# Building a low-carbon economy – the UK's innovation challenge

July 2010

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# Foreword

In October 2009, the Committee was asked by the Government's Chief Scientific Adviser, Sir John Beddington, to review the adequacy of the UK's research and innovation arrangements for delivering technologies required to meet the UK's climate change objectives.

In carrying out the Review, we have built on our previous analysis of technologies required to meet the 2050 target to reduce emissions by 80% relative to 1990 levels. Specifically, we have assessed current technology challenges and UK capabilities to support technology development, and we have recommended priorities for Government support on the basis of where challenges are best matched to capabilities.

Our analysis suggests that there are opportunities for the UK to develop a range of low-carbon power generation and vehicles technologies. At an earlier stage of development, the strong UK research base provides potential for innovations to reduce emissions from agriculture and industry, and to store energy.

We are very clear that a *reduction* in current funding levels would increase risks of missing carbon budgets, and would forego opportunities to build a green economy in the UK. *Increased* funding will be required in specific cases (e.g. electric cars) and for innovation more generally over the next decade.

The current UK energy strategy only covers the period to 2020. However, a longer term focus is required given the 2050 emissions target in the Climate Change Act. We therefore recommend that the Government should set out a long-term strategy for the whole economy covering the period to 2050.

We have not taken a view on whether the number of institutions in the low-carbon innovation landscape should be reduced (e.g. through the creation of a Green Investment Bank). However, the crucial point for the Committee is that whatever the institutional makeup, delivery bodies should have clear objectives that are fully consistent with the Government's long-term strategy. There should also be improved monitoring and evaluation to ensure that objectives are achieved.

This is our third report in 2010, and our sixth report in around 20 months. On behalf of the Committee I would like to thank the Secretariat for their excellent support and dedication through this very busy period.

# The Committee on Climate Change

**Lord Adair Turner, Chair**
Lord Turner of Ecchinswell is the Chair of the Committee on Climate Change and Chair of the Financial Services Authority. He has previously been Chair at the Low Pay Commission, Chair at the Pension Commission, and Director-General of the Confederation of British Industry (CBI).

**David Kennedy, Chief Executive**
David Kennedy is the Chief Executive of the Committee on Climate Change. Previously he worked on energy strategy at the World Bank, and the design of infrastructure investment projects at the European Bank for Reconstruction and Development. He has a PhD in economics from the London School of Economics.

**Dr Samuel Fankhauser**
Dr Samuel Fankhauser is a Principal Research Fellow at the Grantham Research Institute on Climate Change at the London School of Economics. He is a former Deputy Chief Economist of the European Bank for Reconstruction and Development and former Managing Director (Strategic Advice) at IDEAcarbon.

**Professor Michael Grubb**
Professor Michael Grubb is Chair of the international research network Climate Strategies. He is a senior research associate at Cambridge University and holds a visiting professorship at Imperial College. Previously he was Head of the Energy and Environmental Programme at Royal Institute of International Affairs, and Professor of Climate Change and Energy Policy at Imperial College.

**Sir Brian Hoskins**
Professor Sir Brian Hoskins, CBE, FRS is the Director of the Grantham Institute for Climate Change at Imperial College and Professor of Meteorology at the University of Reading. He is a Royal Society Research Professor and is also a member of the National Science Academies of the USA and China.

**Professor Julia King**
Professor Julia King CBE FREng is Vice-Chancellor of Aston University. She led the 'King Review' for HM Treasury in 2007/8 on decarbonising road transport. She was formerly Director of Advanced Engineering for the Rolls-Royce industrial businesses. Julia is one of the UK's Business Ambassadors, supporting UK companies and inward investment in low-carbon technologies.

**Lord John Krebs**
Professor Lord Krebs Kt FRS, is currently Principal of Jesus College Oxford. Previously, he held posts at the University of British Columbia, the University of Wales, and Oxford, where he was lecturer in Zoology, 1976-88, and Royal Society Research Professor, 1988-2005. From 1994-1999, he was Chief Executive of the Natural Environment Research Council and, from 2000-2005, Chairman of the Food Standards Agency. He is a member of the U.S. National Academy of Sciences. He is chairman of the House of Lords Science & Technology Select Committee.

**Lord Robert May**
Professor Lord May of Oxford, OM AC FRS holds a Professorship jointly at Oxford University and Imperial College. He is a Fellow of Merton College, Oxford. He was until recently President of The Royal Society, and before that Chief Scientific Adviser to the UK Government and Head of its Office of Science & Technology.

**Professor Jim Skea**
Professor Jim Skea is Research Director at UK Energy Research Centre (UKERC) having previously been Director of the Policy Studies Institute (PSI). He led the launch of the Low Carbon Vehicle Partnership and was Director of the Economic and Social Research Council's Global Environmental Change Programme.

# Acknowledgements

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**A wide range of stakeholders** who engaged with us, attended our expert workshops, or met with the CCC bilaterally.

# Executive Summary

## Key messages from the Review

In October 2009 the Committee was asked by the Government's Chief Scientific Adviser, Sir John Beddington, to review the adequacy of research and innovation arrangements in the UK related to achieving our climate change goals[1].

There are four key messages from our analysis:

- We distinguish between technologies that the UK should *develop and deploy*, versus *deploy*, versus *research and develop*. Based on our assessment of technology portfolios required to deliver climate objectives, current stages of technology development and the UK's research and industrial capabilities, we recommend that the UK should:
  - **Develop and deploy** offshore wind, marine, carbon capture and storage (CCS) for power generation, aviation technologies, smart grids, and electric vehicle technologies.
  - **Deploy** nuclear power, advanced insulation materials, heat pumps and CCS for energy intensive industries (there may also be scope for UK participation in demonstration of industry CCS).
  - **Research and develop** hydrogen fuel cell vehicles, technologies in agriculture and industry, 3rd generation solar PV technologies, energy storage and advanced biofuels technologies.
- Current levels of public expenditure for RD&D should be regarded as a minimum and cuts would be detrimental to the achievement of our climate goals and the new Government's objective to build a green economy. UK energy RD&D funding is low by international standards, and international funding is low relative to benchmarks proposed by the Stern Review, the IEA and the EU (e.g. IEA analysis suggests that a two to fivefold increase is required). For key technologies we recommend that:
  - Currently planned investments in four demonstration CCS plants are key to achieving required early power sector decarbonisation.
  - There is a need for demonstration of gas CCS power generation, which is likely to be a competitive form of low-carbon power generation, particularly in a low gas price world and when operating flexibly.
  - Current ambition for offshore wind is both feasible and desirable but may require additional funding.
  - There may be a case for increased funding for marine generation demonstration; we will consider this further in our renewable energy review to be published in Spring 2011.
  - Current electric car funding of £260 million is required to support pilot projects and early stage market development, with further funding likely to be required in the period to 2020.
  - In aviation, radical technologies (e.g. blended wing) will be required to meet UK 2050 aviation emission reduction targets. Public support for the development of these technologies, in co-operation with international partners, will be necessary.
- The UK currently has an energy strategy covering only the period to 2020. There is therefore a lack of clarity over long-term energy and related technology policy objectives. In order to address this we recommend that:
  - The Government should set out its strategy for developing the technologies required to meet the 2050 emissions reduction target, identifying which technology portfolios will be developed, setting out the level and form of public support and policy to address deployment barriers, and identifying clear responsibilities for delivery within Government.

1 See Annex A for the terms of reference.

- The strategy should also set out how the UK will: increase its influence over the design of EU programmes; exploit scope for international collaboration on technology development (e.g. through the G20 in the case of coal CCS generation, and the North Sea Task Basin on gas CCS generation); and seek to secure new international agreements limiting emissions from aviation, shipping and energy intensive sectors (e.g. iron and steel) to strengthen incentives for innovation.
- The strategy should place greater focus on effective monitoring and evaluation than is currently the case, and that success should be judged against the Government's long-term objectives.

- We have not taken a view on whether there should be consolidation of institutions (there are examples of where multiple bodies have delivered successfully). The crucial point for the Committee is that whatever the institutional landscape, objectives for delivery bodies should be fully consistent with Government objectives for technology development, and should be fully integrated to cover all stages of the innovation process. That is currently not the case, given the absence of a long-term government strategy.

