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

Supporting analysis and review of evidence

Contents

Introduction

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, and investment in, low-carbon technologies.

In October 2009 the Committee was asked by the Government's Chief Scientific Advisor, Sir John Beddington, to review the adequacy of research and innovation arrangements in the UK related to achieving our climate change goals, including the institutional arrangements for supporting low-carbon innovation (Box 1).

The main report setting out the Committee's conclusions and recommendations was published in July 2010 and is available at: http://www.theccc.org.uk/topics/low-carbon-innovation

This paper sets out the underlying analysis and evidence considered by the Committee and which informs those conclusions and recommendations.

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 likely to play a role in helping the UK meet its 2050 target to reduce emissions by 80% on 1990 levels, but which have not yet become competitive with high-carbon alternatives, and / or technologies where the UK is likely to contribute significantly to global mitigation efforts.

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

Box 1: Terms of reference

The terms of reference drafted by Government for this project requested that the Committee:

- 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 or other 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.

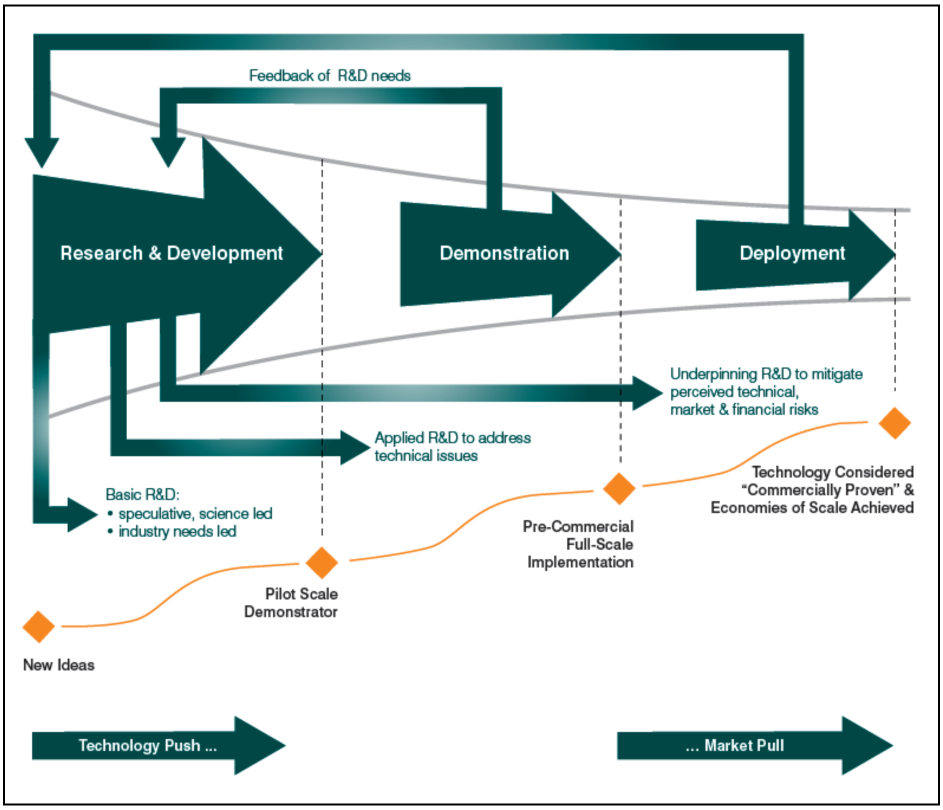
Our analysis draws on a range of technology studies (including our own Markal modelling, and analysis by the International Energy Agency (IEA), UK Energy Research Centre (UKERC) and Energy Research Partnership (ERP)), patent analysis by the London School of Economics (LSE), and interviews with a wide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

Definitions

Before proceeding it is worth defining some terms, in particular what we mean by 'innovation', the components of 'RDD&D', 'low-carbon' and 'technology'.

- **Innovation**: covers the full research, development, demonstration and deployment process. It should not be considered a linear process, but allows for interactions between different actors – government, academia, businesses, financiers – and involves feedback loops across stages (Figure 1). It is not inevitable that ideas conceptualised at the R&D stage will successfully move through the various stages and transform into a technology that is ready for commercial deployment (e.g. companies with technologies at the demonstration stage may identify problems and need to revisit earlier stages). Transition through the various stages of the innovation cycle does not take place in a vacuum, but depends on:
  - Expectations about future technological, market and policy developments.
  - Institutional structures, which may provide incentives to progress, but also have potential to inhibit progress.

Figure 1: 'Innovation funnel' diagram



Source: Energy Research Partnership

- **RDD&D**: we refer to research, development, demonstration and deployment (RDD&D) throughout this supporting analysis. The definitions of these terms are set out in Box 2.

Box 2: Definition of RDD&D

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 pre commercial demonstration of technologies at scale, designed to test and improve design, reliability and performance, and to give a stronger indication of production and operating costs, and the opportunities for cost reduction.

RDD&D: Research, development, demonstration and deployment, as RD&D but also including issues such as integration into existing systems and customer perception and response. Technologies are not yet competitive in the market.

Source: BERR (2008), *UK Environmental Transformation Fund: Strategy*

- **Low-carbon**: there is no existing agreed definition for data collection purposes. We treat a new product, service or process as low-carbon if it:
  - Leads to an absolute reduction in GHG emissions (e.g. renewables displace existing coal fired plants). [1]
  - Improves the carbon intensity of an activity (e.g. improved engines in surface transport and aviation will help increase fuel efficiency), in which case we need also to consider potential rebound effects.[2]
- **Technology**: we focus on major technological systems (e.g. wind turbines, electric vehicles), rather than individual component technologies. In identifying which technologies should receive targeted support, we consider which are likely to contribute most to achieving emission reductions (both in the UK and globally), the key challenges to deploying these technologies, and what capabilities exist within the UK to lead development of the technology. We do not consider in detail:
  - More mature technologies (e.g. onshore wind, which - so long as fossil fuel prices remain high - is already competitive with fossil fuel generation at the best wind sites, and biomass boilers, which have been deployed quite widely on the continent).
  - Technologies that are unlikely to contribute significantly to UK mitigation efforts in the period to 2050 (e.g. nuclear fusion[3]), and / or where UK R&D efforts are unlikely to contribute significantly to global mitigation efforts (eg. concentrated solar power).
  - Technologies to geo-engineer the climate.
  - Technologies which can help the UK adapt to a changing climate.

[1] In the context of this report low-carbon covers all six Kyoto GHGs (carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, hydroflurocarbons, and perflurocarbons) as defined by the UNFCCC, although our ability to capture all spend aimed at reducing these emissions is mixed.
[2] For instance the impact of fuel efficiency improvements on emissions in the aviation sector will be lower if airlines then fly longer distances or carry more weight. Similarly, improved fuel efficiency of surface transport may induce consumers to drive longer distances.
[3] IEA (2008), *Energy Technology Perspectives 2008*

Our analysis is set out in five chapters:

- Chapter 1 outlines the case for public support for low-carbon technologies and briefly considers the effectiveness of different instruments.
- Chapter 2 summarises the available evidence on which technologies are likely to be required to meet 2050 emission reduction targets and assesses UK capabilities relevant to these technologies.
- Chapter 3 presents estimates of current levels of public funding and other financial support.
- Chapter 4 examines the effectiveness of the deployment framework in delivering low-carbon technologies and considers whether new approaches are required.
- Chapter 5 provides an assessment of the effectiveness of the current institutional arrangements for public support.

Chapter 1 – The case for public intervention

Public RDD&D support is often required to bring technologies to market. In the case of low-carbon technologies there is likely to be a particular need given their relatively high cost compared to high-carbon alternatives. In this chapter we summarise the arguments justifying public support and discuss the types of instruments and policy approaches that are required.

We now consider:

1.1 The case for public support for low-carbon technologies

1.2 The effectiveness of different instruments

1.3 The need for a systems approach

1.1 The case for public support for low-carbon technologies

Costs of greenhouse gas emissions

It is well understood that emissions of greenhouse gases (GHGs) impose costs on wider society through climate change.

- The overarching market failure associated with climate change is the negative externality of greenhouse gas emissions. Polluters fail to take account of the wider social implications of the greenhouse gas emissions that they generate. Over-production of high-emission technologies results.
- As long as the market, without public policy intervention, does not reflect the 'true' price of carbon emissions, the level of demand is distorted in favour of 'high-carbon' products, processes and technologies and incentives to develop low-carbon technologies are reduced.

Innovation related market and system failures

Even if a carbon price is fully embedded into the market, thus reflecting the social costs rather than the private costs of the emissions, a number of market failures and barriers still exist that can lead to continued underinvestment in low-carbon innovation. These failures apply to innovation generally, but may be relatively pronounced for low-carbon innovation:

- **Market power and dominant designs**: a number of barriers to the development and adoption of innovative activities stem from issues around market power. Alongside natural market barriers (such as economies of scale), the development and commercialisation of new technologies may require significant set-up or capital costs. There are many low-carbon innovative alternatives that potentially fall into this category. Related to this, current infrastructures have evolved to meet the needs of the existing technological paradigm. Energy and transport systems have dominant designs, which are supported by well developed infrastructures based on fossil fuels, encouraging 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 a barrier. Barriers to entry may also be institutional: policy makers may be heavily influenced by the views of proponents of the existing technology paradigm.[4]

- **Uncertainty**: 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. Many investments in the energy sector are highly-capital intensive, so uncertainties are particularly important in this area. Long time-scales for investment and deployment of technologies, frequent in the energy sector, increase the amount of time investments are at risk and reinforce risk aversion.
- **Policy uncertainty**: Uncertainty is also likely to be greater for low-carbon investments, since the presence of a market is reliant on government regulation for its maintenance. Lack of information about the future path of carbon prices, and the regulatory environment over the longer-term, creates uncertainty around potential returns from investments in innovative activities – higher risk can then act as a disincentive to innovation.
- **Product differentiation**: Some companies operate in markets where product differentiation is difficult or impossible. This is a particular issue in the energy sector. 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 – for example, customers value electricity, but they care less whether the electricity is generated from a wind or gas turbine.
- **Spillovers**: Left to the market, investment in innovation will be underprovided as a result of the existence of positive externalities:
    - The generation of knowledge, which can spill over to other firms and users (Box 3).
    - Where innovation leads to lower product prices, there are additional welfare benefits to users of that product which are not reflected in the product price. In the absence of complete intellectual property protection, investors will not take these wider social benefits into account.[5]

Box 3: Social returns to R&D

There is a wide body of evidence that suggests that social returns to R&D can be substantial and exceed returns to private investors:

- The private returns to R&D cluster around 10-15% although they can be as high as 30%.
- The social rate of return to industry from R&D conducted by firms within the same industry ranges from 17% to 34%.
- The social return attributable to R&D conducted in one industry but used in another (for example, R&D carried out in one part of the supply chain can benefit other parts) could be up to 80%.

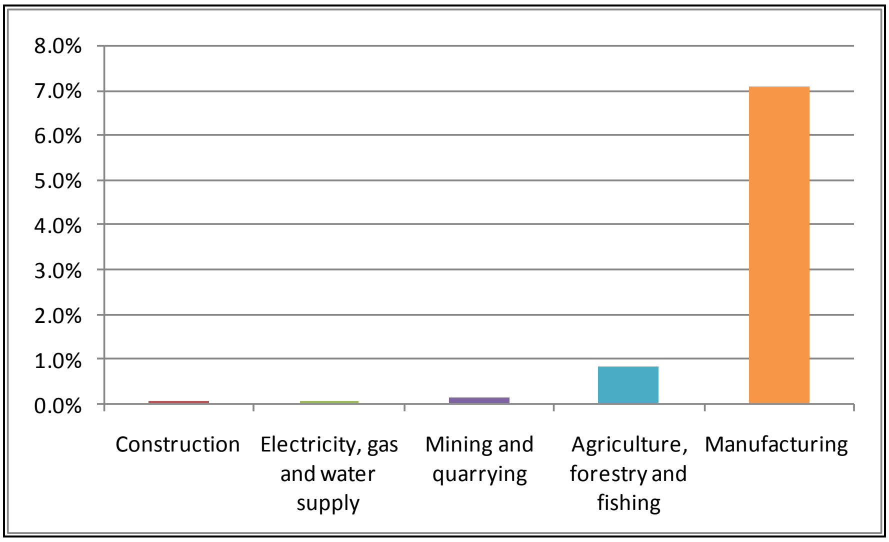
Source: Griffith (2000), *How important is business R&D for economic growth and should Government subsidise it?*

Factors such as lock-in and difficulties in differentiating products help explain why the R&D intensity of utilities is low compared to the rest of the economy (Figure 2). Innovation and R&D activities in the energy generation and distribution sector are low. Furthermore, 'green' motivations for R&D seem to

[4] Foxon et. al (2007), *Energy Technology Innovation: A systems perspective*
[5] Jaffe (1996), *The importance of "spillovers" in the policy mission of the Advanced Technology Programme*

be given a low priority by this sector.[6]

