allows us to perform functions that are independent of the internet itself, in buildings sensors and actuators “can compute and communicate to solve problems locally rather than having functions fixed by a central controller”.

## **Conclusions**

This review has described some of the many ways in which science and technology are closely related to our understanding of climate change and how to respond to its effects. While the focus is on international dimensions, these are sometime hard to separate from national issues and interests.

The breadth of the UK’s activity on science and technology related to climate change is extensive. And yet the challenges are so large that there is a continuing need to consider where there might be gaps and opportunities that are not covered by the existing portfolio of work.

An obvious requirement will be for a skilled workforce that can take forward science, turning it into technologies, products and services. The size and nature of that

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<sup>105</sup> “Intelligent Infrastructure for Energy Efficiency”, Neil Gershenfeld et al., *Science*, vol. 327, p 1086

workforce changes as ideas progress from the laboratory to the marketplace. A process that starts with the need for scientific talent moves on to become the domain of engineers.

While the UK has breadth in its scientific talent, it is less clear that there are the skills in place, along with the availability of finance, that will allow the UK to capitalise on the international opportunities that will arise from remediating and adapting to climate change.

If the UK is to draw on international activities, then it needs to ensure that the programmes that it joins are in line with the country's needs. For example, the EU supports many R&D programmes that are relevant to the UK's needs, and yet the Committee on Climate Change believes that the UK is less effective than other member states in influencing the nature of those programmes.<sup>106</sup>

The CCC is of the view that "More generally, there is scope for collaboration with other countries in developing key technologies." In particular, the UK's demonstration projects for coal CCS "should interface with projects in other countries (e.g. Australia, Canada, China, US) so that learning can be shared, possibly under the auspices of the G20 or the Major Economies Forum". The UK can also work through the EU to exert its influence at the global level where the CCC believes that "there is scope for the UK to influence arrangements to pull through technologies". One area where this could be important is in the approach to international aviation emissions.

## **Challenges and opportunities**

One purpose of this review is to highlight areas where we face scientific a technical challenges, where we need more information or where there are gaps in the tools available to us as we strive to adapt to reduce our impact on the climate or adapt to climate change.

### **Understanding climate change**

The scientific understanding of climate has developed considerably over the past two decades or so, but it is still a relatively new area of science with many uncertainties. As a leading player in global research on climate, the UK will be called on to make a substantial contribution to many areas of science.

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<sup>106</sup> *Building a low-carbon economy – the UK's innovation challenge*, Committee on Climate Change, 2010 <http://www.theccc.org.uk/reports/low-carbon-innovation>

Understanding climate change		
	Challenges	Opportunities
Climate science	Develop early warning systems for areas at particular risk of damage from extreme weather. <sup>107</sup>	<p>Opportunities remain in such areas as computer modelling, an area where the UK has particular expertise in the work of the Met Office, for example.</p> <p>Support other countries in their understanding of the potential effects of climate change.</p> <p>Develop tools and techniques to measure factors that may be important to climate change.</p>

### Reversing climate change

Geoengineering, a controversial approach to climate change, involves direct intervention in the atmosphere in an attempt to modify the climate. For it to happen, we have to fill large gaps in our understanding of how the climate 'works'.

Reversing climate change		
	Challenges	Opportunities
Geoengineering	<p>Large scientific gaps.</p> <p>Can we achieve international agreements on geoengineering?</p>	<p>Research opportunities in understanding how geoengineering can 'reverse' climate change.</p> <p>Many technologies will be needed if geoengineering proves feasible.</p>

<sup>107</sup> *IDCC Report R6.1: The Implications on the UK of the Impacts of Climate Change and Sea-Level Rise on Critical Coastal Infrastructure Overseas, 2010 to 2100.* Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

## Health

We are already seeing the effects of climate change on health. An inherently international concern, climate change could alter the pattern of diseases, with outbreaks on malaria, for example, in regions where it has not previously been an issue. Climate change could also cause migration of populations, with further consequences for health.

The UK's position as a world leader in medical research, and in the commercialisation of that research, will put the country at the forefront of the science and technology required to understand and respond to the effects of climate change on health.