**Approach to the Review**

In carrying out the Review, we have focused on:

- All stages of technological innovation, including research, development, demonstration and deployment (RDD&D).
- Technologies which are likely to play a role in helping the UK meet its 2050 target to reduce emissions by 80% on 1990 levels, but have not yet become competitive with high-carbon alternatives, and/or technologies where the UK is likely to contribute significantly to global mitigation efforts. Although we exclude on-shore wind because it is already competitive, at the best sites, with high-carbon alternatives, our analysis shows that it is likely to play an important role in meeting carbon budgets.

Our approach is based on identifying technology paths to 2050, mapping these to priority areas for UK RDD&D support, assessing current support levels and mechanisms, and considering institutional arrangements:

- Technology paths to meeting the 2050 target have the same broad shape (e.g. early decarbonisation of the power sector and extending low-carbon generation to transport and heat). However, there is uncertainty over the specific technologies to deliver these paths. Therefore, we adopt an approach based on the UK developing a portfolio of technologies.
- We make an assessment of current support levels on the basis of whether these are sufficient to deliver technologies required to meet climate objectives. We also consider deployment barriers, highlighting where new policy approaches are required.
- We consider current institutional arrangements focusing on the extent to which these ensure that support has clear objectives for domestic and international action, that these cascade to delivery bodies involved in all stages of technology development, and that effective monitoring and evaluation systems are in place.

Our analysis draws on a range of technology studies (e.g. our own Markal modelling, together with analysis by the International Energy Agency (IEA), UK Energy Research Centre (UKERC) and Energy Research Partnership (ERP)), patent analysis by the London School of Economics (LSE), and interviews with a wide range of stakeholders.

The evidence and arguments which support these recommendations are set out in the following sections.

1. Public support for low-carbon technologies
2. Technologies that the UK should support
3. Government funding and policies
4. The institutional framework

Supporting analysis will be made available at: http://www.theccc.org.uk/topics/low-carbon-innovation.

# Part one

## Public funding and policy measures are required to support the development of low-carbon technologies.

# Public support for low-carbon technologies

Without public policy intervention, market prices do not reflect the costs associated with greenhouse gas emissions (GHGs) and therefore do not provide appropriate incentives for the development of low-carbon technologies.

In addition there are at least four market or system failures that reduce or stop private investment in low-carbon RDD&D:

- Energy and transport systems have **dominant designs**, which have developed based on fossil fuels and tend to encourage evolutionary rather than revolutionary technological change. New technologies, which do not conform to the dominant design, can be locked out because, for example, high fixed costs of developing new infrastructures act as barriers to entry.
- Investments in innovation are characterised by **uncertainty** – i.e. it is known that investments may fail, but a precise probability cannot be placed on failure. Unable to calculate precise risks, investors will act on imperfect information and will often be risk averse. Long timescales for investment and deployment of technologies increase the length of time investments are at risk and increase risk aversion. For high capital cost investments, frequent in the energy sector, this may be a particular barrier.
- Some companies operate in markets where **product differentiation is difficult or impossible**. For example this is an issue for the energy sector – customers value electricity but they care less whether the electricity is generated from a wind or gas turbine. In this case, the company cannot recoup a return from investments in innovation which make no material difference to the customers' enjoyment of the service provided.
- Investments in innovation generate knowledge and this can **spill over** to other firms or users. Where innovation leads to lower product prices (e.g. electricity prices), there are additional welfare benefits to users of that product (e.g. reduced fuel poverty) which are not reflected in the product price. Unable to fully appropriate these additional benefits, the investor does not take these into account in their investment decision and hence investment in innovation is below its social optimum. A wide body of evidence suggests that the extent of spill over benefits can be substantial.

These failures apply to innovation generally but they are more pronounced in the case of low-carbon innovation, as evident in the low R&D intensity in the utilities sector compared to the rest of the economy (Figure 1).

**Definition of terms**

**R&D:** Research and development, includes investigation of underlying phenomena and observable facts through to research with a more commercial application.

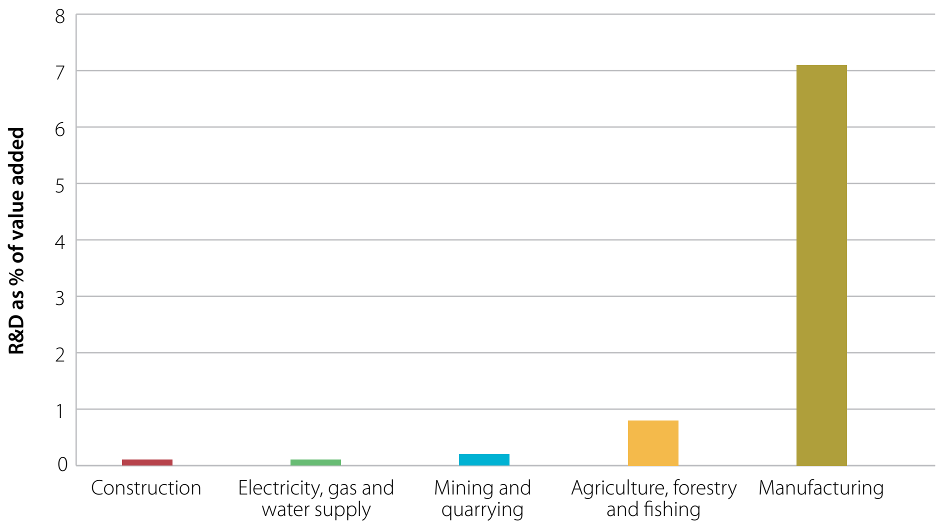
**RD&D:** Research, development and demonstration, as above but also includes large scale pre-commercial demonstration of technologies designed to test and improve reliability, improve designs and establish and reduce operating costs.

**RDD&D:** Research, development, demonstration and deployment, as RD&D but also includes integration into existing system. Technologies are not yet competitive in the market.

**Low-carbon:** We treat a new product, service or process as low-carbon if it leads to an absolute reduction in GHG emissions or improves the carbon intensity of an activity.

**Source:** UK Environmental Transformation Fund Strategy and CCC.

**Figure 1** Business R&D intensity by sector (2006)




**Source:** ONS and CCC calculations.

Together these factors can result in a 'valley of death' (Figure 2), where there is insufficient funding to drive technologies through the various stages of development to commercialisation. A range of public policy interventions are therefore required to address this.

The Stern Review suggests three key areas for public policy which could support low-carbon technology development:

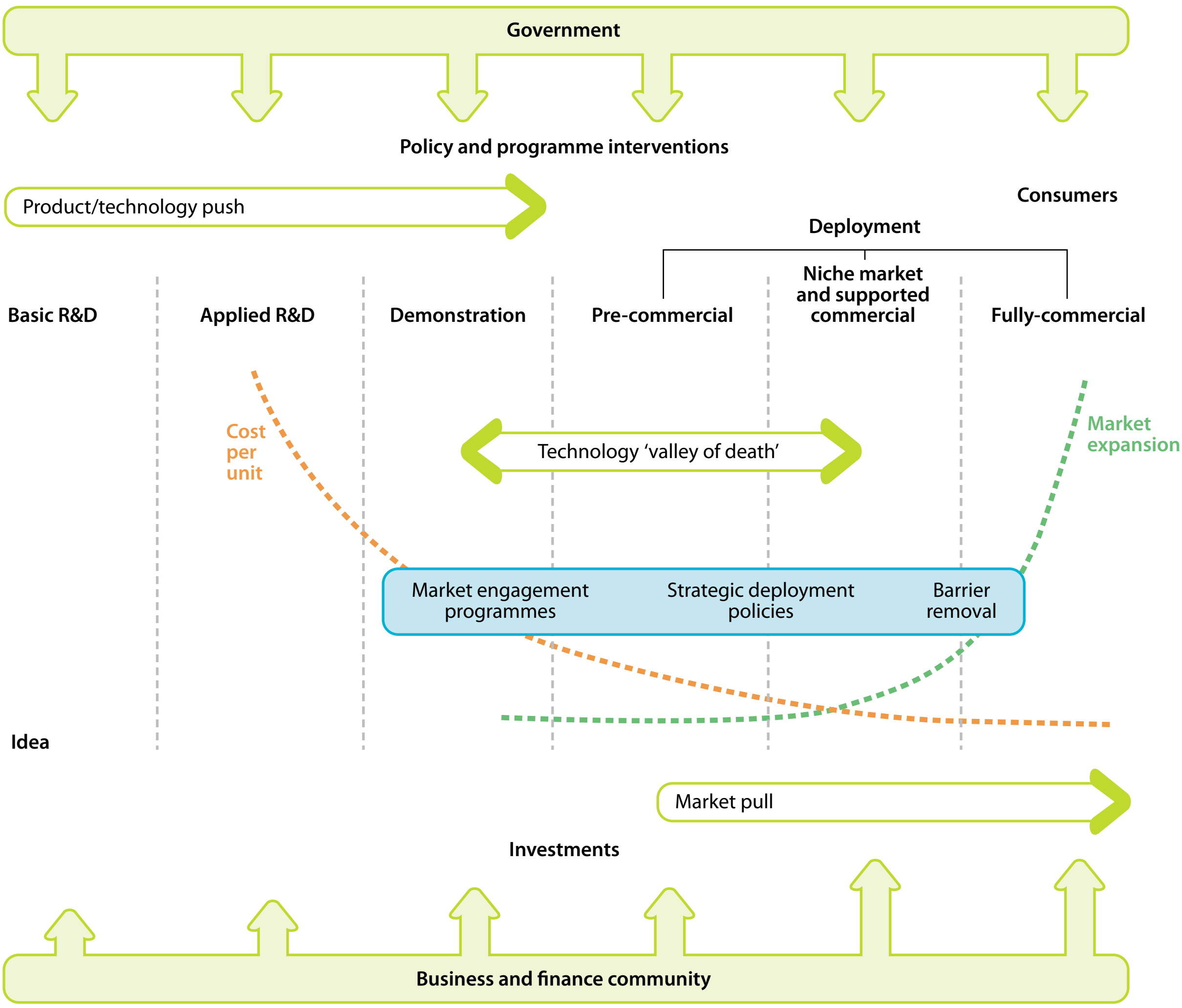
- Supply push policies (including public funding) to support the development of a range of low-carbon and high-efficiency technologies,
- Establishing an explicit carbon price through tax or trading, or an implicit carbon price through regulation, supporting pull through of technologies,
- The removal of barriers to the take-up of new technologies.

The Stern Review stresses the need for urgent action on technology development with increased funding and new policies if climate objectives are to be met.

Given the need for urgent action, our focus in the remainder of the report is:

- To identify which technologies are likely to require support, and
- To assess whether current public policy approaches adequately address the valley of death, and in particular, to consider the extent to which additional RD&D funding may be required, where new approaches are needed to address deployment barriers, and how the Government's strategic approach could be strengthened to meet climate change and wider economic objectives.

**Figure 2** The valley of death




**Source:** Grubb M (2004), Technology Innovation and Climate Change Policy: an overview of issues and options.

# Part two

## Public support should reflect uncertainties around technology development and deployment. This requires the development of technology portfolios to provide insurance in case individual technologies fail to deliver.

# Technologies that the UK should support

The starting point for an assessment of the UK's framework for low-carbon innovation is to consider what technologies are likely to be required to meet carbon budgets and targets under the Climate Change Act (2008). Given an assessment of what is likely to be required, the next step is to consider whether public RDD&D support is necessary and sufficient, and the extent to which UK institutions are well placed to deliver the required support.

We now consider:

(i) Technology paths to 2050

(ii) Priorities for UK support

## (i) Technology paths to 2050

We and others have set out a range of technology paths consistent with the UK meeting its 2050 emission reduction targets. Although these differ in terms of the precise balance between technologies, they provide a broadly consistent vision of what the future energy system needs to look like:

- Early power sector decarbonisation is required, with investment in low-carbon generation reducing emissions intensity from the current level of over 500g $CO_2$/kWh to around 100g/kWh by 2030 and 50g/kWh in 2050.
- With early power sector decarbonisation, significant cuts in transport emissions through vehicles with electric powertrains would become feasible. In addition, there is likely to be a role for sustainable biofuels and fuel cells.
- Early power sector decarbonisation would also facilitate reductions in heat emissions through increased electrification of both residential and non-residential heating.
- Much higher levels of energy efficiency are required in all sectors to reduce emissions, to facilitate deployment of electric heating (which requires energy efficient buildings) and to make energy more affordable for households and businesses.

Figure 3 shows an illustrative scenario from our Markal modelling of the path to meeting the 80% target. In this scenario, power sector decarbonisation is achieved through a combination of renewables, CCS and nuclear technologies. Cuts in transport and heat emissions through energy efficiency[2] and increased electrification begin in the 2020s and continue in the 2030s and 2040s. By 2050, remaining emissions within the limit implied by the 80% reduction target are concentrated in industry, agriculture, aviation and shipping.

There are two key points to note on the Markal modelling and other modelling approaches:

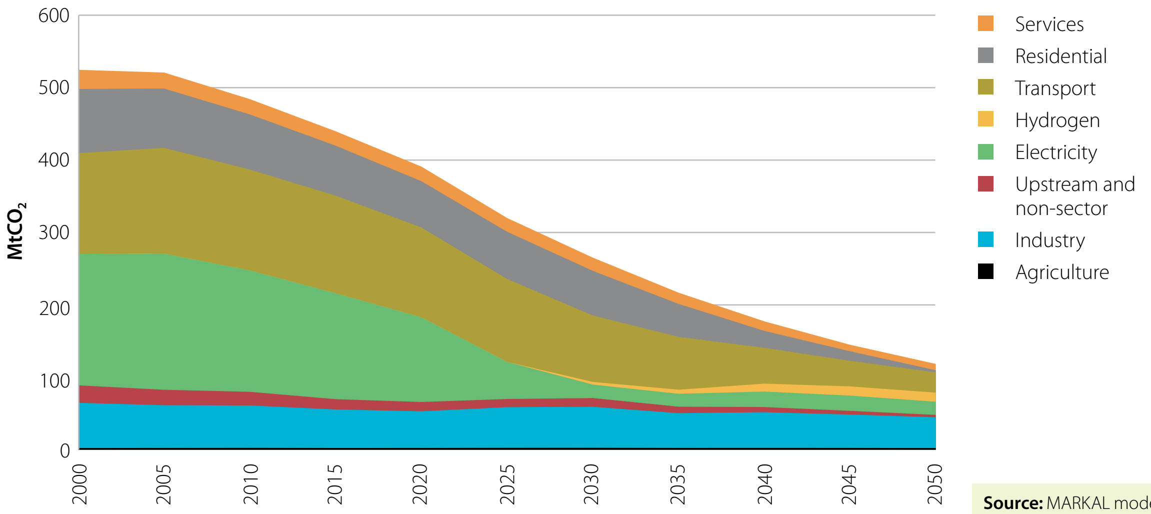
- Key technologies are currently not mature (e.g. CCS is at the demonstration stage, deployment of offshore wind and electric cars is only just starting), and therefore RDD&D support for technologies will be required.
- There is a great deal of uncertainty around technical and economic characteristics of low-carbon technologies yet to come to market. Depending on relative costs, a different balance of technologies may be appropriate. For example, if CCS turns out not to be viable, then higher levels of investment in renewable generation would be required.

There are two implications resulting from these uncertainties:

- Firstly, it is prudent for the public sector to support a wider range of technologies than may actually be deployed in case some of our technology options fail to deliver. Some reserve options may be necessary to meet targets and they will only be available if resource is dedicated to them in the short to medium-term.
- Secondly, public investment in any low-carbon technology should occur in stages, with the performance of that technology periodically reviewed to see whether it is still likely to deliver the abatement required.

2 Although not explicitly shown in Figure 3, technologies to improve energy efficiency are generating emissions reduction across sectors.

**Figure 3** UK sectoral $CO_2$ emissions on an illustrative 80% emissions reduction path




**Source:** MARKAL modelling based on CCC assumptions (2008).

We have developed our priorities for UK support to reflect uncertainty, and therefore the need to develop a portfolio of options. The list of technologies presented should not be considered exhaustive – we have focussed on technologies which are not yet mature but which are likely to contribute most to achieving emission reductions (both in the UK and globally).