Figure 2: Business R&D intensity (R&D as % of value added) by sector, 2006



Source: Office for National Statistics and CCC calculations

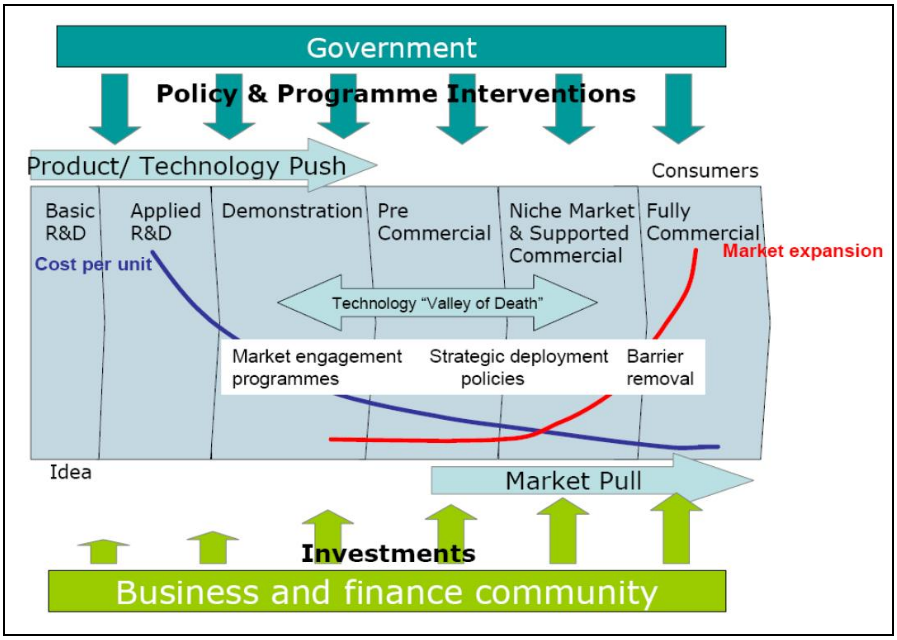
Even with public support for research, development and demonstration (RD&D) it does not necessarily follow that low-carbon technologies will be commercialised. This is because:

- At the end of the RD&D phase the low-carbon technology has not yet been produced and operated in sufficient scale – learning is likely to have been limited, and costs will be high relative to the incumbent technology. This matters particularly in sectors where product differentiation is weak and where there is not a group of lead users willing to pay more for using the new product.
- There may be barriers to deployment, such as planning, which limit take up and keep costs high.

In these circumstances a 'valley of death' (Figure 3) may arise where there is insufficient support to drive technologies through to commercialisation and where technologies can be trapped in a cycle of small volumes and high costs. Public support for RD&D needs to be complemented by measures to pull technologies through the valley of death (e.g. obligations, feed-in tariffs), and address deployment barriers or skills gaps.

[6] Aghion et. al (2009), *Cold start for the green innovation machine*

Figure 3: The Valley of Death



Source: Grubb (2004), Technology Innovation and Climate Change Policies: An Overview of Issues and Options

By stimulating additional technological change, it is possible for policy to reduce the costs of meeting a given climate change target.[7] Induced technical change may lead, through cumulative learning effects and the development of a broad range of mitigation options[8], to reduced long-term marginal costs of emission abatement. Analysis by UKERC[9] finds that short-term steps to accelerate technological development could have a considerable impact by 2050, significantly reducing the cost of abatement in the long-term.

1.2 The effectiveness of different instruments

There are many ways to provide financial support for RDD&D. Measures fall into two categories: those – generally operating at early stages of the innovation chain – which encourage the creation of technologies, described as supply-push, and those, such as carbon prices, obligations or feed-in tariffs at later stages closer to commercialisation, which are described as demand-pull policies. Given the different market failures and barriers, both are likely to be required.

Supply-push

The market failures highlighted in Section 1.1 clearly suggest that without government intervention, the private sector will almost certainly under-invest. This is particularly likely for early stage R&D (inventions and innovations that are a long way from market), and for 'blue skies' research with no clear commercial application at that stage.

---

[7] Pew Center (2004), *Induced technological change and climate policy*
[8] Edenhofer et. al (2006), *Induced Technological Change: Exploring its Implications for the Economics of Atmospheric Stabilization*
[9] UKERC (2009), *Decarbonising the UK Energy System: Accelerated Development of Low-carbon Energy Supply Technologies*

The objective of supply-push measures is to directly stimulate research and innovation through the provision of grants, loans, tax credits or venture capital to research organisations or businesses. Such measures promote learning by research, but are less likely to increase learning in use as, typically, support is limited to the early stages of innovation e.g. first prototype phase. The rationale for these measures usually rests on the high risk of research activities and the wider benefits generated by investments in research. Their impact depends on the amount of additional private sector investment leveraged by public funds, which is a function of instrument design and the types of project supported.

Government has a number of options for directly supporting such early stage activity[10]:

- **Grants**: government provides money to research institutions or businesses to fund research. Grants for early stage research, where there is little scope for intellectual property protection, are likely to be highly additional in that they stimulate innovative activity that would not have otherwise taken place.
- **Government loans:** less common than grants in the UK. Typically a lower interest rate is payable compared to the market alternative but the subsidy element is smaller than with grants, and the impact on investment smaller. Where companies are highly geared, additional loans, even if provided by government, may not be attractive.
- **Prizes**: a lump sum or perhaps a contract is awarded to an organisation that is first to achieve a particular outcome. Prizes are most likely to be used when an intense R&D effort is required to meet a specific goal.[11] The main challenge in designing a prize is choosing the goal and this is key to ensuring that prizes produce additional innovative activity and do not encourage premature technological lock-in.
- **Matched equity funding:** for example public backed venture capital, is unlikely to be attractive for early stage R&D since private sector partners will require a reasonably quick return. Matched equity funding is likely to have the greatest impact at the demonstration stage where successful demonstration could provide the trigger for an initial public offering on a stock market and, therefore provide an exit for private (and public) sector investors.

In addition to more targeted means of delivering support to businesses undertaking innovative activity, there are also more general supply-push schemes such as the R&D tax credit system in the UK (a corporation tax relief that can reduce a company's tax bill by more than the actual expenditure on allowable R&D costs). There are two schemes, reflecting the differences between large firms and small and medium-sized enterprises (SMEs). The primary purpose of provision of tax credits in this area is to stimulate R&D spending by companies, with the firms themselves able to decide where and how to spend their R&D budgets.

Demand-pull

The objective of demand-pull measures is to increase the deployment of technologies. Its effect on research is indirect – by increasing the rate of return to certain types of technology it makes further research into that technology more attractive and may stimulate further learning by research. It is more likely however to stimulate learning in use as installers advance their understanding of how the technology operates in real conditions.

These measures address under-valuation of low-carbon technologies. They are best used where

[10] Frontier Economics (2009), *Alternative policies for promoting low-carbon innovation*
[11] Office of Climate Change (2008), *Global Technology Project*

there is a significant cost disadvantage for the low-carbon technology relative to its high-carbon comparator, but they can be very costly:

- **Carbon pricing**: Establishing a carbon price improves the likelihood that low-carbon technical solutions become cost-competitive:
    - Attaching a financial cost to emissions should create demand for low-carbon alternatives (switching demand away from the original high-carbon products and technologies)[12]. There is then a demand-driven, profit-based incentive for the private sector to invest effort in developing new, lower-cost, climate-friendly innovations.
    - A carbon pricing mechanism has the attraction that it does not directly discriminate by sector, but against the status quo (where high-carbon alternatives are preferred). Carbon pricing, whilst a useful and necessary policy lever may not be sufficient, alone, to drive forward the level of innovative activity required.[13] For example, the carbon price from the EU Emissions Trading System is too low, too volatile and too uncertain over the longer-term to act as a major driver for investment in innovation[14].
- **Targets**: The use of targets and their delivery mechanisms, such as those mandated by both the EU and the UK for increasing the percentage of energy supplied from renewable energy sources, can help underpin an expectation of market demand for particular portfolios of technologies. A key aspect of any target and delivery mechanism is to provide credibility over the longer term and deliver confidence to investors about potential returns.
- **Product and technology standards:** standards can help focus innovative activity (e.g. energy efficiency standards on boilers). Standards can take a number of different forms depending on their objective. They may be applied horizontally across industries (e.g. environmental performance standards), or vertically across specific supply chains (e.g. technical standards). In the context of inducing low-carbon innovation, research suggests that flexible environmental performance standards induce more environmental R&D than technology standards (e.g. those enforcing the use of mandatory pieces of equipment)[15]. The former allows firms to determine how best to meet the standard, thereby encouraging the generation of a number of competing options. Technology standards can focus innovation on making the mandated technology more efficient, and are more appropriate if a clearly superior technology has emerged.
- **Public procurement:** In the UK, public procurement spending is around £150bn per year – approximately nine times more than UK companies themselves invest in research and development[16]. The public sector can use its purchasing power to create early demand and stimulate the market for a new technology. This is likely to be easier for some low-carbon technologies than others. For example, procurement decisions on government vehicles or buildings could help create demand for innovative low-carbon products in the transport and buildings sectors. There is much less opportunity to use public procurement as a demand-pull measure in the power sector.

Demand-pull support must be in place well in advance of a technology being deployed as it helps to reduce uncertainty through providing a credible long-term commitment to a policy[17]. Accelerated

[12] Newell (2009), *The Role of Markets and Policies in Delivering Innovation for Climate Change Mitigation*
[13] Bosetti et. al (2009), *The role of R&D and technology diffusion in climate change mitigation: new perspectives using the WITCH Model*
[14] Committee on Climate Change (2010), *Meeting Carbon Budgets – ensuring a low-carbon recovery*
[15] Newell (2009), *The Role of Markets and Policies in Delivering Innovation for Climate Change Mitigation*
[16] CBI (2006), *Innovation and public procurement: A new approach to stimulating public procurement*
[17] Frontier Economics (2009), *Alternative policies for promoting low-carbon innovation*

private investment in innovation is best guaranteed through the expectation of a rapidly growing demand for the products based on the new technologies[18].

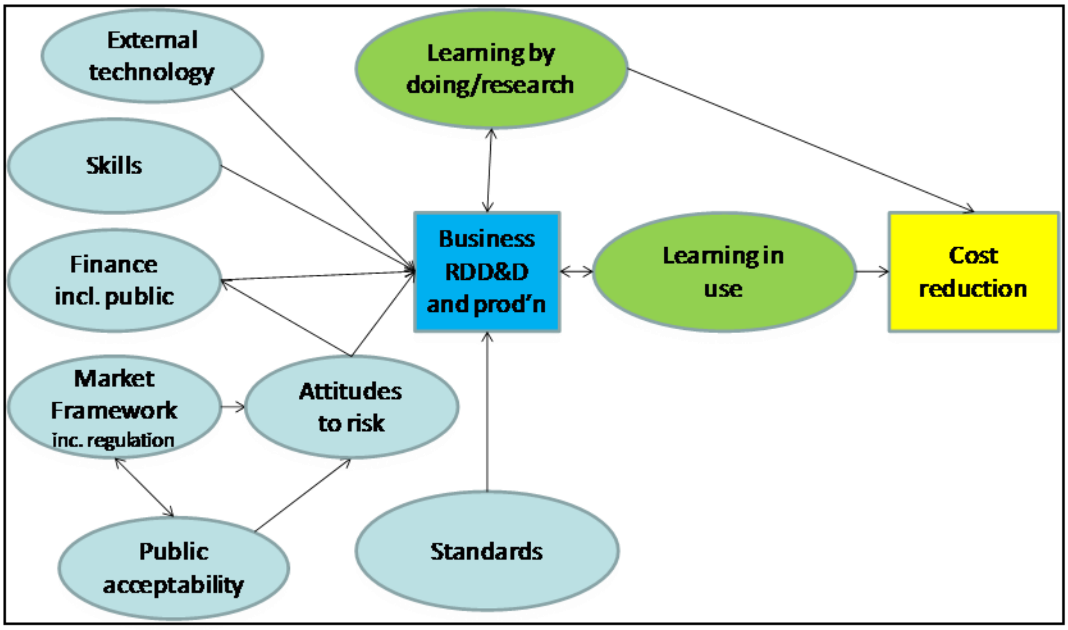
A package of instruments is likely to be effective in delivering both the scale and scope of innovative activity required to meet the challenge of reducing carbon emissions. Effective policy needs to take account of different stages of development and the critical milestones for deployment. Government support for early stage R&D is fundamental in encouraging investment in new areas, but will not effectively pull technologies through to market if there is no prospect of a sufficiently large market demand from which firms can see potential returns.

1.3 The need for a systems approach

Public funding for technology development is only one factor in the success, or otherwise, of new technologies[19]. Firms require access to other resources to enable them to increase technological learning and bring new technology down the cost curve. For example, firms will:

- Require access to external technology to complement technologies produced in-house, and the skills to integrate these.
- Be influenced by regulatory frameworks and public acceptability – some technological paths may be restricted or closed off, others may open up.
- Be influenced by, or require access to, standards which relate to product performance and quality or allow technologies to operate with other systems.

Figure 4: Influences on business innovation



Source: CCC analysis

[18] Henderson & Newell (2009), *Accelerating Energy Innovation: Insights from Multiple Sectors*
[19] Foxon (2003), *Inducing innovation for a low-carbon future* (report for the Carbon Trust)

This representation of the system (Figure 4) illustrates that deployment of low-carbon technologies may be held up by a range of factors.

In Chapters 3 and 4 we assess key technologies against four conditions for successful deployment:

- Whether RD&D support is sufficient,
- Whether market pull measures are sufficient to create the market and stimulate technology development and / or deployment,
- Whether there are any barriers to deployment e.g. planning, regulatory or public acceptance,
- Whether the UK has the capabilities to use and deploy the technology.