Health		
	Challenges	Opportunities
Health	What are the relationship between climate change and health	Develop tools and models to predict the possible spread of diseases and disease vectors.
Epidemiology	What are the implications of climate change for the health of populations as opposed to individuals?	
Human diseases	Which diseases, and disease vectors, could be important to the UK and to the rest of Europe?	
Society	How will climate change affect human and animal migration?	Access to telecommunications has the potential to drive health and educational improvements. <sup>108</sup>

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<sup>108</sup> *IDCC Report R6.2: The Impacts of Climate Change on Overseas Infrastructure.*  
Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

## Food and agriculture

The global nature of food and agriculture is such that there are numerous gaps in our understanding of just which factors will affect the UK.

Food and agriculture		
	Challenges	Opportunities
Farming	Can we reduce the energy intensiveness of agriculture?	Research to allow intensification of agriculture, and to improve productivity, without damaging the environment.
Crops	How will water stress and flooding affect the supply of locally produced and imported food crops?	<p>Mathematical modelling to investigate disease patterns for wheat.</p> <p>Develop new strains of crops that can tolerate water stress and saline water.</p> <p>The UK has significant experience in crop science that can benefit global markets.</p> <p>Genetically modified crops could contribute to many areas of agriculture.</p>
Agricultural diseases	How will climate change affect crop and animals diseases?	Develop mathematical models of disease patterns.
Fisheries	How will climate change affect global fish stocks that are relevant to the UK?	Greater use of fish farming could reduce dependence on wild stocks, with the proviso that wild fish are often the primary food source for farmed fish. <sup>109</sup>
Food safety	How will climate change affect microbial	Technologies to deal with food safety challenges that

<sup>109</sup> *IDCC Report R3: Physical Resources and Commodities and Climate Change*. Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

Food and agriculture		
	Challenges	Opportunities
	populations and the population of pests or other vectors that influence food safety?	could arise from climate change.
Forestry	Will climate change bring 'imports' of diseases that affect forests in the UK?	Modelling of forest growth in response to climate change.  Develop early warning and monitoring systems.
Biofuels	Is there a conflict between agricultural production for food and energy?	
Food business	How will changing price of imported foods affect the UK's food processing sector?	

### **National security**

Climate change could alter the nature of the environments in which the armed forces operate, especially in their work for humanitarian relief. This could change the technologies that the security forces will need. Climate change could also affect the infrastructure on which the forces depend, the coastal stations that are important to the Navy for example.

National security		
	Challenges	Opportunities
Operational environments	What will the environmental conditions be like in the areas where armed forces will operate?	Develop technologies that are appropriate for the changed operational conditions.
	Will oceans change in ways that affect the operation of submarines, for example?	Develop acoustical sensors and torpedoes that work in sweater with changing thermal structure, ocean salinity and acidification.
Energy supply	The UK will continue to depend on energy imports, with the risk of temporary disruption to infrastructure systems. <sup>110</sup>	Develop energy technologies that allow the armed forces to reduce their use of fossil fuels.
Natural disasters	How will climate change affect the patterns of national disasters, home and abroad, that affect national security?	Mobile technology and the use of 'internet relief kits' will make the internet the most accessible and reliable form of communication and see it quickly rolled out to affected areas in the wake of disasters. <sup>111</sup>
Infrastructure	How will climate change affect infrastructure –such as coastal installations – that is important to national security?	Develop technologies to adapt infrastructure to withstand changed environmental conditions.

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<sup>110</sup> *IDCC Report R6.1: The Implications on the UK of the Impacts of Climate Change and Sea-Level Rise on Critical Coastal Infrastructure Overseas, 2010 to 2100.* Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

<sup>111</sup> *IDCC Report R6.2: The Impacts of Climate Change on Overseas Infrastructure.* Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

## Energy supply

Any response to climate change will bring dramatic changes to change the nature of energy supply. No technology will be untouched. The UK's position in a number of areas could open up new markets. The UK has a strong position in research some areas in energy supply and consumption. However, the UK can no longer lay claim to a position as a world leader in energy R&D.

A review of patent data by the Centre for Climate Change Economics and Policy showed that "Innovation is highly concentrated in three countries – Japan, Germany and the USA– which account for 60% of total innovations. Surprisingly, the innovation performance of emerging economies is far from being negligible as China and South Korea together represent about 15% of total inventions."<sup>112</sup> Thus the UK will find itself on the receiving end of technology transfer in energy.