## (ii) Priorities for UK support

**Matching technology support to UK capabilities**
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 (Table 1):

- 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. In these technologies, UK based companies will lead international collaborations and the technology will be significantly developed, demonstrated and deployed in the UK. In this case the Government should adopt a **'develop and deploy'** strategy and offer the full range of RDD&D support, where appropriate.
- 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. In this case a **'deploy'** strategy is likely to be more appropriate, where public support is targeted at demonstrating and, if necessary, adapting technologies to local conditions and building the skills required for operation and maintenance.
- Some technologies may currently be further from market and it is unclear which country has, or will have, a particular advantage. Public support should not direct academic research but should ensure that the results of research and development programmes are disseminated widely. In this case, where the UK has a significant research capability and the potential to develop a leadership role, we propose a **'research and develop'** strategy.

**Table 1** Types of public support required for technologies in different portfolios

| | Develop and deploy | Deploy | R&D |
|---|---|---|---|
| **Public RDD&D support** | Full range of RDD&D support – tailored as necessary. | Demonstration support to test and adapt to UK conditions. Some R&D where UK based suppliers have advantage in components. | Largely R&D with small-scale demonstration. Scientific research is not directed. Explicit decision on whether to progress technology post-demonstration. |
| **International collaboration** | UK based companies lead international collaboration. Drawing on foreign suppliers where appropriate. | UK based suppliers usually participate as partners of overseas based businesses. | International research programmes with strong involvement of academics. |

To assess relative UK capability we have drawn on a number of data sources. These include data from the Research Councils, patent data analysis (an indicator of the UK capacity to develop ideas), analysis of initial public offering and merger and acquisition data (indicators of the UK capacity to translate ideas into commercially attractive propositions), and trade data analysis (an indicator of UK industrial capacity). We have further supplemented this analysis with other available data and information from various government and commercial sources cited in the supporting analysis.

### Technologies which the UK should 'develop and deploy'

Our analysis of technology priorities and UK capabilities suggests that the UK should adopt the 'develop and deploy' approach to offshore wind, marine, CCS for power, smart grids, aviation and electric vehicle technologies:

#### Power

- **Offshore wind** has the potential to significantly reduce power sector emissions in the period to 2020 and beyond. It is particularly attractive because it can be added at scale over the next ten years, and could therefore contribute to required power sector decarbonisation in the 2020s. Our analysis suggests that there is an important role for offshore wind as part of the least cost path for decarbonising the power sector. The UK has a unique resource and is building a strong offshore wind research capability (e.g. SUPERGEN wind technologies consortium) and recent investment announcements by Siemens, Clipper Windpower, Mitsubishi and GE suggest that UK based companies will be well placed to drive technology development. With significant capability already established, the UK is uniquely placed to accelerate development and deployment of offshore wind power.

- **Marine (wave and tidal)** technologies are at an earlier stage of development and, although the abatement potential is less than wind, they increase the diversity of the power system and increase its resilience if other technologies fail to materialise. With a sizeable share of all device developers and patent analysis indicating a very strong global position, the UK has potential to be a world leader. The UK has a significant natural resource, estimated to be around 65 GW (or 192TWh/yr), and UK based companies also have experience in marine engineering and design. The UK therefore has an important role to play in developing marine energy generation technologies for both domestic and global markets.

- **Carbon Capture and Storage** technologies are potentially central to power sector decarbonisation through the 2020s, given current evidence which suggests that both coal and gas CCS have the potential to become relatively low-cost forms of clean generation. The UK is well placed given its depleted offshore oil and gas fields, which could be used as storage sites. The UK may not have particular strengths in carbon capture technologies when compared to the US but it does have strengths in both $CO_2$ transportation and storage. The UK has a wide and deep experience base regarding power plant efficiency and clean coal technologies, but presently limited domestic capability to build all parts of a plant. Demonstration projects in the UK are likely to build further capabilities. The UK is very strong on subsurface evaluation and geotechnical engineering because of North Sea oil and gas developments.

- **Smart meters/smart grids:** These will be needed to balance growth in electricity demand from the transport and heat sectors, with increasing levels of intermittent wind generation alongside other relatively high capital cost inflexible generation as well as local generation and the new 'feed-in' environment. The UK has significant university-based research capabilities, coupled with industrial capabilities in electrical machinery, power electronics and communications. Developments in smart grid technologies will also be important for reducing demand through the adoption of new end-use technologies and behavioural changes.

**Transport**

- The UK has a strong capability in **aviation technologies** including engine and airframe development and manufacturing. UK based companies produce wings and engines for the global market. The UK is also a world leader in high-quality composite manufacturing and research. Aviation technologies which increase fuel efficiency could contribute to abatement if other policy instruments are in place to encourage airlines to take the efficiency gain as a carbon saving rather than longer aircraft ranges or increased payloads.

- **Electric vehicles** are highly likely to be required to start to cut transport emissions in the period to 2020, preparing for deep cuts through the 2020s and beyond. The UK has research capabilities in innovative design, and in systems and components such as electric motors and power electronics, although leadership on the direction of technology development within key automotive manufacturers rests overseas. Recent decisions by Nissan and Toyota to invest in electric vehicle production and battery manufacture are likely to increase UK capabilities further and strengthen supply chains.

**Technologies where the UK should focus on deployment:**

Our analysis of technology priorities and UK capabilities suggests that the UK should adopt the 'deploy' approach to nuclear fission, advanced insulation technologies, heat pumps and industry CCS.

**Power**

- **Nuclear fission** is an established and proven low-carbon technology which is expected to contribute to decarbonising the UK power sector. UK research capabilities in nuclear fission technologies have decreased considerably following cuts in R&D funding and decisions to stop building reactors in the UK. The UK will need to rely on overseas based suppliers offering standardised designs.

**Buildings**

- A combination of improved energy efficiency through insulation and increased penetration of renewable heat, particularly but not solely from **heat pumps**, will be required to cut emissions from buildings in the next decades. Most insulation materials and renewable heat technologies are reasonably mature technologies, but have not been deployed at a large scale in a UK context. Whilst the UK does not have significant capabilities in either **advanced insulation** technologies (e.g. new thinner materials) or heat pumps individually, it does have a capability in work to integrate systems and technologies in the buildings sector.

**Industry**

- **Industry CCS** is a potentially important technology, currently at the demonstration stage, and will become more important over time as emissions from industry make up a greater proportion of total UK emissions (Figure 3). Although the UK has currently chosen to focus on power generation, there may also be opportunities for participation in industry CCS, particularly as funding constraints ease and spending is increased (see Part three below); this should be considered further by Government. Beyond demonstration, deployment of CCS in the UK's energy intensive industries is very likely to be important given the required emissions reductions and the absence of alternative low-carbon technologies.

**Technologies where the UK should adopt a 'research and develop' strategy:**
Our analysis of technology priorities and UK capabilities suggests that the UK should adopt the 'research and develop' approach to 3rd generation solar PV technologies, energy storage, hydrogen fuel cell vehicles, advanced biofuel technologies, technologies in agriculture and industry and production of biogas from biomass.

**Power**

- The deployment of solar PV technologies may well make a significant impact on UK emissions post-2030, if advances in products and manufacturing processes bring improved performance and lower costs. Although the UK solar PV research community is smaller than those in other countries (e.g. Germany, US, Japan), UK activity focuses on novel **3rd generation solar technologies** which are still at the research stage, but potentially offer considerable performance improvement.
- In addition to smart meters and smart grids, there may be scope for **new storage technologies** to better balance the time profile of power demand and supply. Possibilities here include advanced batteries, super-capacitors and superconducting magnetic energy storage.

**Transport**

- **Hydrogen fuel cell vehicles** could make a substantial contribution to reducing transport emissions by 2050 although they are not as close to commercial deployment as electric vehicles. There are several fuel cell vehicle projects ongoing in the UK which suggests potential, although if hydrogen fuel cell vehicles are developed, their successful roll out will depend upon the completion of research into, and the development of, hydrogen storage and infrastructure and low-carbon hydrogen production.
- Second and third generation biofuels, or **advanced biofuels**, have the potential for widespread application using existing infrastructures, although sustained research into feedstocks and efficiency of conversion technologies is necessary. The UK bio-energy research community is small relative to those in the US or other EU states, although it is strong on aspects of research such as fermentation technologies and pyrolysis.