Chapter 2 – Selection of key technologies

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 support for RDD&D is necessary and sufficient (Chapters 3 and 4), and the extent to which UK institutions are well placed to deliver the required support (Chapter 5).

We now consider:

2.1 Why choose particular technologies for support

2.2 Technology pathways to 2050 targets

2.3 Contributions to mitigation efforts and challenges to deployment

2.4 An assessment of UK capabilities

2.1 Why choose particular technologies for support

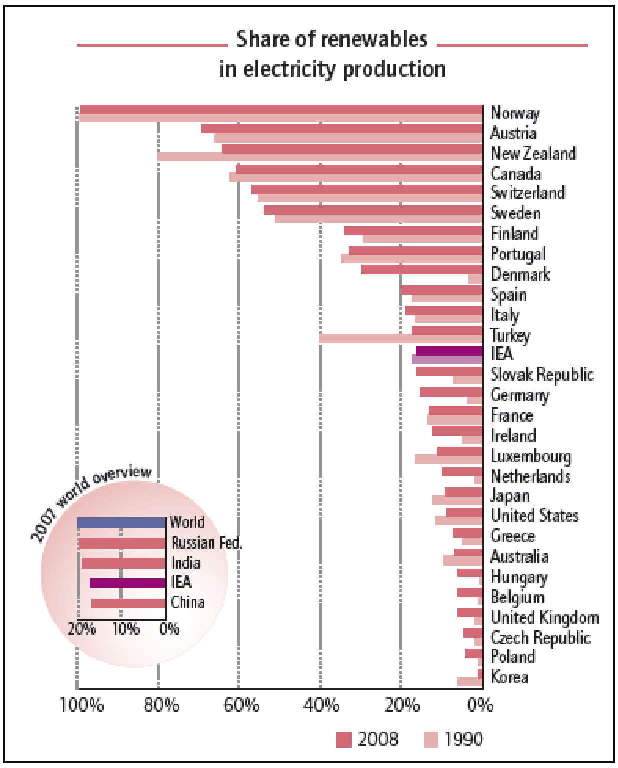
Since the 1980s, Government has pursued a policy of technology neutrality, relying on generic market mechanisms to deliver innovation, avoiding 'picking winners' and fostering competition between technologies. The rationale for this approach was that leaving choices to the market would deliver the most economically efficient outcomes, but the results has been a tendency to favour close to market technologies with known and relatively low costs. It has not necessarily encouraged investment in further from market technologies, including those which are needed to make a substantial contribution to the UK's energy mix in the longer-term as the costs of many renewable technologies remain high, compared to high-carbon alternatives.[20] The approach is therefore one reason why the UK lags behind most other IEA countries in terms of renewables deployment (Figure 5).

There are several arguments for a more technology-focussed approach:

- Technology neutrality, if pursued, risks spreading available resources too thinly (with limited impact). Medium-sized economies like the UK cannot give substantive, meaningful support to all candidate options (even if budgets were increased substantially)[21].
- Different technologies have different needs and will therefore require particular sets of solutions to facilitate deployment and eventual commercialisation[22]. There are ways to customise the innovation system to deliver particular outcomes without adversely affecting competition (e.g. through competition for support between companies active within a technology family).

[20] Watson, J. (2008), *Setting Priorities in Energy Innovation Policy: Lessons for the UK*
[21] Watson, J. (2008), *Setting Priorities in Energy Innovation Policy: Lessons for the UK*
[22] Carbon Trust (2009), *Focus for Success – A new approach to commercialising low-carbon technologies*

Figure 5: Share of renewables in electricity production, 1990 vs. 2008



Source: IEA, Scoreboard 2009

Any approach to selecting technologies for investment needs, however, to take into account that forecasting the future role of technologies is highly uncertain. Technologies currently in development provide an indication of those which may be in widespread use in the near future, although even here there are difficulties:

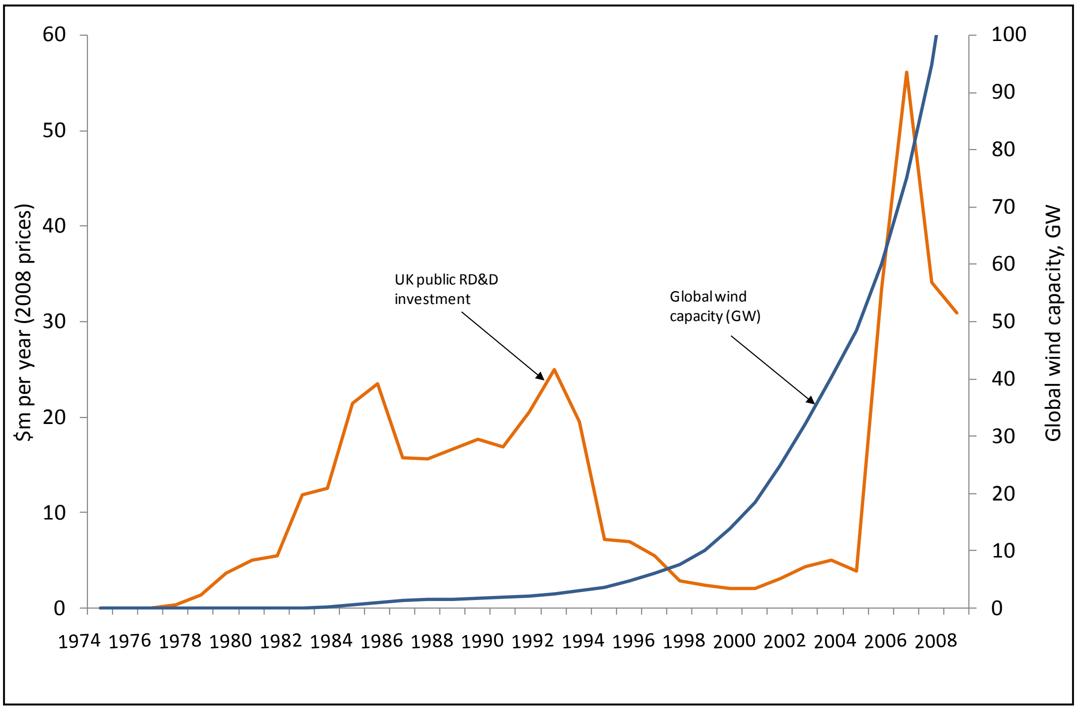
- Costs may not evolve as assumed because learning rates, or input costs, do not turn out as predicted, or because markets develop for key materials which introduce price distortions.
- Some technologies depend on infrastructure, which may in practice be established at a faster or slower rate than anticipated.
- Successful deployment of low-carbon technologies, often more expensive than pre-existing high-carbon technologies, may depend on levels of public support which are not forthcoming.

The implications of these uncertainties include:

- Recognising that some technology options may not deliver, it is prudent for the public sector to support a wider range of technologies than may actually be deployed. Reserve options may be necessary, but will only be available if some resource is dedicated to them in the short to medium term.
- Public investment in low-carbon technology should occur in stages, with the performance of the technology periodically reviewed to consider if it is still likely to deliver the abatement required.

Striking a balance between support for certain technology families and a system that is flexible enough to be able to respond to new information and events requires fine judgement, since it is clear that successful technology development depends upon consistency of funding. There is a case for arguing that the UK has got this judgement wrong in the past for some technology areas, for example, UK RD&D funding for wind technology fell away in the mid-1990s just as the market for wind technology started to take off (Figure 6).

Figure 6: UK publicly funded wind RD&D vs. Global wind capacity (1974 – 2008)



Source: BTM Consult, Carbon Trust, Renewable Energy World

2.2 Technology pathways to 2050 targets

There is inevitably 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. The main uncertainties are:

The extent to which energy demand will reduce. There are uncertainties as to the availability of demand side technologies and in the way people will interact with the technologies (which may create inefficiencies),

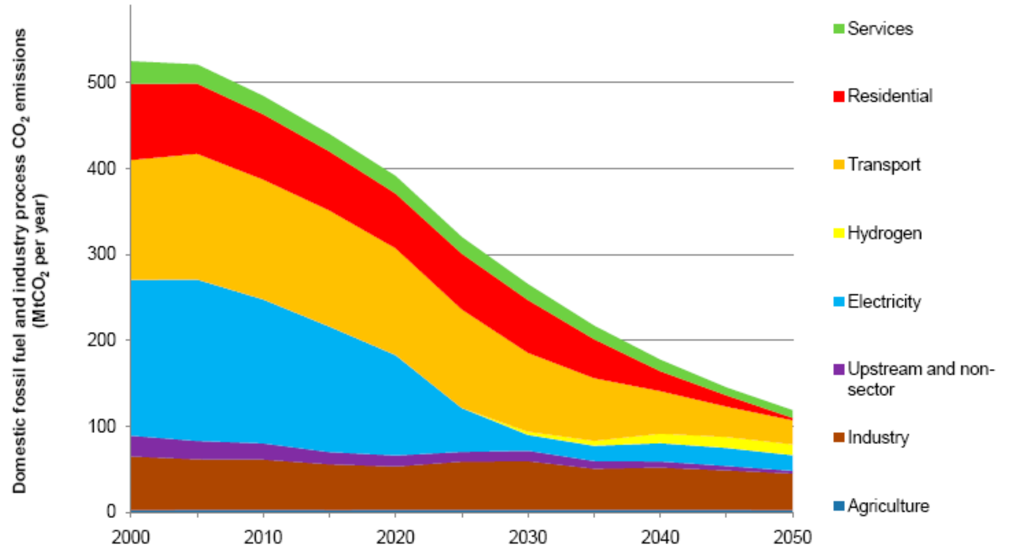
- Learning rates, and costs, for power generation technologies,
- Efficiency rate assumptions for electric, biofuel and fuel cell vehicles,
- The role of bioenergy in the energy system, given uncertainties about availability, sustainability and conflicting demands between transport and other uses,
- Delivery and costs of transport infrastructures,
- Public acceptability of new heating technologies which change the way that domestic dwellings receive heat services, may not be compatible with the existing housing stock and may not be used efficiently,
- Resource constraints and material supply constraints in an uncertain future world.

The Committee[23] and others[24] have, however, set out a range of paths consistent with the UK meeting its 2050 emissions reduction targets, and these provide a reasonably 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 power sector decarbonisation, significant cuts in transport emissions become feasible, through vehicles with electric powertrains. In addition, there are likely to be roles for sustainable biofuels and fuel cells.
- Power sector decarbonisation also facilitates 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 7 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. Transport and heat emissions are reduced through energy efficiency[25] and through increased electrification, beginning in the 2020s and continuing in the 2030s and 2040s, with hydrogen fuelled vehicles starting to make a contribution through the 2030s. By 2050, remaining emissions within the limit implied by the 80% reduction target are concentrated in industry, agriculture, aviation and shipping.

Figure 7: UK sectoral CO_2 emissions on an 80% emissions reduction path



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

---

[23] Committee on Climate Change (2008), *Building a low-carbon economy – the UK's contribution to tackling climate change*
[24] Energy Research Partnership (2010), *Energy Innovation Milestones to 2050*; UKERC (2009), *Decarbonising the UK Energy System: Accelerated Development of Low-carbon Energy Supply Technologies*; IEA (2010), *Energy Technology Perspectives*
[25] Although not explicitly shown in Figure 7, technologies to improve energy efficiency are generating emissions reduction across sectors

From this and other modelling approaches it is apparent that key technologies to support decarbonisation 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 will be required.

2.3 Contributions to mitigation efforts and challenges to deployment

Recognising the uncertainties and having made the case for a more technology-focused approach, it is possible to draw some general conclusions on likely abatement technologies. This section looks further at the technologies that will reduce emissions.[26]

In addition to the technology-specific challenges described in more detail below, the deployment of low-carbon technologies will require both technological and institutional change (e.g. infrastructure for electric vehicles will require planning and cooperation between vehicle manufacturers, electricity companies[27] and local government). It is crucial that innovation policy also addresses these challenges.

Power sector

Onshore and offshore wind are likely to be the only renewable energy technologies to make a very significant difference to the generation mix before 2020. Biomass-fired power stations are also likely to be deployable within this timescale, but given demand for the feedstock from other sectors, are likely to make a much smaller contribution to the mix. Post-2020, new nuclear and carbon capture and storage[28] (CCS) are likely to be significant contributors if existing constraints and technological challenges can be overcome. Marine technologies such as wave, tidal stream and tidal range technologies may also have a role to play post-2020. Solar PV is expected to play a significant role in future global electricity generation[29] but is unlikely to feature strongly in the UK generation mix unless costs fall significantly. Low-carbon power generation is also likely to require a wide range of enabling technologies to balance the supply of and demand for electricity.