Energy supply		
	Challenges	Opportunities
Infrastructure	<p>What effect will climate change have on important energy infrastructure in the UK and abroad?</p> <p>Much energy infrastructure, such as nuclear power stations, oil refineries and natural gas terminals, is in coastal regions that are especially vulnerable to the extreme events that could arise from climate change.</p>	<p>In the medium term, climate change will open up some new opportunities including opportunities for energy exploration opportunities.<sup>113</sup></p>
Solar energy		<p>New technologies to turn sunlight into electricity, such as polymer photovoltaic solar cells.</p>
Electricity transmission	<p>Electricity generation will increasingly come from distributed sources of</p>	<p>Technologies for the long distant transfer of electricity from regions rich</p>

<sup>112</sup> *Invention and Transfer of Climate Change Mitigation Technologies on a Global Scale: A Study Drawing on Patent Data*, Centre for Climate Change Economics and Policy, 2010 [http://www.cccep.ac.uk/Publications/Working%20Papers/Papers/WPapers%2010%20-%2019/Working\\_Paper19.pdf](http://www.cccep.ac.uk/Publications/Working%20Papers/Papers/WPapers%2010%20-%2019/Working_Paper19.pdf)

<sup>113</sup> *IDCC Report R6.2: The Impacts of Climate Change on Overseas Infrastructure*. Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

Energy supply		
	Challenges	Opportunities
	<p>varying output rather than large centralised power stations.</p>	<p>in sustainable energy to large markets with less local low-carbon generation potential.</p> <p>New 'smart grid' technologies to allow the integration of variable supplies of electricity from renewable energy sources into national and international distribution networks.</p>
Biofuels	<p>Can we develop fuel crops without jeopardising food supplies?</p> <p>Will the UK be able to obtain adequate imports of crop feedstocks for biofuels?</p>	<p>Biofuels will depend on many different approaches to turning organic materials into fuels – wheat, algae, Miscanthus and <i>Jatropha</i> are just some of the feedstocks under active development.</p> <p>There are scientific opportunities in the understanding of the biology of photosynthesis and energy capture by living organisms.</p> <p>Biofuels will require large economically competitive processing plants that can scale up and commercialise the processes now being developed in laboratories.</p>
Carbon capture and storage (CCS)		<p>There will be a global market for technologies to capture, transfer and sequester CO<sub>2</sub>.</p>

## Transport

The main concern around transport and climate change is the high dependence on carbon rich fuels. It will take several technological revolutions to change the face of transport, for example, to convert motor vehicles from oil to electricity.

Transport		
	Challenges	Opportunities
Aviation		The use of lightweight materials in commercial aviation in the short to medium term. <sup>114</sup>
Biofuels		Technologies that allow biofuels to be used in transport.
Information and communications technologies		Intelligent transport systems can make more efficient use of, and to reduce the need for, transport.
Infrastructure		Electric vehicles will need new infrastructure – for recharging batteries, for example – providing global opportunities for technology companies.  Climate change will open up some new opportunities including new shipping routes and energy exploration opportunities. <sup>115</sup>

## Infrastructure

While infrastructure affects the environment in many ways, the primary concern with climate change is in its vulnerability. With changed weather patterns, storms and flooding may be more common and/or more severe.

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<sup>114</sup> *IDCC Report R6.2: The Impacts of Climate Change on Overseas Infrastructure.*  
Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

<sup>115</sup> *Ibid.*

The IDCC report on The Impacts of Climate Change on Overseas Infrastructure, R 6.2, points that there is a lack of analysis around the impacts of climate change on international infrastructure and that connective infrastructure between states is neglected as is infrastructure in the developing world<sup>116</sup>.

The IDCC report on the Implications on the UK of the Impacts of Climate Change and Sea-Level Rise on Critical Coastal Infrastructure Overseas, 2010 to 2100, R6.1, says that 60 per cent of the world's biggest cities with a population of over 5 million are located within 100 km of the coast<sup>117</sup>. As a consequence, much critical infrastructure is in areas that are increasingly vulnerable to events like natural disasters, such as flooding and extreme storms.