**Agriculture**

- Options to reduce emissions in the **agriculture** sector can generally be grouped as those targeting crops and soils and those targeting livestock. These include options relating to changes in practice and use of new technologies. Further research is necessary to explore the impacts of these potential measures (particularly scope for longer term options) within the UK farming context, to improve measurement of emissions and to build up the evidence base. Given the fragmented nature of the industry this is unlikely to be carried out at sufficient scale unless led by Government.

**Industry**

- There is a range of technologies to reduce emissions from energy-intensive **industry** at the early R&D stage, such as the development of low-carbon cements or to reduce emissions from steel making. The Committee will publish new analysis on industry options in its advice on the fourth budget. There may also be scope for UK R&D on production of biogas from gasification of biomass, which together with Anaerobic Digestion could account for a significant proportion of total heat demand in 2030, and could be potentially important as a cost effective means of cutting industry emissions.

# Part three

## Current levels of funding are appropriate only as a minimum, with a need to increase funding in certain areas. Cuts in funding would increase risks of missing carbon budgets.

# Government funding and policies

As Part one explained, due to the existence of market failures, public RDD&D support is required to bring new low-carbon technologies to market. This support should leverage additional investment by the private sector. Available estimates suggest that annual private sector R&D could be just over £200m, although as we set out in the supporting analysis, this estimate may not be robust.

In this section, we provide a high level view on current levels of public funding, and highlight key areas where new policy approaches are required to pull through technologies.

We now consider:

(i) Adequacy of current public funding levels for low-carbon RD&D

(ii) Areas where new policy approaches are required to address deployment barriers

## (i) Adequacy of current public funding levels for low-carbon RD&D

### Overview of current funding

No existing data source provides a complete picture of public spend on low-carbon innovation. Moreover, there is no established definition of low-carbon and each source has its own limitations, both in terms of coverage and quality. We have therefore used a broad range of data sources to estimate the level of spend on low-carbon innovation (set out in the supporting analysis). However, to enable consistent monitoring and evaluation of public support (which we return to in Part four), Government should in future ensure data on funding for low-carbon technologies is collected and reported on a consistent and regular basis.

We estimate that during 2009/10 total Government funding, including RDAs and some funding in Scotland and Wales, amounted to around £550m for **low-carbon** RD&D. This is broken down as follows[3]:

- **Power sector:** Around £170m in public funding was allocated to RD&D in the power sector.
- **Transport:** Approximately £190m in public funding is dedicated to transport RD&D, of which around £50m was devoted to aviation[4].
- **Buildings and industry:** Around £90m in public funding is dedicated to RD&D for buildings and industry technologies.
- **Agriculture:** Public funding for low-carbon RD&D in agriculture amounts to around £30m, with an additional £20m for RD&D in the waste sector.
- **Other:** In addition, there is a further £40m in RDA funding and £10m of funding by the Scottish Government which cannot be allocated to any particular category.

Of the £550m allocated to low-carbon RD&D we estimate that around 20% is spent by Research Councils[5], although this excludes investments in basic science which will benefit a wide range of technologies, including low-carbon.

3 All sector expenditure totals are rounded to the nearest £10m.
4 In addition, the Government provided launch investment, a repayable loan worth £340m in 2009/10, to the aerospace industry. This is not included in the total figure.
5 Note that this will include support for nuclear fusion, which is not considered by the analysis.

In addition, we estimate up to £5 billion in deployment support, including[6]:

- **Power sector:** Support for deployment is not provided directly by the Government. The main instrument – the Renewables Obligation – is effectively a levy on fuel bills which is recycled to renewable energy suppliers worth approximately £1 billion in 2008/9.
- **Transport:** Deployment mechanisms include the Renewable Transport Fuel Obligation (£300m).
- **Buildings and industry:** Deployment mechanisms amount to around £1.7 billion from CERT (£1.3 billion) and Warm Front (£400m); DCLG also spends around £700m p.a. on its Decent Homes Programme to install new heating systems, windows and insulation in council housing.
- **Tax measures:** We estimate that tax measures, including Enhanced Capital Allowances, Climate Change Agreements, Levy Exemption Certificates and Vehicle Excise Duty differentials and R&D tax credits, cost the Exchequer over £700 million per annum.

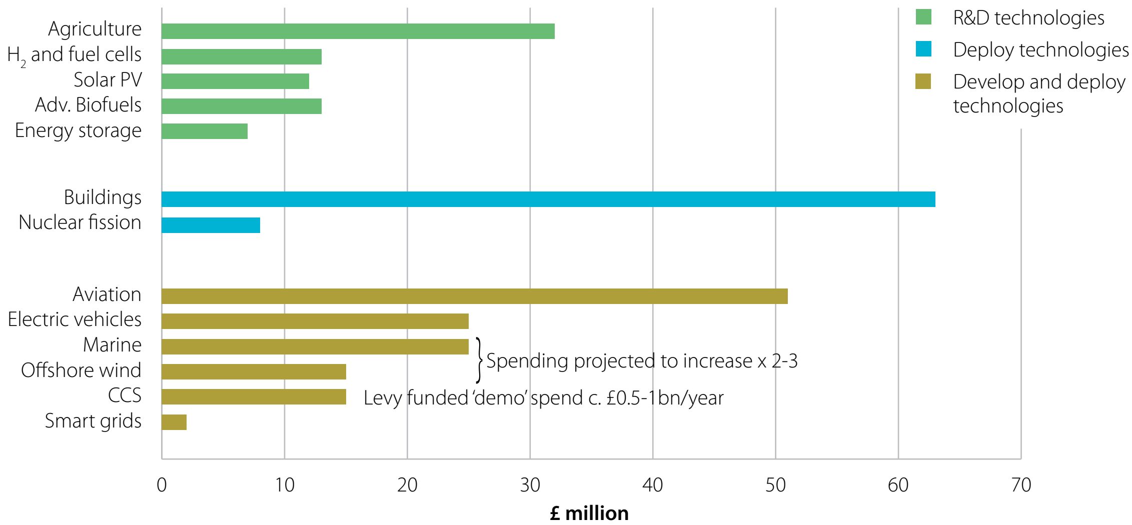
Going forward, these mechanisms are likely to continue to provide substantial support, with additional commitments for supporting demonstration of CCS, deployment of electric vehicles, and other innovation activity through public funding and consumer levies. (Table 2).

**Table 2** Commitments to support low-carbon innovation in the period to 2020

| Technology | Commitments | |
|---|---|---|
| | **Consumer levies** | **Public expenditure** |
| Low-carbon electricity networks and smart grids | £7bn over 5 years raised from electricity customers which includes £500m for the low-carbon networks fund. | |
| Renewables and CCS | £4.2-£5.3bn for CCS demonstration raised by levy from electricity suppliers. | £98.5m support for wind and marine energy. A further £90m to support CCS preparatory studies was announced as part of Budget 2009. |
| Buildings and Industry | | £45m worth of loans to SMEs to install energy efficiency measures; £20m for the Central Government Low Carbon Technology Programme to help reduce emissions from the government estate. |
| Aviation | | £45m to support low-carbon aircraft engines. |
| Electric vehicles | | Up to £230m to subsidise the uptake of ultra low-carbon vehicles from January 2011, subject to state aid approval from the European Commission, with a further £30m for charging infrastructure. |

6 Within deployment support we include funding raised through levies on customers enforced through regulation and directed towards low-carbon uses, although it is not public money in the usual sense. We exclude EU ETS.

**Figure 4** UK public RD&D support for identified technologies (FY 2009/10)




**Source:** CCC calculations based on various data sources (see supporting analysis for further details).

**Notes:**
1. Buildings includes energy efficiency, energy management, microgeneration, biofuels for heat and electricity, and renewable construction.
2. Excludes expenditure on energy efficiency measures for automotive internal combustion engines, which amounted to £50m in 2009/10.
3. This chart excludes expenditure which could not be attributed to particular technologies.

## Adequacy of funding

Our analysis suggests that Government RD&D support exists for most of the technologies contained within the portfolios in Part two above (Figure 4).