- **Wind** can make a significant contribution to decarbonisation, particularly in the UK, at an acceptable cost. Offshore wind technology is entering the deployment phase, although deep offshore wind is not expected to reach demonstration before 2015, and floating offshore wind is further from deployment. In addition to improving efficiency, reliability and costs, key challenges are:
  - Reducing the mass of components through new materials, improving control algorithms to reduce fatigue and increase component lives and improvements to design to improve energy extraction[30].
  - Reducing maintenance costs in an aggressive and relative inaccessible environment.
  - The inherent intermittency of wind power, which brings challenges for widespread deployment, even in a wind-rich country like the UK. Intermittency is technically manageable, but imposes costs (which include system balancing costs, increased transmission capacity and the requirement for backup). At the levels of deployment of intermittent generation

[26] We recognise that the impact of behavioural change can be significant but do not include this as it lies outside the terms of reference for the review.
[27] Watson, J. (2008), *Setting Priorities in Energy Innovation Policy: Lessons for the UK*
[28] Carbon capture and storage involves the capture of CO_2 from a large-scale stationary power source or industrial emission process, its transportation via pipeline or ship and injection into suitable underground geological layers.
[29] IEA (2010), *Energy Technology Perspectives*
[30] UKERC (2009), *Decarbonising the UK Energy System: Accelerated Development of Low-carbon Energy Supply Technologies*

envisaged in the UK to 2020 and beyond, these costs are likely to be manageable[31].

- **Nuclear** power is a long established and proven low-carbon technology, with further improvements in efficiency and safety likely to be achieved by a new generation of reactors. Third generation reactors are being commercially deployed but fourth generation reactors are still at the R&D stage and are unlikely to be deployable until the 2030s. Nuclear fission is likely to be an important and cost-competitive option for decarbonisation. However:
  - There may be constraints on the feasible pace of deployment, given limits to the supply of technically competent engineers and companies, and the importance of tightly controlled planning, licensing and safety inspection regimes.
  - Nuclear power stations are very capital intensive and become less cost-effective when run at low-load factors, making them less suitable to meet segments of demand which vary across the day or the year.
- The application of **Carbon Capture and Storage** (CCS) to fossil fuel electricity plants, once demonstrated successfully, is likely to be an important element within an abatement strategy but will not be a sufficient solution in itself. CO_2 capture technology is available today, but the associated costs need to be lowered and the technology still needs to be demonstrated at commercial scale[32]. The early demonstration of a CCS system is critical for determining which generation technologies will be deployed out to 2050 (both in the UK and globally). The UK Government has committed to four demonstrator projects based on coal generation technologies, 1200 – 1600 MW in total, but has no current plans for demonstrating gas CCS. The technical R&D priorities for CCS relate mainly to the storage and capture steps (rather than transport)[33]. The feasibility of CCS also depends on the availability and capacity of potential CO_2 storage sites.
- **Marine** renewable technologies could have the potential to contribute significantly post-2025. The UK has significant natural resource, estimated to be around 65GW or 192TWh[34] (from wave, tidal stream and tidal range), although the practical offshore resource for marine technologies is lower than for wind in the UK.
  - Tidal range power exploits the rise and fall of the tide in estuaries.
  - Tidal stream power derives electrical energy from the kinetic energy of fast-flowing tidal currents. It is at an earlier stage of technology development than most tidal range power technologies, with substantial uncertainties over the best system design and challenges of installation, maintenance and grid connection.
  - Wave power technology, which captures energy from wave movement, is subject to similar uncertainties.
- The global theoretical potential for marine energy is significant[35]. A major proportion of the development work is taking place in the UK. However, the uncertainties associated with the costs and practical potential of tidal and wave technologies mean that there is no real consensus

---

[31] Committee on Climate Change (2008), *Building a low-carbon economy – the UK's contribution to tackling climate change*
[32] IEA (2009), *Technology Roadmap: Carbon Capture and Storage*
[33] UKERC (2009), *Decarbonising the UK Energy System: Accelerated Development of Low-carbon Energy Supply Technologies*
[34] The Offshore Valuation Group (2010), *The Offshore Valuation: A valuation of the UK's offshore renewable energy resource*
[35] IEA Open Energy Technology Bulletin (2008), *Harnessing the Power of the Oceans*

on how big a role they might play in the future generation mix. Given the importance of maintaining diversity within the generation mix, and the uncertainties around the deployment of other low-carbon technologies such as CCS, keeping the option of significant deployment of marine resources open will be key. The priority is to demonstrate the most advanced designs and continue further research on more radical but less developed designs and components. This could lead to the emergence of industry design standards by 2020[36].

- Relatively high costs are likely to keep the uptake of **solar**[37] **PV** in the UK low until at least 2030. The main R&D challenge for solar PV is to design and manufacture low cost, stable and efficient PV cells so the technology can compete with conventional and other low-carbon sources[38]. With third generation solar PV still at the R&D stage it is unclear to what extent cost reduction might be possible. Solar is likely to play a more significant role in countries with a better solar resource and fewer alternative low-carbon options.
- Electricity supply and demand need to be balanced at each point in time. A system dominated by low-carbon power generation (much of which is intermittent or relatively inflexible) is likely to require a wide range of enabling technologies to balance the increasingly variable supply of electricity with fluctuating electricity demand. **Energy storage** and **demand side measures**, alongside increased interconnection, are likely to play a critical role in helping to match supply and demand at each point in time and in making the best use of the generation capacity on the system, by allowing plants to run at higher load factors. Demand side measures include intelligent decentralised demand response (e.g. smart meters), and intelligent centralised demand side response (e.g. smart grids). Electricity storage is also likely to play a very important role – both at large scale, and at smaller scale, (e.g. from electric vehicles and domestic energy storage). With the exception of pumped hydro and compressed air energy storage, further R&D effort is required to provide cost-effective storage[39].

Transport sector

In the period to 2020, efficiency improvements to conventional vehicle technologies[40] will deliver significant emission reductions[41]. Alongside this progress, other investments need to be made to ensure that alternatives to the internal combustion engine become available in the longer term. This section focuses on those options. There are three potentially substitutable technologies for parts of road transport – electric vehicles, hydrogen and biofuels – and all will have different infrastructure requirements:

- There is some consensus on the likely role of **electric vehicles** (EVs)[42]. They offer a promising long-term technology option (providing electricity generation is decarbonised). However, electric vehicles will initially be more expensive than conventional vehicles – electricity storage and battery cost reduction remain key challenges. Significant infrastructure provision will also be

---

[36] UKERC (2009), *Decarbonising the UK Energy System: Accelerated Development of Low-carbon Energy Supply Technologies*
[37] We do not include concentrated solar power in our analysis of solar technologies as this is not expected to contribute significantly to UK mitigation efforts and the UK is unlikely to play an important role in its development.
[38] UKERC (2009), *Decarbonising the UK Energy System: Accelerated Development of Low-carbon Energy Supply Technologies*
[39] Energy Research Partnership (2010), *Energy Innovation Milestones to 2050*
[40] For example, internal combustion engine and transmission innovations and vehicle weight and drag reduction
[41] New Automotive Innovation and Growth Team (2008), *An Independent Report on the Future of the Automotive Industry in the UK*
[42] Energy Research Partnership (2010), *Energy Innovation Milestones to 2050*

necessary for electric vehicles to be deployed at scale, but the extent of the requirement and the eventual charging technology involved are not yet clear.

- There is less consensus on how significant a role **hydrogen fuel cell vehicles** might have out to 2050, though the NAIGT roadmap[43] (drawing upon UK industry views) is relatively optimistic about prospects. Hydrogen vehicles are not as close to commercial deployment as electric vehicles, although there are number of demonstrations globally, notably in California, Germany and Japan[44]. A number of significant technological challenges still need to be addressed, including low-carbon hydrogen production, hydrogen storage (to reduce costs), and cost, power density and safety of fuel cells. In addition, there will be a requirement for major infrastructure provision if take up is to be wider than just fleet operators.

- There is still significant uncertainty over the future potential of **advanced biofuels**[45] in the transport sector. It is generally recognised that the scope for widespread application (particularly in the medium term when electric and hydrogen fuel cell technologies are still being developed) could be considerable[46]. Technologies have already been developed for producing biodiesel or bioethanol from a variety of crops. Initial products (derived from food crops and referred to as first generation) have utilised natural oils, fruits and sugars, which can be converted easily to biodiesel and bioethanol. However, deriving fuel from food crops is unlikely to be sustainable at scale. Second generation technologies will be able to use a variety of processes to derive biofuels from biomass material with a lower calorific value, using bio-wastes and fast-growing crops grown on marginal land, and using the whole plant rather than just the edible part. Third generation fuels (e.g. those derived from algae) are in the early stages of development. Research into feedstocks and improving the efficiency of conversion technologies is critical, with sustained R&D efforts necessary to deliver more sustainable and productive fuels[47].

UK **aviation** CO_2 emissions have grown by over 50% in the past ten years due to increasing demand in both passenger and freight traffic. This increase has occurred despite substantial improvements in aircraft fuel efficiency (Figures 8 and 9), illustrating that airlines have placed greater priority on increasing aircraft range and increasing payloads. Looking forward:

- Analysis for the Committee's aviation report[48] found that evolutionary engine and airframe improvements could increase the fuel efficiency of new aircraft designs by up to 40% in the 2020s relative to new aircraft in 2005. The impact on emissions depends upon other policy instruments being introduced to encourage airlines to take the efficiency improvement in the form of carbon saving rather than longer aircraft ranges or increased payloads, as well as on the rate of introduction of new aircraft designs into the fleet.

- To go beyond this improvement, more radical technology innovation will be necessary (e.g. open rotor engines or blended wind bodies). The high cost and risk of such developments and long development times (typically 10 to 15 years), combined with long aircraft lives (typically around 25 years for individual aircraft and longer for aircraft designs) means that penetration of such technologies into the fleet will be slow. To have a significant impact in the period to 2050,

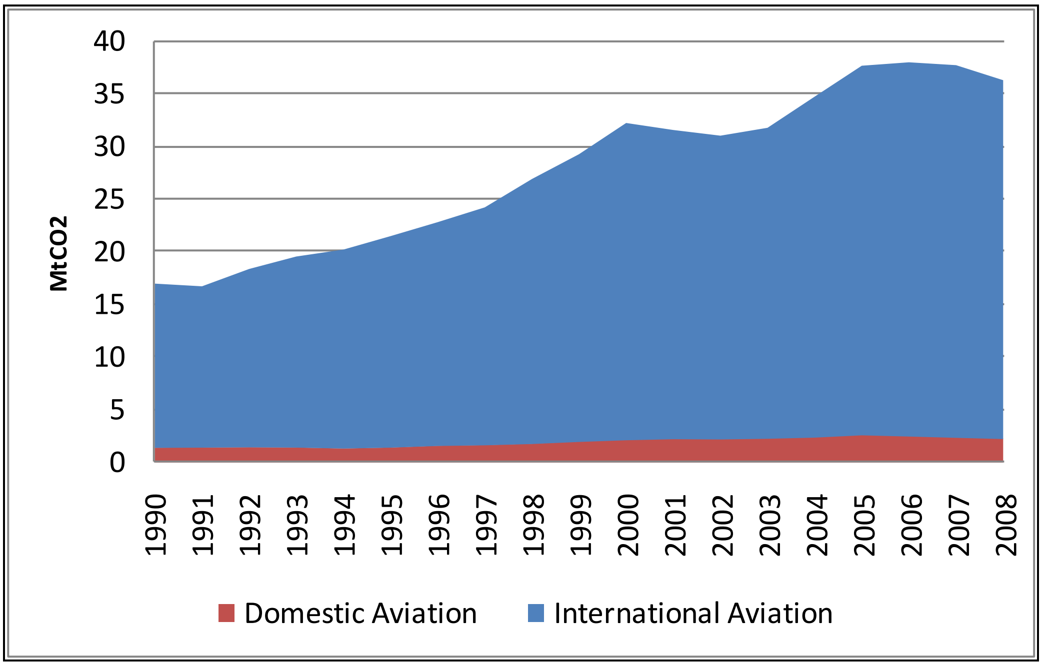
---

[43] New Automotive Innovation and Growth Team (2008), *An Independent Report on the Future of the Automotive Industry in the UK*
[44] http://www.fuelcelltoday.com/online/survey?survey=2009-06%2F2009-Infrastructure-Survey-Free
[45] The term 'advanced biofuels' is intended to capture both second and third generation biofuels – second generation biofuels use non-food crop feedstocks and third generation use advanced processes such as engineered micro-organisms
[46] Energy Research Partnership (2010), *Energy Innovation Milestones to 2050*
[47] UKERC (2009), *Decarbonising the UK Energy System: Accelerated Development of Low-carbon Energy Supply Technologies*
[48] Committee on Climate Change (2009), *Meeting the UK Aviation target – options for reducing emissions to 2050*

progress would have to be made in the short-term to allow deployment in new aircraft families in the coming decades.