Infrastructure		
	Challenges	Opportunities
Infrastructure	<p>How will climate change affect infrastructure – transport, energy, telecoms and water – as we see changed weather patterns?</p> <p>Climate change could have particularly pronounced impacts on coastal areas, a focus of a growing population and economy, generally focussed on expanding urban areas with growing infrastructure demands and needs.<sup>118</sup></p>	<p>Technologies to enable 'smart infrastructure' can reduce the carbon footprint of the development and use of infrastructure.</p> <p>Incorporate natural disaster mitigation measures into the planning, design and implementation of all sustainable development programmes in coastal areas.<sup>119</sup></p>
Construction		New low-carbon materials to reduce the impact of buildings on the climate.

<sup>116</sup> IDCC Report R6.2: *The Impacts of Climate Change on Overseas Infrastructure*. Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

<sup>117</sup> IDCC Report R6.1: *The Implications on the UK of the Impacts of Climate Change and Sea-Level Rise on Critical Coastal Infrastructure Overseas, 2010 to 2100*. Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

<sup>118</sup> IDCC Report R6.1: *The Implications on the UK of the Impacts of Climate Change and Sea-Level Rise on Critical Coastal Infrastructure Overseas, 2010 to 2100*. Available at: <http://www.bis.gov.uk/foresight/our-work/projects/current-projects/international-dimensions-of-climate-change>

<sup>119</sup> Ibid.

## **Other areas**

While focusing on key sectors helps to simplify the discussion of climate change, there are areas that do not fit easily into a simple classification. For example, information and communications technologies (ICT) pervade everything that we do.

We have already seen that the idea of smart infrastructure is one area where information and communications technologies (ICT) can play an important role in any responses to climate change. Another area is transport, where the technologies of intelligent transport systems can do much to reduce the carbon footprint of transport.

In general, ICT can help in many ways, such as monitoring energy use to provide better feedback to consumers.

It is also important to look at the burden that ICT imposes on the environment. An often overlooked aspect of energy consumption is the growing demand for electricity for ICT. The move towards 'cloud computing', with applications running not on the user's computer but over the internet on large centralised processing systems, will lead to the development of large clusters of 'computer farms'. Large 'warehouses' filled with air conditioned computer system like these demand ever more electricity.

One suggestion is to locate computer farms in parts of the world where there is abundant renewable energy. Then, rather than electricity moving around the world, the data would move. After all, a network of optical fibres already connects most parts of the world.

This is an intrinsically global concept, with significant implications for technology, business and policy. It would require detailed international negotiation to arrive at a system that people would accept.

This is just one of many possibilities that could arise from the development of science and technology. Many more are likely to arise as we learn more about climate change and the many associated areas of science and technology. The other reports in this project suggest other ideas where we need a better understanding of the underlying science and where developments in technology might help us to mitigate the effects of, or adapt to, climate change.

## Resources

### An inventory

Any analysis of science and technology related to climate change would benefit greatly from access to a database of related activities. While individual organisations do try to bring together their work in these areas, it is often informal, with few attempts to make connections to other work that may be related.

The Research Councils work together through various joint initiatives. The Met Office also works with NERC through the Joint Climate Research Programme. However, there is no obvious 'gateway' into this work. This makes it harder for Research Councils to achieve their goal of maximising their impact.

One model for such a facility could be the database that EPSRC maintains of its active research grants. This shows more than 400 grants with some reference to "climate change". The NERC is in the process of updating its own database of research grants. Its old database yields more than 1000 grants associated to "climate change". The "consumers" of that research – companies and other organisations that could pick up ideas and turn them into new technologies, services and so on – have no obvious way of comparing these two sources, let alone the wider research activity in this area.

### Academic

Global Change Research Group, Department of Animal and Plant Sciences,  
University of Sheffield

<http://www.sheffield.ac.uk/aps/research/globalchange.html>

### Research Centres

Met Office Hadley Centre

<http://www.metoffice.gov.uk/climatechange/science/hadleycentre/>

NERC Climate & Land-Surface Systems Interaction Centre

<http://www.nerc.ac.uk/research/sites/collaborative/eo/classic.asp>

NERC Earth Observation Centre of Excellence for Terrestrial Carbon Dynamics

<http://ctcd.group.shef.ac.uk/ctcd.html>