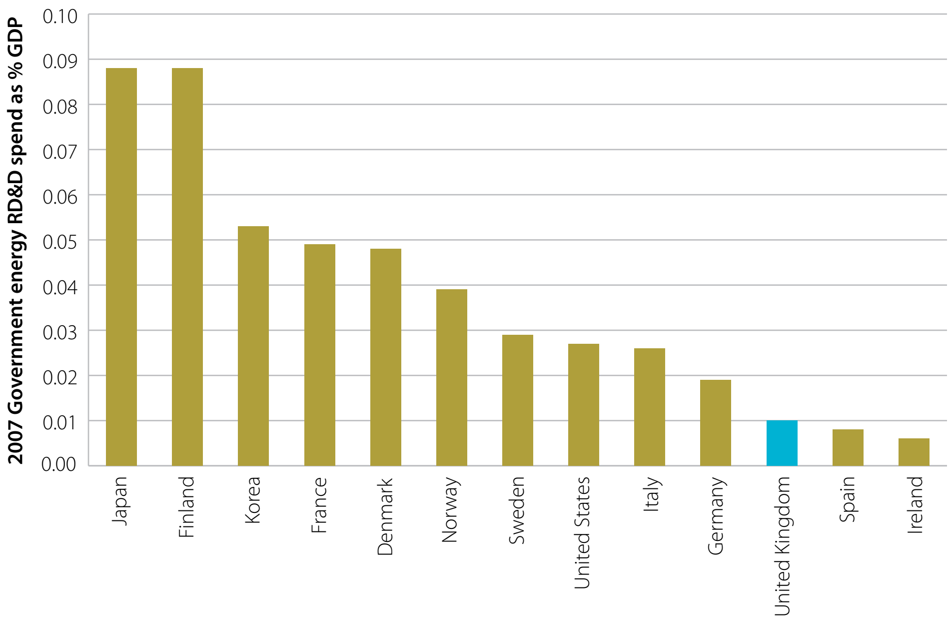
However, the current level of funding should be regarded as a minimum, with a need for increased funding in certain areas. Cuts would be detrimental to the achievement of our climate goals and the new Government's objective to build a green economy. More generally, UK support for energy RD&D is low by international standards (Figure 5) with international funding low relative to benchmarks proposed by the Stern Review, the IEA and the EU. For example, the IEA estimate that public support for energy RD&D requires between a two to fivefold increase globally. Whilst it is unlikely that there is scope for increased funding at the current time, this should be seriously considered as fiscal constraints ease.

## Technologies where current funding is adequate but reprioritisation is needed: CCS coal and gas generation

The new Government has committed to fund four CCS demonstration projects. These will make a direct contribution to reducing emissions in the third and subsequent carbon budgets, and provide a critical mass for international collaboration and early deployment of what is likely to be a key technology for power sector decarbonisation through the 2020s.

Our analysis suggests that gas CCS is likely to be competitive even in a central gas price scenario, and more so in a low gas price scenario (e.g. if significant quantities of unconventional gas comes to market) and when operating flexibly.

**Figure 5** International comparisons of energy RD&D spend (including nuclear)




**Source:** IEA.

There is an opportunity to fund a gas CCS demonstration project as one of four CCS projects to which the Government is committed. In doing this, the UK could become a leader in gas CCS, and develop a potentially valuable option for decarbonisation of the power sector both in the UK and in other countries.

Failure to support demonstration would push back feasible deployment dates, resulting in greater reliance on nuclear power generation for required power sector decarbonisation and increased risks of missing carbon budgets.

### Technologies where more funding should be considered

- **Electric cars:** The previous Government announced £260 million in funding for electric cars, both to support purchase of electric cars (£230 million) and investment in battery charging infrastructure. Development of an electric car market now, reaching a critical mass by 2020 (e.g. 1.7 million electric cars on the road), would provide the option for widespread roll out in the 2020s, which is likely to be required both to support cutting of transport emissions and power sector decarbonisation. Therefore, protecting this support is crucial to underpinning longer term transport and energy objectives. Previous Committee analysis suggests that funding of up to £800m may be required to support purchase of electric cars before this technology becomes competitive with conventional alternatives around 2020. Requirements for additional funding depend on the design of the battery charging network (e.g. more funding will be required for a public network with fast charging points). It may therefore be necessary to rebalance support provided to the automotive sector. For example, around £50m a year is currently spent on improving the fuel efficiency of internal combustion engines.

- **Offshore wind:** The Renewable Energy Strategy envisages that 13 GW of offshore wind capacity will be added to the UK's generation mix in the period to 2020 to help achieve the UK's 15% renewable energy target. Our analysis suggests that this level of offshore wind investment is feasible and desirable in terms of emissions reductions and, with scope for driving down offshore wind costs through learning, it is a potentially low-cost option for deployment through the 2020s. Failure to deliver offshore wind at this level would increase reliance on nuclear power generation for required power sector decarbonisation, and increase risks of missing carbon budgets. Analysis by the Carbon Trust suggests that up to £50m for public RD&D is required annually to take full advantage of opportunities for cost reduction, compared to funding of £15m in 2009/10 and planned expenditure of £40m in 2010/11.

- **Marine:** Carbon Trust analysis suggests that there is a funding gap for some marine technologies. Current support may be appropriate given the relative stages of development of these technologies, and likely relative costs. However, it may also be the case that marine is more promising than current funding would suggest. We will consider the technical and economic aspects of marine technologies in detail in our review of renewable energy, to be published in Spring 2011.

- **Aviation:** Radical technologies (e.g. blended wing) will be required to meet UK aviation emission reduction targets. Public support for the development of these technologies, in co-operation with EU partners, will be necessary.

**Additionality of public funding**

It is important that public support for low-carbon innovation leverages private investment. The available evidence for low-carbon innovation is limited, but evidence about public support for R&D more generally suggests that public funding via grant programmes does stimulate R&D, for example:

- An evaluation of early Technology Strategy Board funding found that the majority of R&D projects were additional, in the sense that without government funding they would not have been carried out.

- Evaluations of DTI's R&D support for small firms showed that only 10% of projects would have gone ahead without government support (i.e. 90% were additional).

- A recent evaluation of support for small firms R&D showed that 70% of projects were wholly additional (and would not have gone ahead at all without support) and a further 26% were partly additional (would have gone ahead, but later and/or on a smaller scale and/or narrower in scope).

- A recent National Audit Office review of innovation support for renewable energy concluded that schemes had supported projects that would not have proceeded and contributed to an increase in renewable generation.

- The evidence on R&D tax credits suggests that the additional incentive effect for investment in low-carbon RD&D is likely to be modest compared to direct funding measures. Based on estimates of the sensitivity of R&D to changes in its price, we estimate that the R&D tax credit might generate an additional £20m in low-carbon R&D for a cost of £20m in lost tax revenues[7].

7 Based on the recent pilot survey carried out by ONS for DECC on levels of private low-carbon R&D – estimated to be £236m. For details of the method see the supporting analysis.

### (ii) Areas where new policy approaches are required to address deployment barriers

The previous sections considered the adequacy and additionality of public support for RD&D and found that, broadly, Government is supporting the right technologies. This section considers the current arrangements for deployment support. Whilst the policy framework has evolved considerably over the last ten years or so, there are significant gaps in deployment support which will compromise the UK's ability to deliver key low-carbon technologies. Failure to address these issues would make the deployment of technologies more difficult, less likely or more costly.