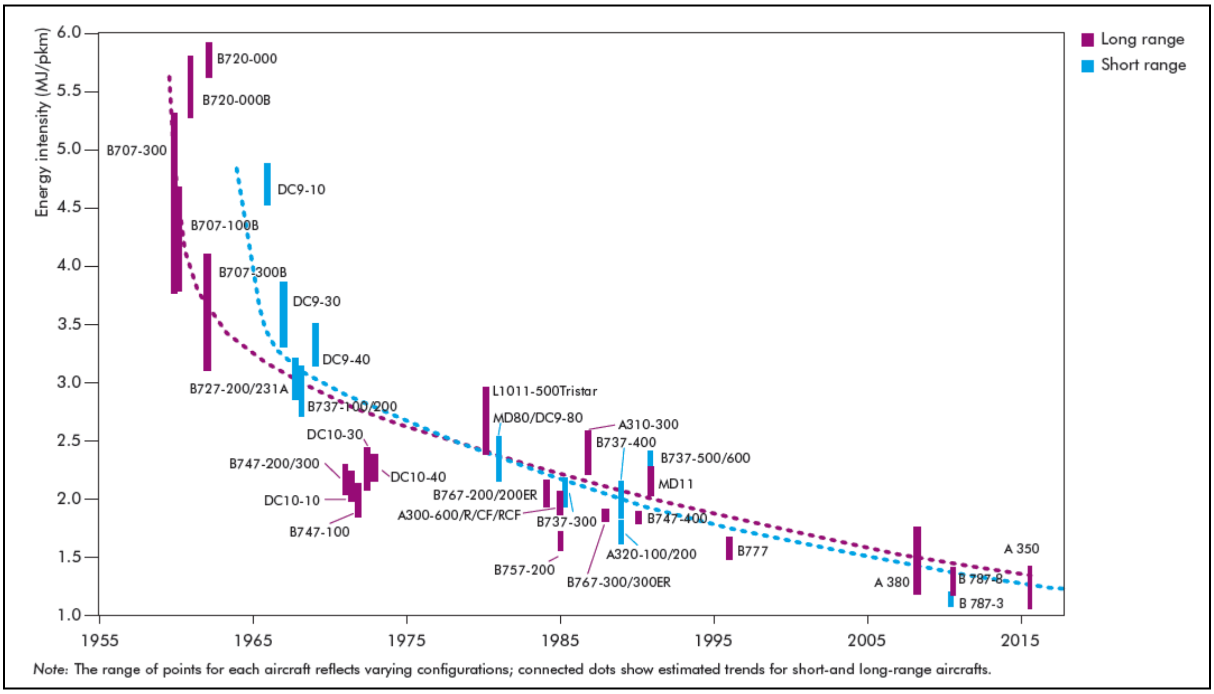
- Use of alternative fuels (e.g. liquid biofuels) has already been demonstrated to be technically feasible. The Committee will be assessing the potential contribution of biomass for power generation, heat and biofuels for transport in a report to be published in 2011.

Figure 8: UK aviation CO_2 emissions (1990-2008, bunker fuels basis)



Source: DECC (2010), UK Emissions Statistics 2008 Final UK Figures

Figure 9: Historical improvements in aircraft fuel efficiency



Source: IEA (2009)

Increasing demand for seaborne trade will lead to an increase in CO_2 emissions from **shipping**. While technological developments and operational improvements can be expected to contribute to reduced emissions from individual ships, such measures will – without more radical development and deployment – only slow the rate of growth of total fleet CO_2 emissions[49].

- There is a wide range of abatement options that could be applied to ships, including design improvements and upgrades, operational improvements, alternative fuels, and renewable energy technologies. Potential improvements in the design of ships include optimising the design of the underwater hull and propeller, recovering energy from the propeller and engines and after body flow control systems. 'Electric ship' designs can be used to optimise efficient operation of the prime movers. Other efficiency technologies include novel hull coatings (e.g. special polymers or air bubbles) that reduce hull resistance against the water[50]. The most promising alternative fuels are liquefied natural gas and wind power (e.g. sails), although other sources of energy, such as solar energy, for example for secondary systems, and biofuels, have potential to be used on ships[51].
- International regulation of global shipping and the nature of seaborne trade with multiple stops in different jurisdictions complicates the mitigation of emissions from the sector[52]. If significant changes in overall vessel dimensions were required for new hull designs, this may mean that ships are not able to dock without changes to the design of port infrastructure. Use of alternative fuels in shipping would also introduce infrastructure challenges. Some options, therefore, are likely to require an international agreement that includes all the major ports.

Buildings sector

In the buildings sector, heat pumps are currently a promising low-carbon option for meeting future heat demand, although they still need to be proven as effective in the UK housing stock and climate. Fuel cell micro CHP appliances and use of biogas as a substitute for natural gas are also potential options. New insulation materials will be required to achieve a significant improvement of the large stock of 'hard-to-treat' buildings. New lighting technologies could significantly lower electricity demand in buildings and major improvements can also be made to the energy efficiency of household appliances. Solar thermal technologies could have an important global role to play (in sunny climates) if payback periods can be reduced.

- **Heat pumps** could meet a significant proportion of heat demand from both residential and non-residential buildings.[53]
  - Deployment of heat pumps outside the UK is already fairly significant, although costly.
  - Current understanding is that ground-source heat pumps can deliver three to four times as much usable heat energy as they require in electricity input, and that they are, in general, more efficient than air source heat pumps. However, air source heat pumps can be deployed in many buildings (e.g. in dense urban areas) where ground source heat pumps are impractical.
  - Performance has not yet been fully tested within the UK housing stock.

---

[49] AEA (2008), *Greenhouse gas emissions from shipping: trends, projections and abatement potential*
[50] Pew Center (2010), *Marine Shipping Emissions Mitigation*
[51] AEA (2008), *Greenhouse gas emissions from shipping: trends, projections and abatement potential*
[52] Pew Center (2010), *Marine Shipping Emissions Mitigation*
[53] Energy Research Partnership (2010), *Energy Innovation Milestones to 2050*

- The key challenge for greater UK deployment is adapting heat pumps to UK conditions (climatic, building stock and heating systems) and improving insulation of the UK housing stock. Field trials to explore the potential performance of heat pumps in domestic settings are ongoing, and will improve estimates of performance. There are no current trials underway to test heat pumps in industrial or commercial settings.

- The Government recently announced plans to introduce a renewable heat incentive scheme from April 2011, which should provide financial support for those installing renewable heating (including heat pumps). If better insulation were available then this would cut heating demand and allow smaller heat pumps to be deployed and to work more efficiently (i.e. use less electricity)[54].

- **Fuel cell micro CHP** appliances are now entering the demonstration phase[55]. Ceres Power, a UK company developing fuel cell technology for use in small scale combined heat and power products, is currently collaborating with British Gas on a trial programme[56]. Ceres estimate that their residential CHP product could save around 25% of a household's total energy costs, and reduce each home's CO_2 emissions by up to 2.5 tonnes per annum[57].

- Another potential source of renewable heat (as a substitute for natural gas) can be manufactured using a thermal gasification process to decompose biomass into a **biogas** containing carbon monoxide and hydrogen. The components can then be recombined to form methane[58]. This technology is still at the R&D stage but could have significant potential. Anaerobic digestion technologies, which are already relatively mature, (discussed below in the context of agriculture) could also deliver heat from biogas to help meet heat demand from buildings.

- Roll out of existing **insulation** materials (e.g. loft insulation, cavity walls and glazing) is generally expected to reach saturation levels by 2020[59]. The large stock of more difficult building types (in particular solid-wall homes) could be treated with conventional material but key challenges are the large hassle factor of installation and thickness of current materials. New insulation materials are thus likely to be needed to significantly improve the energy efficiency of this 'hard-to-treat' stock. There is significant scope for materials R&D to improve future products – a new thinner product has recently become available but is currently expensive and requires greater demonstration in the UK.

- In **lighting**, an overlapping set of new technology developments could reduce electricity demand to a fraction of current levels in residential buildings and to a significantly lower level[60] in commercial buildings – initial steps include transitions to higher efficiency ballasts and fluorescent tubes in commercial buildings and from incandescent to compact fluorescent lighting in residences[61]. This transition is now underway assisted by a phase-out of incandescent lights. In the medium to long term, LED technologies are likely to deliver more radical improvements. In addition, better management of lighting, via the application of movement sensitive or light sensitive switches, could significantly reduce the amount of lighting demand currently wasted in unused rooms. Solid-state lighting is emerging as a promising efficient technology of the near future. There is high potential for further technical improvements in semiconductor (e.g. LED)

---

[54] Energy Research Partnership (2010), *Energy Innovation Milestones to 2050*
[55] Energy Research Partnership (2010), *Energy Innovation Milestones to 2050*
[56] http://www.cerespower.com/store/files/12-BG%20development%20supply%20and%20distribution%20agreement.pdf
[57] http://www.cerespower.com/ProductOverview/ResidentialCHP/
[58] NERA (2010), *Decarbonising Heat: Low-Carbon Heat Scenarios for the 2020s* (forthcoming)
[59] Energy Research Partnership (2010), *Energy Innovation Milestones to 2050*
[60] For example, 10% to 50%
[61] IEA (2008), *Energy Technology Perspectives 2008*

and metal halide lamps[62]. While overall market penetration is still low, solid-state lighting has reached the deployment stage and is likely to fully commercialise by 2014[63].

- Major improvements can be made in the energy efficiency of **household appliances**. The IEA reports technical potential in most regional and national studies for 30-60% energy efficiency improvements in appliances[64].
- IEA analysis suggests that **solar thermal** technologies are unlikely to deliver significant global CO_2 savings compared to energy efficiency improvements in buildings and appliances but they could still have an important role to play, particularly in sunny climates. The full potential of solar thermal systems has not been reached in most IEA countries, as capital costs are relatively high and pay-back periods are long. There is a need for R&D on higher efficiency operation under UK conditions and further work is required more generally to help drive down unit costs.

A general challenge in the buildings sector is addressing the lack of monitoring data to prove real world performance of new technologies. There is a need for a clear monitoring framework to see, for example, how new technologies interact with each other in a building, and how they perform under different conditions (e.g. technology performance may differ between warm and cold years). For the data to be comprehensive and account for natural variability in the climate it needs to be collected and reported over a number of years, not just one or two.

Industry sector

Electricity is used throughout manufacturing industry to drive machinery, and in addition is very intensively used in specific industrial processes such as electric arc steel production and aluminium smelting. Low cost opportunities to reduce demand in the intensive use areas are less than in commercial and residential buildings, reflecting the strong focus on energy efficiency that already exists in industries where energy is a significant element within the cost base. In addition, direct CO_2 emissions from industries like cement and steel production can be significant – scope to reduce these emissions currently exists in changes to fuel and raw material inputs and potentially the application of CCS.

- CO_2 emissions from **cement** production currently account for around five per cent of global anthropogenic CO_2 emissions[65]. There is scope for reducing emissions by improving the efficiency of fuel use in the production process and potentially developing new low-carbon or carbon-negative cements. However, low-carbon and carbon-negative cements are at the development stage – they are not proven as economically viable or tested at scale to determine their long-term suitability[66]. Further R&D is required to assess their future potential.
- The feasibility of over 80 technologies to reduce emissions from **steel-making** has been investigated through the ULCOS (Ultra-low CO_2 steel-making) programme[67]. The aim of the programme is to reduce CO_2 emissions by at least 50% compared to current methods. Four process concepts have been taken through to the next stage (three of which include some form

---

[62] IEA (2008), *Energy Technology Perspectives 2008*
[63] Carbon Trust (2009), *Focus for Success – A new approach to commercialising low-carbon technologies*
[64] IEA (2008), *Energy Technology Perspectives 2008*
[65] IEA (2009), *Technology Roadmap: Cement*
[66] IEA (2009), *Technology Roadmap: Cement*
[67] ULCOS is a consortium of 48 European companies and organisations from 15 European countries that have launched a cooperative research and development initiative. The consortium consists of all major EU steel companies, of energy and engineering partners, research institutes and universities and is supported by the European Commission.

of CCS) to test proof of concept at scale.

- The current focus of **CCS demonstration** in the UK is coal generation technologies but it could also have useful applications in high emitting industries, where other abatement opportunities are limited and / or very costly (e.g. cement). Improving understanding of these other abatement opportunities is important as the evidence base in this area is currently limited.

Agriculture sector

Options to reduce emissions in the **agriculture** sector can generally be grouped as those targeting crops and soils and those targeting livestock. They include options relating to changes in practice and use of new technologies. Both aim to reduce emissions of methane and nitrous oxide, of which agriculture accounts for the vast majority[68]. Further research is necessary to explore potential to reduce emissions within the UK farming context. Moreover, there is currently limited measurement of emissions at the farm level – better measurement is necessary to enable robust assessment of impacts.

- Potential **measures relating to crops and soils** include:
  - Nitrification inhibitors (these reduce N_2O emissions by slowing down the conversion of ammonium to nitrate in soil).
  - Precision farming – the use of technologies (e.g. GPS, sensors, satellites, aerial images and information management tools) to collect spatially explicit information on soils, allowing the farmer to target inputs of nutrients.
  - Soil carbon management, for example, adding biochar[69] to soils.
  - Use of more nitrogen efficient plants, for example, introducing species not commonly used in the UK at present and selectively breeding plants that utilise nitrogen more efficiently.
- Potential **measures relating to livestock** include:
  - Animal / system interactions, for example, research into genotype and system interactions, specifically whether breeds or lines of livestock could be identified with lower methane emissions.
  - Rumen manipulation to reduce enteric methane emissions, for example, through changes in diets or use of dietary additives.
  - Manure management to reduce methane emissions from manure and slurry.
- **Anaerobic digestion** (AD) is a treatment process whereby biodegradable materials, for example waste, can be broken down to produce a methane-rich biogas that can substitute for fossil fuels. It could be rolled out on farms or in centralised locations to produce heat and / or power, reducing greenhouse gas emissions. Availability of organic materials like manures, slurry and food wastes would mean a readily available supply of feedstocks. The basic technology for AD is proven but there are still many technical questions to be resolved for rolling out on-farm or

[68] In 2008, waste management accounted for 43% of methane emissions and agriculture accounted for 38%. Agriculture also accounted for 76% of nitrous oxide emissions.
http://www.decc.gov.uk/media/viewfile.ashx?filepath=statistics/climate_change/1_20100325084241_e_@@_ghgnationalstatsrelease.pdf&filetype=4
[69] Biochar is formed by incomplete oxidation of organic matter, and when added to soils it is known to have a strong influence on soil nutrient turnover.

on a more centralised basis in the UK.

- **Genetic modification** (GM) of plant and / or animals could be developed to improve nitrogen use efficiency in plants or produce lower emissions animals, ensuring that they work in real farming systems. This would require resolution of EU and consumer issues with respect to GM.

R&D will be required in the UK to ensure technologies developed elsewhere, for example the use of nitrification inhibitors, are effective under UK climatic conditions as well as acceptable (e.g. the use of dietary additives in livestock).

Waste sector

A number of relatively mature technologies can be applied to recover **energy from waste**.

- In addition to anaerobic digestion (described above), energy can be recovered from waste through mechanical biological treatment[70], which produces either solid recovered fuel (which can be used in power stations and cement kilns) or an alternative to fertiliser. Incinerating waste at high temperatures can also produce heat and / or electricity. These technologies are all relatively mature.
- The use of smarter food packaging (e.g. through nanotechnology and active packaging that extend the shelf life of products and monitor freshness) can reduce food waste, and thus indirectly reduce GHG emissions.

2.4 An assessment of UK capabilities

This section sets out where the evidence suggests the UK has a particular advantage in developing a technology.

Our approach

To assess relative UK capabilities in particular technologies, we have drawn on a number of data sources. These include funding data from the Research Councils, patent data analysis[71] (an indicator of the UK capacity to develop ideas), analysis of initial public offering (IPO) and merger and acquisition data[72] (indicators of the UK capacity to translate ideas into commercially attractive propositions), and trade data analysis (an indicator of the UK industrial capacity). We have further supplemented this analysis with other available data and information from various other government and commercial sources.

- We use patent data analysis to compare both the relative level and trends in "clean" innovation activity between companies in different countries (using patent counts as an innovation measure). Patents do not measure all innovation but they provide an indicator of the results of innovative activity. To ensure that the results are driven by commercially valuable patents, only

[70] A range of treatment activities that include sorting and separating, cutting or grinding and composting the waste. Shredded waste is subjected to aerobic digestion for 10-15 days which stabilises the waste. A combination of sieving, weight separation and metal extraction splits the waste into recyclable materials and a residue. The residue is suitable for burning and energy recovery. The residue remains classified as waste. http://www.environment-agency.gov.uk/static/documents/Business/7_wip_wm_options_2147947.pdf
[71] LSE (2010), *Low-carbon innovation in the UK: Evidence from patent data*
[72] IPO and M&A data has been extracted from the CleanTech database, http://cleantech.com/research/databases.cfm

international patents (patents that are filed in at least two countries) have been included.

- An IPO (initial public offering) is the first sale of publicly tradable stock shares in a company that has previously been owned privately. IPOs are most often companies seeking capital to expand their business. Merger and acquisition (M&A) data is also useful as an indicator of ability to translate ideas into commercially attractive propositions. Since 2000, the number of IPOs in low-carbon technology companies from the UK has been relatively high – individually, however, these have tended to be quite small transactions and the total value is not as high as in other countries. Data on UK mergers and acquisitions tell a similar story, with a relatively high number of UK transactions but a lower total value.
- It has been possible to analyse some trade data using the UN Comtrade[73] database. It is difficult to identify all the products and components relevant to low-carbon technologies as these are not coded separately in the database, but the analysis provides an indication of trends relating to some of the relevant technologies.
- We have also drawn on a technologies matrix published by the Energy Research Partnership[74], which provides a qualitative assessment of UK capabilities in particular technologies.

The following sub-sections summarise results from the capability analysis.

Our assessment of UK strengths

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.

[73] United Nations Commodity Trade Statistics Database
[74] Energy Research Partnership (2008), *Energy Technologies Matrix*

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

	Develop & 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 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 suppliers usually participate as partners of overseas based businesses	International research programmes with strong involvement of academics.

The judgements we have made concerning the status of the various technologies are based on the information available in the first part of 2010. As we noted earlier, the prospects for different technologies, and the strategy the Government wishes to adopt, may change as new information emerges about the performance of the technology, progress at developing infrastructures and changes to the policy and regulatory framework.

'Develop and deploy' technologies

Evidence suggests that the UK has a capability (or is well placed to develop a capability) in offshore wind, marine, aviation and CCS technologies. The UK is also strong in particular areas of research relevant to electric vehicles and smart meters / smart grids, so could be well placed to secure some of the benefits from these growing markets.

Offshore wind

Analysis by the Carbon Trust[75] has concluded that the UK could be a global market leader in offshore wind by combining a large global and domestic market and building on existing skills while attracting key manufacturers. Further evidence is provided from:

- The SUPERGEN wind energy technologies consortium has just started the second phase of its work, focussing on offshore wind research priorities[76], an area where the UK is building a strong research capability.
- Patent analysis (Table 2) suggests that wind energy generation technologies are one of the technologies where the UK has a comparatively high global share of patents.

[75] Carbon Trust (2009), *Focus for success - A new approach to commercialising low-carbon technologies*
[76] http://www.supergen-wind.org.uk/

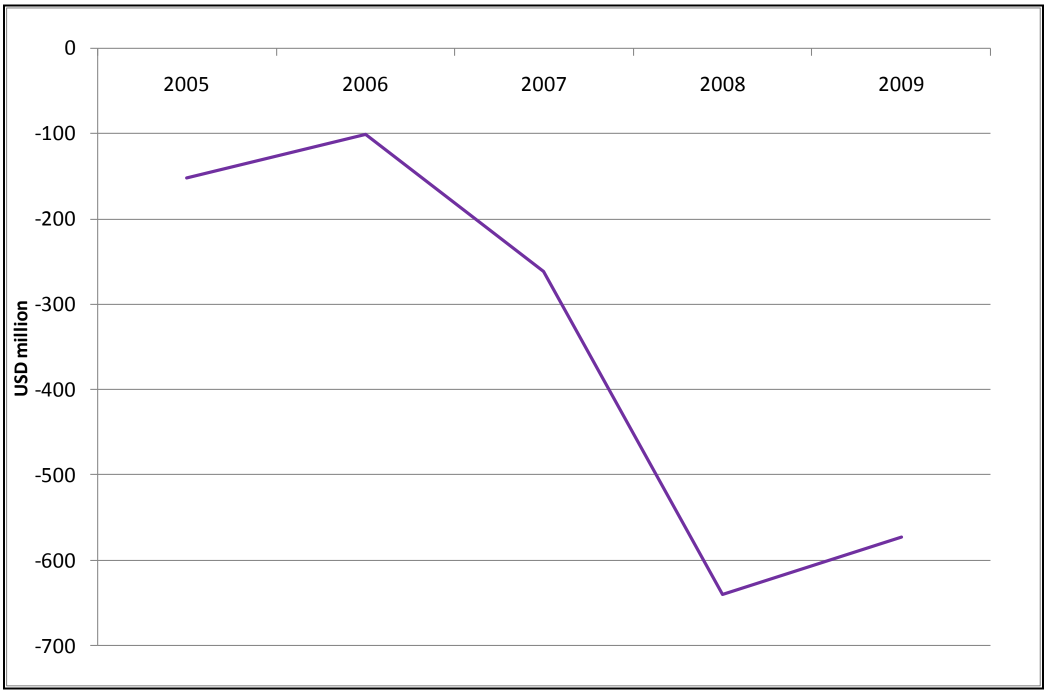
Table 2: Share of UK inventions in world innovation by technology (power)

Technology	1980-1996	1997-2002	2003-2007
	Share in world's innov.	Share in world's innov.	Share in world's innov.
Marine energy	17.4%	12.8%	17.5%
Nuclear	4.1%	4.4%	1.3%
Solar PV	2.3%	2.2%	2.6%
Wind	8.9%	3.5%	5.5%

Source: LSE (2010), Low-carbon innovation in the UK: Evidence from patent data

- Less positively, analysis of trade data[77] for wind suggests that the UK currently has a negative net trade balance for products and components associated with wind energy (Figure 10).

Figure 10: Wind: UK trade balance, 2005-2009



Source: UN Comtrade database

- Analysis published by UKTI also concluded that the UK does not have a relatively strong capability in the manufacture and supply of wind components[78]. This is because, at present, the UK contribution to the blades and nacelles, two of the highest value-added elements in a turbine, is low[79]. The Scroby Sands wind farm was built in 2002/03 and although nearly 50% of the

---

[77] Data extracted from the UN Comtrade database
[78] UKTI (2008), *Market opportunities in environmental goods and services, renewable energy, carbon finance and CATs*
[79] EEF (2008), *Delivering the low-carbon economy – Business opportunities for UK manufacturers*

contract value was UK sourced (Table 3), UK content in subsequent wind farms has fallen to just 15-25%[80].

Table 3: UK content in the Scroby Sands wind farm

Component	Value (%)	UK share (%)
Nacelles	41	1
Piles	24	100
Blades	15	0
Towers	12	98
Cables	7	100
Indirect costs	1	8
Overall	**100**	**43**

Source: EEF (2008), Delivering the low-carbon economy – Business opportunities for UK manufacturers

- Budget 2010 announced a £60m competition to develop manufacturing and assembly sites for the offshore wind industry. Following the Budget statement, Siemens announced plans to invest £80 million in the UK for offshore wind production facilities. Since autumn 2009, Clipper Windpower, Mitsubishi and GE have all announced investments in the offshore wind sector in the UK. This suggests that UK based companies will be well placed to drive technology development.

Marine

Marine energy is also an area where the UK has the potential to be world leading[81],[82], with significant work being undertaken at the European Marine Energy Centre (EMEC) in Scotland, the EPSRC SUPERGEN Marine consortium and through the Wave Hub project in Cornwall. NaREC (the national centre for the UK dedicated to accelerating the deployment and grid integration of renewable energy and low-carbon generation technologies) is also assisting wave and tidal stream marine developers move their innovative design concepts towards commercialisation. Patent data analysis shows that although the UK cannot be considered a leader in low-carbon technologies overall, the UK has a very strong position in marine energy generation (Table 2). Other evidence finds that there are more businesses engaged in the development of devices to harness energy from waves and tidal stream in the UK than in any other country.[83]

Carbon Capture and Storage (CCS)

The patent data analysis carried out by the LSE did not include CCS[84], however, other analysis does

[80] BERR (2008), *Comparative advantage and green business* (report by Ernst & Young)
[81] UKERC (2009), *UKERC Energy Research Landscape: Marine Renewable Energy*
[82] IEA-OES (2009), *Ocean Energy: Global technology development status*
[83] EEF (2008), *Delivering the low-carbon economy – Business opportunities for UK manufacturers*
[84] There is a risk that irrelevant patents could be included if an International Patent Classification class includes patents that bear no relation to climate mitigation. In order to avoid this problem, those classes that do not consist only of patents related to climate change mitigation have been excluded. This is why some key technologies in terms of carbon reduction potential, including clean coal technologies, were outside the scope of the study.

consider CCS patents[85]. This shows that the US currently dominates in the area of carbon capture, with only a tiny fraction of these patents originating from the UK[86]. The UK does not have particular strengths in carbon capture technologies. Other international players are likely to win out in key areas such as pipeline assessment, CO_2 injection and surveillance[87]. However, the UK does have strengths in both transport and storage[88]. Further:

- Due to its large and now significantly depleted offshore oil and gas fields the UK is relatively well placed for deployment of CCS. The capacity of saline aquifers – potentially considerably larger than the depleted oil and gas fields – is less well characterised at present, but the Energy Technologies Institute has launched a project to assess CO_2 storage potential in the UK[89]. In terms of relevant skills, the UK is very strong on subsurface evaluation and geotechnical engineering because of the North Sea oil and gas developments[90].
- As CCS enters the demonstration phase, there is evidence that other countries are now moving faster than the UK on CCS, potentially diminishing any role the UK may be able to secure in a future global market[91]. However, there could still be an opportunity for the UK to exploit some of its natural resources and build a competitive advantage. 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[92]. The planned four commercial-scale UK demonstration projects could help the UK to develop further capability in CCS.

Aviation

In the aviation sector the UK has strong capability in both engine and airframe development and manufacturing. UK based companies produce wings for 50% of all large aircraft in the world and over 600 airlines operate Rolls-Royce made engines[93]. The wing centre of excellence for the Airbus consortium is based in the UK and the UK aerospace supply chain has grown as a result[94]. The UK (led by Rolls-Royce) currently holds over 35% of the global market for aero engines and the UK is also a world leader in high-quality composite materials manufacturing research[95], an important input for an industry that requires high performance but low weight materials.

Electric Vehicles

Analysis presents a mixed picture:

- Although a recent assessment of UK capabilities in automotive technologies did not find strengths in battery cell technologies, it did find strengths in battery pack development, electric motors and power electronics[96].