**Power generation**

- Given volatile electricity and carbon prices, and uncertainties over development of electric vehicle and heat markets, there is a significant risk that **current electricity market arrangements will not deliver required investments** in nuclear, CCS and storage and renewable technologies during the 2020s. Therefore reform of the current arrangements is required to provide more confidence to investors in low-carbon technologies. New arrangements could be strengthened through the introduction of an Emissions Performance Standard (EPS) for coal fired generation as proposed by the Government and, in parallel, an EPS for new gas generation. Introduction of a carbon price floor as proposed by the Government would complement market reforms, and would provide transitional support for investments before new arrangements are introduced.
- **Planning approval for wind projects remains a barrier**, both as regards the planning period, and the approval rate. In 2009 the average planning approval period for on and offshore wind remained at 15 months – well above the statutory target (16 weeks for on-shore), whilst the approval rate at local authority level fell from 68% in 2008 to 53% in 2009. A reduced planning period and increased approval rate would provide more confidence that very ambitious targets for deployment of wind generation in the period to 2020 will be achieved.
- A current barrier to deployment of CCS beyond the demonstration stage is the **lack of a $CO_2$ infrastructure**. There is currently uncertainty around where $CO_2$ should be stored, the design of pipelines to transport $CO_2$, and the appropriate location of CCS plants. These issues should be addressed through development of a CCS infrastructure strategy, which would include an assessment of whether a market-based or a more planned approach to infrastructure development is appropriate. The strategy could be anticipated by inviting bids for joint infrastructure as part of the demonstration project, therefore opening up the possibility that economies of scale could be exploited.
- There is a risk that there will be insufficient numbers of **specialists** to support deployment of new technologies e.g. deployment of nuclear requires scaling up of university courses to train nuclear specialists and some funding of nuclear research.

**Transport**

- **Electric cars:** One of the main barriers to electric car deployment is the absence of a battery charging network. In order to support market development, Government funded investment in a charging network will be required. Our analysis suggests that this should largely be based on home charging overnight, given that this is the least expensive option, that most trips/car miles are short distance, and that the majority of households in the UK have off street parking. However some public charging infrastructure will be required, particularly to provide confidence to drivers and to cater for drivers making longer journeys. Currently there is around £30 million available for funding of battery charging infrastructure, and the new Government has committed to roll out a national battery charging network, although there are key questions of detailed design outstanding.
- **Aviation:** New aviation technologies are already subject to strong market pull given that aircraft fuel efficiency is a key consideration for airlines as fuel costs are a significant share of total costs (i.e. up to 35%). Additional market pull is likely with the inclusion of aviation within the EU ETS in 2012, although the carbon price signal is unlikely to be sufficiently strong to pull through more radical technology options, such as blended wing configurations.

**Buildings**

- Market pull for insulation technologies is currently low. There were only 15,000 solid wall installations in 2009 under CERT. Although ambitious targets for deployment of solid wall insulation were set in DECC's Household Energy Management Strategy (e.g. 2.3 million insulations annually), there is currently no policy in place to deliver this ambition, and a new policy approach which addresses both financial and non-financial deployment barriers (such as the thickness of available insulation) is required. The proposed Renewable Heat Incentive could in principle pull through renewable heat technologies in residential and non-residential sectors. However, there are currently a number of design questions outstanding, including the precise level of support for different technologies, the balance between up front grants and annual payments, levers to address non-financial barriers to uptake, and integration of the approach to renewable heat with new policies to encourage energy efficiency improvement.

# Part four

## Clear Government and delivery body objectives, desired outcomes, and effective monitoring and evaluation are required to ensure maximum value from public spending and improve investor confidence.

# The institutional framework

The UK currently has an energy strategy covering only the period to 2020. However, a longer term focus with clear objectives for the period to 2050 is required to ensure that appropriate technologies are developed. These long-term objectives, and implications for action in the near term, should determine the objectives of, and monitoring frameworks for, delivery bodies. The activities of delivery bodies together with innovation taking place internationally should deliver a set of technologies to meet the UK's long-term objectives. The current framework suffers from a lack of long-term Government thinking.

We now consider in more detail:

(i) Adequacy of objectives and long-term focus

(ii) Adequacy of delivery arrangements

### (i) Adequacy of objectives and long-term focus

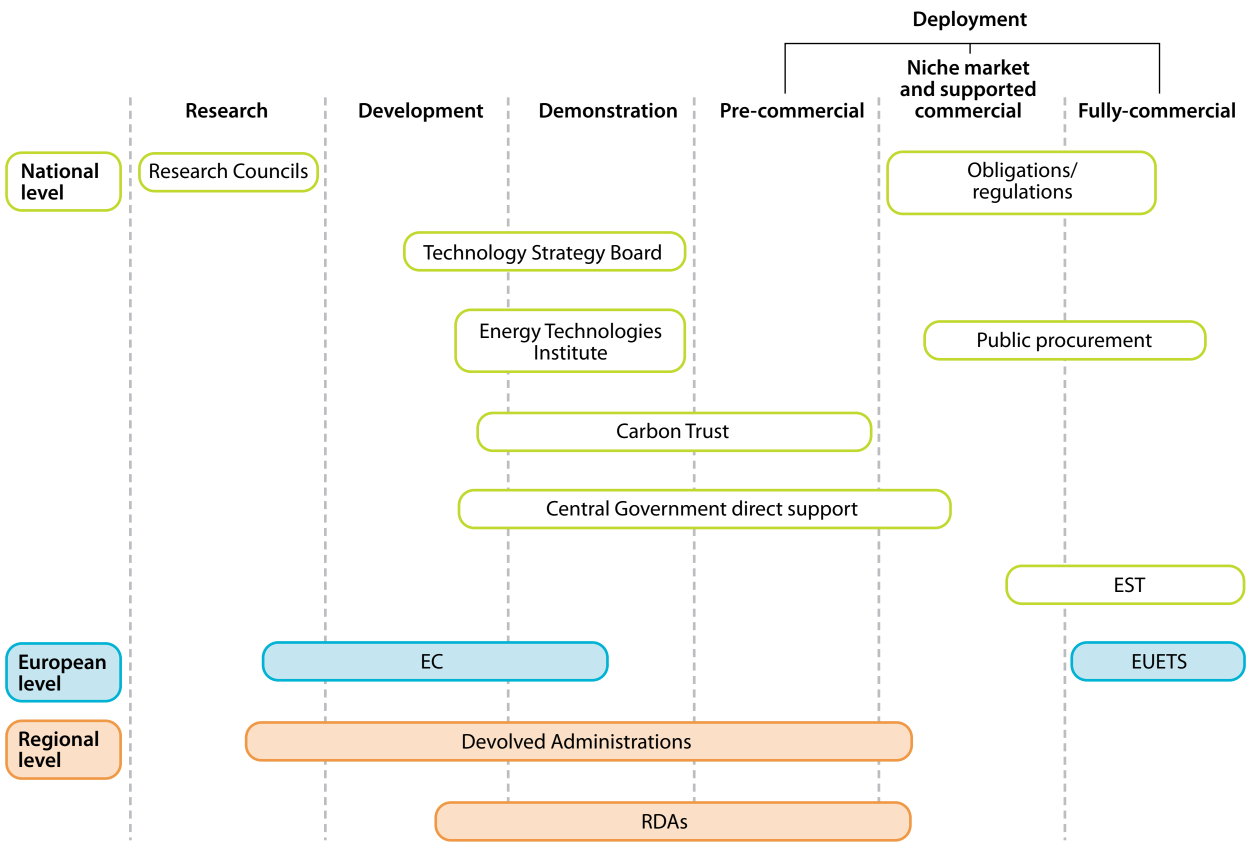
The formation of DECC and the publication of the Low Carbon Transition Plan (LCTP) and related strategies, together with EU legislation on renewable energy, have provided greater clarity on Government objectives.

However, the LCTP and EU renewable energy targets only cover the period to 2020. Therefore, there is considerable uncertainty about the path from 2020 to 2050, the technologies that this will require, and implications for technology support over the next few years. This uncertainty is compounded by short timescales for funding, with limited confidence around which technologies will be supported beyond the next few years.

In order to reduce this uncertainty, and therefore improve the investment climate for low-carbon innovation, we recommend that the Government should:

- Set out its whole economy strategy for reducing emissions by 80% relative to 1990 levels by 2050 (e.g. including a Government view on the Committee's recommendation that early power sector decarbonisation and extension of low-carbon power to transport and heat is required on the path to meeting the 2050 emissions target). This strategy should have a clear lead, with support from all relevant departments (e.g. DECC, BIS, DfT, HMT).
- Within the strategy, set out which portfolio of technologies the public sector will support to achieve that objective (e.g. whether these concur with the portfolio of technologies that we have recommended in Part two above).
- Identify the level and form of public support and policy that it believes will be necessary to address deployment barriers and develop those technologies (e.g. including the extent to which funding should be increased in the medium-term, and the approach to electricity market reform, as we have recommended in Part three above).

**Figure 6** The public support landscape for energy innovation programmes




**Source:** Adapted from UK Environmental Transformation Fund Strategy.

The strategy should also address the following international aspects:

- How to increase UK influence over the design of EU programmes for low-carbon technologies (e.g. to ensure that there is adequate funding of CCS demonstration for energy intensive industries). This is an area where our interviews with stakeholders suggested that the UK is not as effective as other Member States.
- More generally, there is scope for collaboration with other countries in developing key technologies. For example, UK coal CCS demonstration projects 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. Similarly, in the case of gas CCS demonstration, this should interface with projects in Norway, possibly under the auspices of the North Sea Basin Task Force. In both cases, collaboration would leverage the experience gained here, improving prospects for early roll out in the UK.

- At EU and global levels there is scope for the UK to influence arrangements to pull through technologies. Whilst there has been progress in key areas (e.g. the EU renewable energy framework), there are a number of areas where more effort is required. Of particular importance are new global approaches to pull through new technologies in aviation (e.g. open rotor engines, blended wing planes), the shipping sector (e.g. new hull configurations and propeller designs, new fuels) and energy intensive sectors (e.g. iron and steel). We have previously advised on an approach to international aviation emissions, and will review international shipping emissions, including any international deal, in 2012.

## (ii) Adequacy of delivery arrangements

### Delivery bodies

There are many institutions involved in the delivery of low-carbon innovation, each with different objectives (Figure 6). Some focus solely on developing low-carbon technologies, others will invest in low-carbon if it will help the UK develop greater competitiveness. The number of bodies and differences in approach mean that the landscape lacks clarity and overlaps can result where multiple institutions seek to invest in the same technology.

Recently there has been progress to improve the coherence of the institutional landscape. A Low Carbon Innovation Group, comprising the Technology Strategy Board, Carbon Trust and Energy Technologies Institute, has been formed to try to ensure that the strategies of these organisations are aligned. Membership was recently extended to include DECC, BIS and the Research Councils.

We have not taken a view on whether there should be consolidation of institutions (e.g. through the creation of a Green Investment Bank): there are examples internationally where multiple institutions have successfully delivered technology innovation, and others where a more monolithic structure has been successful.

The crucial point for the Committee is that whatever the institutional landscape, this should be driven by clear objectives for delivery bodies that are fully consistent with Government objectives for technology development. That is currently not the case, given the absence of a long-term Government strategy. The priority should therefore be to set a Government strategy, and then to reflect this in the objectives of delivery bodies.

### Green Investment Bank

On 29th June the Green Investment Bank Commission set out its proposals for a Green Investment Bank to tackle the low-carbon investment needs of the UK.

The Commission proposed that the Bank would have two priority tasks:

- To identify and address market failures limiting private investment in low-carbon technologies.
- Provide coherence to public efforts to support innovation in relation to climate change by rationalising Government established bodies and funds.

In addition to the perceived complexity of the landscape, noted above, there are multiple schemes covering the same technologies (e.g. there are over 30 schemes available for supporting R&D into algae in the East of England alone). Clearer signposting of support (including non-funding measures) would be helpful and this has been recognised by DECC, the Carbon Trust, the Technology Strategy Board, UKERC and the Energy Generation and Supply Knowledge Transfer Network who are collaborating to produce a funding landscape navigator for businesses.

Our interviews with stakeholders also suggest that the UK is not as effective at providing the support required to take technologies through to the later stages of development and commercialisation. This in part arises because public funding is, for the most part, based on three year budget cycles, and hence does not match the development cycles of most technologies. A number of stakeholders contrasted the situation in the UK with that in the US where the expectation of continuity of funding and other policy measures was more robust, providing that technology milestones were hit. Therefore we recommend that the Government should ensure that there is continuity and integration of support across the different stages of technology development (e.g. any framework should support far from market technologies as well as the deployment of near to market technologies).

**Appraisal, Monitoring and Evaluation processes**

Adequate resources for appraisal, monitoring and evaluation are essential given the levels of uncertainty involved in low-carbon technology development. However, there is little evaluation evidence on the effectiveness of spend. For example, the National Audit Office reports in its review of funding for renewable energy programmes that there is little data on which to judge scheme performance and that the Government lacks a framework for consistently reporting performance across all the main organisations involved in technology development. Stakeholders also identified a lack of resources dedicated to the long-term monitoring of measures. We therefore recommend that there should be increased focus on monitoring and evaluation, and that success should be judged against the Government's long-term objectives and related objectives for delivery bodies.

# Conclusion

In summary, there is a set of technologies currently under development that could deliver the UK's target to reduce emissions by 80% in 2050 relative to 1990 levels. Given its research and industrial capabilities, the UK is well placed to support the development of some of these technologies.

The current programme of support is broadly targeted at the right technologies. However, funding is at the minimum level required to bring technologies forward, and consideration should be given to increase funding, particularly as financial pressures ease. In addition, new policy approaches are required to improve the investment climate and pull low-carbon technologies through to deployment. A strengthened institutional framework – with clear objectives, desired outcomes and responsibilities, and improved monitoring and information flows – is required to ensure that public money is well spent and to increase investor confidence.

The case for action is strong. With adequate funding, new policies and strengthened delivery arrangements, we would expect UK firms to lead on development of key technologies, driving down emissions to meet carbon budgets and targets, and fulfilling the new Government's clear objective to build a low-carbon economy. We therefore urge Government to put appropriate low-carbon technology support arrangements in place to unlock environmental and wider economic benefits.

# Annex A: Terms of reference for review

The Committee should:

- review the effectiveness of current measures (both public and private) to support relevant RDD&D in the UK in light of Government policies and targets on climate change, including the impact of public policies in leveraging private sector investments.
- review the frameworks and institutional arrangements under which such RDD&D is carried out – including the mechanisms by which demand drives investment and the incentives for businesses to invest – grants, regulations etc, and the institutions which distribute them;
- consider the balance of funding across the RDD&D spectrum and how this should develop linked to policy goals, taking account of related policy measures and regulation at UK and EU/ international levels;
- consider whether there are lessons the UK could learn from arrangements for supporting climate change related RDD&D overseas;
- provide advice on making best use of the research base, including economics, social research and arts and humanities, as well as the outputs of the Foresight programme;

The Committee should consider each of the above issues at a high strategic level in order to provide advice, building on existing information and analysis, and have scope to decide itself in which areas/sectors to place greatest attention at a more detailed level, based on the Committee's own judgment on key issues and the degree of past scrutiny afforded.

**Timetable**

The project is expected to begin in Oct 2009 and complete by around June 2010.

**Key context**

Through the Climate Change Act and other measures the Government is taking bold action to radically transform the UK to a low-carbon economy, with challenging emissions targets for 2020 and 2050 and a framework for achieving these. At the same time, the Act addresses the need to adapt to those impacts from climate change that cannot be avoided

Research and innovation will be key to achieving these goals, including to improve understanding of the challenges faced, to inform development of the appropriate responses, and to create and accelerate towards market those technologies that will enable the UK to meet its goals at least cost over the long term. Both public and private sectors will need to contribute, and an important aim is to achieve an optimum balance between these and to maximise the impact of combined investments.

Against this backdrop, the Committee will review the effectiveness of research and innovation arrangements in the UK related to achieving our climate change goals, focusing in particular on public sector bodies, instruments and budgets and their impact in leveraging private sector investments. The review will be set also in the context of the Stern recommendations for increased global R&D spend and deployment incentives, the UK's relative international position in terms of current public sector support, the post-2012 negotiations related to UK aims and influencing on technology, and also of the very tight UK public finance position for the foreseeable future.

The incentive and regulatory framework (including the carbon price) will be important, as well as more explicit support mechanisms. Overall, the review should adopt a holistic approach, giving due weight to outputs and outcomes as well as inputs, and taking full account in the area of technology development of the constraints/opportunities related to existing institutional arrangements e.g. the Energy Technologies Institute, Environmental Transformation Fund, Technology Strategy Board, Carbon Trust and Research Councils, with the institutional landscape having recently been revamped.

The Committee should be free to make recommendations on improvements affecting any of the above, but recognising the wider responsibilities of bodies such as the Research Councils and the TSB for subjects other than energy and climate change.

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