---

85 Chatham House (2009), *Who owns our low-carbon future?*
86 Although analysis of the geographical location of the parent companies of patent owners that have more than four patents at the time of filing (intended to reveal a clear geographical pattern in patent ownership) shows a more significant share for the UK
87 DECC (2010), *A study to explore the potential for CCS business clusters in the UK*
88 UKERC (2009), *UKERC Energy Research Atlas: Carbon capture and storage*
89 http://www.energytechnologies.co.uk/home/news/09-10-09/ETI_project_to_put_UK_at_the_leading_edge_of_Carbon_Storage_Capacity_Appraisal.aspx
90 UKERC (2009), *Decarbonising the UK Energy System: Accelerated Development of Low-carbon Energy Supply Technologies*
91 House of Commons (2010), *Low-carbon technologies in a green economy (Volume I)*
92 UKERC (2009), *Decarbonising the UK Energy System: Accelerated Development of Low-carbon Energy Supply Technologies*
93 McGinley Support Services Group, *Aerospace Market Profile*
94 UKTI, *UK Aerospace Capability*
95 UKTI, *UK Aerospace Capability*
96 Technology Strategy Board (2010), *Automotive technologies: The UK's current capability*

- The UK also has research capabilities in innovative design, but leadership on the direction of technology development within key automotive manufacturers rests overseas.
- Patent data analysis did not find that the UK has a significant capability in key vehicle technologies (Table 4). The share of UK inventions has been constantly decreasing in electric & hybrid, fuel injection, and batteries.
- For the UK to secure a durable competitive advantage and build a strong consumer market going forward, it will be important to strengthen incentives to purchase electric vehicles and invest in a charging network. Existing commitments on incentives and infrastructure were cited by Nissan as reasons for locating production of its Leaf electric car in Sunderland[97]. Tata plan to develop and manufacture their Indica Vista Electric Vehicle in the UK[98] and Toyota are manufacturing the hybrid Auris car here[99].

Table 4: Share of UK inventions in world innovation by technology (transport)

Technology	1980-1996	1997-2002	2003-2007
	Share in world's innov.	Share in world's innov.	Share in world's innov.
Batteries	4.3%	1.5%	0.9%
Electric & hybrid	4.0%	1.6%	1.4%
Fuel cells	3.2%	2.5%	1.8%
Fuel injection	8.2%	3.8%	3.0%

Source: LSE (2010), Low-carbon innovation in the UK: Evidence from patent data

Smart meters / smart grids

Smart meters / smart grids will be needed to balance growth in electricity demand from the transport sector, and increasing levels of intermittent wind generation. 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. Analysis of energy supply management patents by the OECD shows a relatively high share of patents filed 2000-2008 originated in the UK.[100]

'Deploy' technologies

For a number of key technologies, overall systems will largely be developed outside the UK and then deployed here. Deployment will, nevertheless, require some provision of R&D and demonstration support, for example, for field trials to enable technologies to be adapted for UK use. In addition, provision of support for developing skills will be important to ensure efficient operation and maintenance of new technologies.

---

97 http://www.nissan.co.uk/GB/en/inside-nissan/news/leaf_news/ev_news.html
98 http://www.tatamotors.com/our_world/press_releases.php?ID=466&action=Pull
99 http://blog.toyota.co.uk/toyota-auris-hybrid-to-be-built-in-britain
100 Johnstone and Haščič (2010), *Directing Technological Change while Reducing the Risk of Picking Winners: The Case of Renewable Energy* (forthcoming)

New nuclear reactors will not be developed or demonstrated in the UK but the UK needs to be ready to deploy these and build skills to support their operation. CCS could have useful applications in high emitting industries and there may also be opportunities for the UK to participate in international programmes on this. With the exception of fuel cell micro CHP, capabilities to develop new technologies for the buildings sector probably lie outside the UK. However, UK does have capability in work to integrate systems and technologies, key in a sector where change only takes place if technology development is reflected in codes and standards.

Nuclear fission

UK research capabilities in nuclear fission power generation have decreased considerably over the past few decades following the termination of reactor design and build in the UK and a decrease in R&D funding[101],[102]. Of all the technologies considered in the LSE patent analysis, nuclear was the technology where the UK has its lowest rank for the most recent period analysed. Although the UK does have some specific nuclear R&D capabilities103, it does not have the capacity to design its own reactor system so will depend on global vendors offering standardised designs. An ageing workforce poses some skills challenges. Government needs to invest to build a future nuclear skills base to underpin safe and effective operation.

Industry CCS

CCS could have useful applications in high emitting industries and will become more important over time as emissions from industry make up a greater proportion of total UK emissions. The UK has currently chosen to focus on power generation, but there may also be opportunities for participation in industry CCS, particularly as funding constraints ease and spending is increased. CCS technologies are already being used to capture emissions from industry in other countries104 but further demonstration is required before this can be deployed more extensively. Deployment in the UK is very likely to be important given the scale of the required emissions reduction and the absence of alternative low-carbon technologies.

Buildings technologies

A well insulated housing stock is key to the deployment of heat pumps, powered by a largely decarbonised power sector. However, their suitability for the UK's housing stock still needs to be demonstrated. Heat pumps are already deployed widely in the commercial sector in the UK (often as reverse cycle air conditioners) and the residential sector outside the UK. Although a number of UK companies manufacture heat pumps, the UK is not leading the development of heat pump technologies. More widely:

- Patent data analysis (Table 5) shows that the share of UK inventions in insulation and heating has fallen. However, the reduction occurred 1997 to 2002, and has been partially offset by an increase between 2003 and 2007.

[101] UKERC (2009), *UKERC Energy Research Atlas: Nuclear Fission*
[102] Key investments include a research programme focusing on new reactor technology, waste disposal and materials as well as providing significant levels of training.
[103] Technology Strategy Board (2010), *A Review of the UK's Nuclear R&D Capability*
[104] For example, in Norway (capture and transport) and in North America (capture and injection for increased oil recovery)

Table 5: Share of UK inventions in world innovation by technology (buildings and industry)

Technology	1980-1996	1997-2002	2003-2007
	Share in world's innov.	Share in world's innov.	Share in world's innov.
Cement	2.7%	2.2%	3.8%
Heating	4.1%	1.8%	3.8%
Insulation	5.0%	2.5%	4.0%
Lighting	4.3%	2.9%	1.7%
Solar thermal	4.0%	3.4%	3.2%

Source: LSE (2010), Low-carbon innovation in the UK: Evidence from patent data

- The share of UK inventions in lighting has fallen. This is mainly due to the arrival of new players, in particular South Korea, rather than a decline in UK activity. There is evidence of UK strengths in lighting design and in the specialist luminaire market[105].
- Data on IPOs in the buildings sector is more encouraging. Although the overall value is not significant compared to other countries, IPOs relevant to the buildings sector (e.g. heating, air conditioning, insulation) account for around a quarter of all UK IPOs (in value terms) since 2000.
- The UK has a capability in work to integrate systems and technologies. BREEAM (Building Research Establishment Environmental Assessment Method) developed by the UK Building Research Establishment is the leading and most widely used environmental assessment method for buildings[106]. It sets the standard for best practice in sustainable design and has become the de facto measure used to describe a building's environmental performance. This is key to deployment in a sector where change only takes place if technology development is reflected in codes and standards.

'Research and develop' technologies

There are particular areas of research relevant to solar PV, hydrogen fuel cell vehicles and advanced biofuels where the UK has world-class capability. Work in these areas should continue in order to support UK and global mitigation efforts. In addition, it is important to build up the research base to develop options to mitigate emissions in the agriculture sector, more radical options in the industry sector and large-scale energy storage technologies.

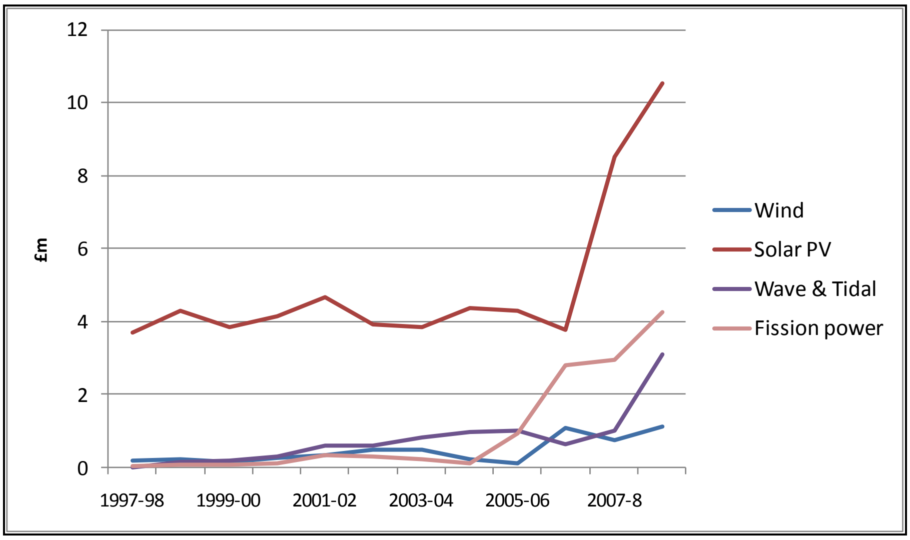
Solar PV

Data from the Research Councils show that funding for a number of low-carbon energy generation technologies has increased quite sharply over the past few years, most notably for solar PV (Figure 11). UK PV R&D activity tends to concentrate on specific areas, particularly novel 3rd generation PV technologies, which are still at the research stage. The UK solar PV research community is small compared to that in the leading countries (Japan, US and Germany) but the UK is leading others in particular aspects of PV research[107].

---

[105] Carbon Trust (2009), *Focus for Success – A new approach to commercialising low carbon technologies*
[106] http://www.breeam.org/
[107] UKERC (2009), *UKERC Energy Research Atlas: Solar Energy*

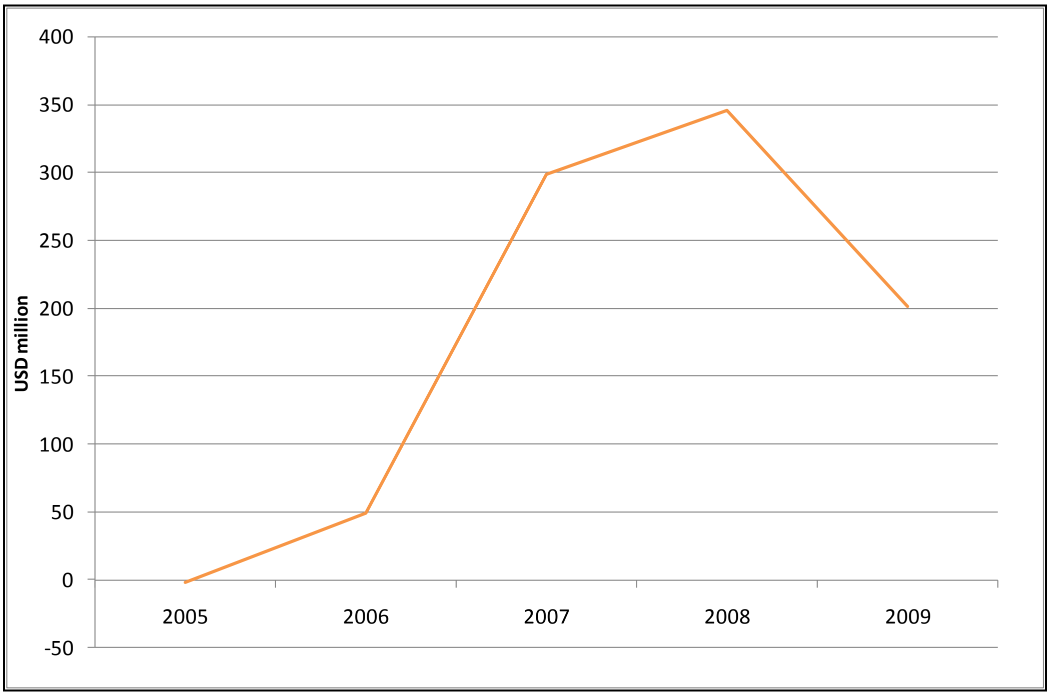
Figure 11: Research Councils' Energy R&D expenditure, 1997-2008 (£m)



Source: Research Councils

Patent analysis (Table 2) found that the UK share of solar PV patents had improved comparing 2003-2007 with 1980-1996 but the UK ranked 8th globally for the most recent period analysed. Analysis of trade data[108] suggests that the UK has a positive balance for solar PV (Figure 12). Analysis published by UKTI also found the UK to have a relatively strong capability in the manufacture and supply of solar PV technologies[109].

Figure 12: Solar PV: UK trade balance, 2005-2009



Source: UN Comtrade database

---

[108] Data extracted from the UN Comtrade database
[109] UKTI (2008), *Market opportunities in environmental goods and services, renewable energy, carbon finance and CATs*

Energy storage

Beyond existing proven technologies (e.g. pumped hydro), further R&D is needed to advance other potential energy storage technologies that could operate on a large-scale.[110] These technologies could include lithium-ion and subsequent generations of batteries, supercapacitors, superconducting magnetic energy storage and adjustable-speed pumped hydro systems.[111]

Hydrogen and fuel cell vehicles

There is evidence of strong research capabilities in fuel cell technologies but currently no complete automotive fuel cell stack manufacturing taking place in the UK[112]. There is some evidence of research activity into hydrogen storage technology but only a limited number of significant UK players[113]. The potential of fuel-cell technology for higher efficiency and zero emission vehicles has already been demonstrated worldwide by various vehicles using hydrogen as fuel. The UK Government has also been running a number of demonstration programmes relating to hydrogen and fuel cell technology.[114] However, major technological breakthroughs are required with respect to robust operation, sufficient lifetime and competitive cost before hydrogen fuel cell technology can enter broad markets.[115]

Advanced biofuels

As used in this report, the term 'advanced biofuels' is intended to mean both second and third generation biofuels[116]. First generation biofuels (based on food crops) are already blended with fossil fuels and used in vehicles. Advanced biofuels are still at the R&D stage and the UK bio-energy research community is small relative to those in the US and other EU countries. UK research has focused on crop science, feedstock supply, technological innovations for combustion and conversion and whole chain developments including environmental impacts of deployment[117]. There is evidence of UK strengths:

- The UK is leading some areas of bioscience research that are relevant to low-carbon, for example, work on cell wall sugars[118] and fermentation technologies[119].
- There is also evidence of UK strength in research relating to pyrolysis[120], and evidence of activity in algae biofuels[121].
- There is evidence of some company driven research[122]. Data on biofuel company IPOs suggests that the UK is not insignificant, with the fourth highest value since 2000 (this may not, however, be a good indication of capability in more advanced biofuel technologies as much of the investment to date will have focussed on investment in first generation biofuels).

---

[110] Energy Research Partnership (2010), *Energy Innovation Milestones to 2050*
[111] IEA (2009), *Prospects for Large-Scale Energy Storage in Decarbonised Power Grids*
[112] Technology Strategy Board (2010), ***Automotive technologies: The UK's current capability***
[113] Technology Strategy Board (2010), ***Automotive technologies: The UK's current capability***
[114] OECD (2009), *Eco-Innovation in Industry: Enabling Green Growth*
[115] European Hydrogen and Fuel Cell Technology Platform (2005), *Strategic Research Agenda*
[116] Second generation biofuels use non-food crop feedstocks and third generation use advanced processes such as engineered micro-organisms
[117] UKERC (2009), *UKERC Research Atlas Topic: Bioenergy for Heat, Power and Liquid transportation fuels*
[118] http://www.bsbec.bbsrc.ac.uk/programmes/cell-wall-sugars.html
[119] http://www.bsbec.bbsrc.ac.uk/programmes/lignocellulosic-conversion-to-bioethanol.html
[120] Energy Research Partnership (2008), *Energy Technologies Matrix;* UKERC (2009), *UKERC Research Atlas Topic: Bioenergy for heat, power and liquid transportation fuels*
[121] http://www.carbontrust.co.uk/emerging-technologies/current-focus-areas/algae-biofuels-challenge/pages/algae-biofuels-challenge.aspx
[122] Technology Strategy Board (2010), ***Automotive technologies: The UK's current capability***

- A recent announcement of plans by INEOS Bio[123] to build Europe's first advanced bioethanol from waste plant in north eastern England suggests the UK could now be starting to build industrial capability in more advanced processes.

Agriculture

At present relatively little research is occurring into technologies that could mitigate emissions in the agriculture sector. For options to be developed and deployed in time to meet climate change targets, particularly longer-term targets, further research and development is required to build up the evidence base. Given the fragmented nature of the industry this is unlikely to be carried out in sufficient scale unless led by government.

Industry technologies

There is currently limited evidence of technological options for reducing emissions in key industrial sectors. It is therefore important to improve the evidence base on industry emissions. The UK has increased its global share in relevant cement patents in the period 2003-2007 relative to its 1980-1996 position but could not be considered a world leader in this area. In the steel sector, the main R&D efforts are being co-ordinated at an EU level and UK companies are participating. Using a thermal gasification process to decompose biomass into a gas that can be used for heat production is not yet a developed technology but could be potentially important as a cost effective means of cutting industry emissions. Development work is taking place outside the UK and the UK is unlikely to host any of the early demonstrations[124]. Anaerobic digestion technologies, which are already relatively mature, could also deliver heat in other sectors.

Summary

In summary, Table 6 sets out the Committee's recommendations for UK technology portfolios.

Table 6: Recommended UK technology portfolios

Develop and Deploy	Deploy	Research and Develop
Offshore wind	Nuclear fission	Solar PV (3rd generation)
Marine	Industry CCS	Energy storage
CCS (power)	Heat pumps	Hydrogen fuel cell vehicles
Aviation technologies	Advanced insulation materials	Advanced biofuels
Electric vehicles		Agriculture technologies
Smart meters / smart grids		Industry technologies

[123] http://www.ineosbio.com/76-Press_releases-11.htm
[124] NERA (2010), *Decarbonising Heat: Low-Carbon Heat Scenarios for the 2020s* (forthcoming)

Chapter 3 - Estimates of public support for low-carbon technologies

This chapter provides estimates of public sector expenditure on low-carbon innovation, covering the entire innovation cycle from basic research through to commercial deployment. The chapter sets out:

3.1 The available data sources

3.2 Our analysis of expenditure

- Public sector expenditure on research, development and demonstration (RD&D)
- Current government support for deployment
- Announced public sector expenditure
- Estimates of private sector R&D investment

3.3 The overall adequacy of public RD&D funding

3.4 The effectiveness of public RD&D funding

The funding landscape for low-carbon innovation is considered in Chapter 5. In pulling together funding data, however, it is worth being aware that existing support is delivered by a range of government departments and agencies and through a variety of policy instruments:

- The different organisations responsible for delivering funds often have different objectives. While organisations such as the Carbon Trust focus only on climate change, there are others such as the Technology Strategy Board (TSB) that have a broader remit such as promoting wealth creation in the UK. This can make the allocation of funding to a specific climate change objective difficult.
- In addition to the centrally managed government programmes, and national organisations (e.g. TSB), the Devolved Administrations and Regional Development Agencies run separate programmes and fund local institutions to capitalise on local strengths and invest in technology priority areas (e.g. marine energy in Scotland).
- The UK also has access to funding from various European programmes, such as the Seventh Framework Programme for Research and Technological Development (FP7)[125]. According to EU regulations and objectives, firms need to forge cross-country partnerships, and involve academia to be able to access funding.

The complexity of the existing landscape means that data collection is not straightforward and inevitably we may not have captured every policy or programme. However, we believe that the estimates we present are a reasonable approximation. We discuss the issue of the complexity of the landscape later when we assess the institutional arrangements for public support.

[125] FP7 is the EU's current main instrument for funding research in Europe and it runs from 2007-2013. It is also designed to respond to Europe's employment needs, competitiveness and quality of life.

3.1 The available data sources

We have used a broad range of data sources to estimate the level of spend on low-carbon innovation. Section 3.2 estimates public sector spend on all low-carbon activity and deployment expenditure. No single data source provides a complete picture. Moreover, each source has its own limitations, in terms of coverage and quality of data and reflecting different definitions of low-carbon. In some cases it is very difficult to allocate spending to specific technologies and avoid double-counting, and we have had to make some assumptions.

In order to estimate the level of public sector spending on low-carbon innovation[126], we have collated data from a number of sources. Our starting point is:

- **Department of Energy and Climate Change (DECC) submission to the International Energy Agency (IEA)[127]:** The IEA collects data from all its member countries and the data is often used to make international comparisons, although aspects of the methodology do need to improve to make country estimates fully comparable.[128] DECC provides data on public sector expenditure on energy RD&D, covering the following seven technology groups:
    - Energy efficiency (industry, residential and commercial, and transport)
    - Fossil fuels
    - Renewable energy sources
    - Nuclear fusion and fission
    - Hydrogen and fuel cells
    - Other power and storage technologies (electric power conversion, electricity transmission and distribution, and energy storage)
    - Other cross-cutting technologies or research (e.g. energy system analysis)

The data supplied to IEA covers the energy sector only (i.e. it does not cover waste and agriculture) and has other important omissions, including:

- Some transport related expenditure (e.g. electric vehicles).
- Expenditure by the Regional Development Agencies.
- Specific programmes run by the Devolved Administrations (e.g. Scottish Biomass Heat Scheme).
- Basic science investments in underpinning technologies which will benefit a wide range of technologies, including low-carbon.

We therefore supplement the DECC submission with other sources:

[126] As set out earlier, we consider 'low-carbon innovation' to be anything that leads to an absolute reduction in GHG emissions or improves the carbon intensity of an activity
[127] DECC's submission to the IEA captures expenditure by the Carbon Trust, TSB and Research Councils and DECC.
[128] IEA (2010), *Energy Technology Perspectives*

- **AEA[129]:** For transport we draw on a forthcoming AEA report that was commissioned by the Department for Transport (DfT)[130]:
  - Unlike DECC's submission to the IEA that is based on actual spend, AEA have based their analysis on annual departmental budgets.
  - In cases where the public sector has committed funds across a number of years, AEA assumes that this funding is split evenly across the time period. This may not be entirely accurate as some projects may require higher expenditure in the initial years, with lower investment later.
  - Based on our engagement with government organisations and funding agencies, we believe that annual budgets are a good proxy for actual spend in 2009/10. There may be cases where actual spend falls short of budgetary spend, but we have not been able to capture this.
- **Regional Development Agencies** (RDAs)[131]**:** The RDAs have identified relevant low-carbon programmes across power, transport, buildings and industry, and environmental technologies (including waste management). We have used data on RDA annual budgets instead of actual spend, as the former allowed us to allocate funding to different sectors.
- **Devolved Administrations:** We have drawn upon data provided by the Scottish and Welsh Governments to capture programmes run by the Devolved Administrations. However, with the exception of energy and buildings and industry, we have not been able to allocate spending to specific sectors.
- **Department for Environment, Food and Rural Affairs** (DEFRA): We have drawn upon direct DEFRA funding to capture investments in the waste and agriculture sectors.
- **Department of Communities and Local Government** (CLG): We have drawn upon direct CLG funding to capture its expenditure on reducing carbon emissions from UK's housing stock.
- **Department for Business Innovation and Skills** (BIS): We have drawn upon direct BIS funding to capture its expenditure on aviation.
- **Research Councils:** We have drawn on actual low-carbon spend data from the Research Councils.

[129] AEA is an energy and climate change consultancy
[130] AEA (2010), *Clean Transport Analysis: A review of the scope for further prioritisation of public sector support for low-carbon technology in UK surface transport* (forthcoming)
[131] Figures for RDAs and Devolved Administrations will include some deployment support that we have not been able to split out.

3.2 Our analysis of expenditure

We present our results of public sector expenditure in four parts:

- Public sector expenditure on research, development and demonstration (RD&D)
- Current government support for deployment
- Announced public sector expenditure
- Estimates of private sector R&D investment

Public sector expenditure on research, development and demonstration (RD&D)

Based on the sources set out in Section 3.1, this section collates our best estimate of public sector expenditure on RD&D over 2009/10. We present the results against the following sectors:

- Power
- Transport (surface transport and aviation)
- Waste and agriculture
- Buildings and industry

While these sectors do not cover the entire spectrum of low-carbon innovation taking place in the UK, they should provide a reasonable estimate of the level of funding. Moreover, meeting UK carbon budgets will predominately depend on emissions reduction in these sectors.

We estimate that total public sector support for low-carbon RD&D across the sectors mentioned above, was around £550m in 2009/10, of which around £40m of RDA spend and around £10m of Scottish Government funding cannot be allocated to a particular sector. In addition, between 2007 and October 2009 the UK received €54 million worth of funding through FP7 for energy, surface transport and aviation. The totals presented below have all been rounded to the nearest £10m.

Power

We estimate that total government funding for RD&D in low-carbon power in 2009/10 was £170m.

Table 7: Estimates of public sector expenditure on RD&D in the power sector (£m)

<table>
<tr><th>Area</th><th>DECC submission to the IEA</th><th>RDA</th><th>Scotland</th><th>Wales</th></tr>
<tr><td>Fossil fuels</td><td>23</td><td></td><td rowspan="5">5</td><td rowspan="5">3</td></tr>
<tr><td>Renewables</td><td>54</td><td>24</td></tr>
<tr><td>Nuclear</td><td>29[132]</td><td>4</td></tr>
<tr><td>Other power and storage technologies</td><td>9</td><td></td></tr>
<tr><td>Other cross cutting technologies or research</td><td>14</td><td></td></tr>
</table>

132 Of which £4m was spent on nuclear fission, the remainder on nuclear fusion.

Total	**170**

Transport

We estimate total public sector spend on transport technologies in 2009/10, including both surface transport and aviation was £190m.[133]

Table 8: Estimates of public sector expenditure on RD&D in the transport sector (£m)

Area	AEA + Research Council data	DECC submission to the IEA[134]	RDA	BIS (TSB funding)
Energy efficiency		50		
Hydrogen and fuel cells		12		
Biofuels		8	21	
Alternative fuels - electricity	24			
Energy Storage	8			
Operational efficiency	9			
Modal shift	4			
Aviation				51[135]
Total	**190**			

Waste and Agriculture

Total public sector spend in agriculture was around £30m in 2009/10. The Biotechnology and Biological Sciences Research Council (BBSRC) spent around £4m on research relating to agriculture and land use[136], including underpinning research such as a study of nitrogen fixation and soil systems. DEFRA's expenditure on RD&D in agriculture has primarily focused on promoting sustainability, and improving efficiency.

Table 9: Estimates of public sector expenditure on RD&D in the agriculture sector (£m)

Area	£m (2009/10)
Agriculture and climate change	5
Non-food crops	1
Sustainable farming systems and biodiversity	11
Resource efficiency and resilient food chain	4
Sustainable water management	6
Sustainable consumption and production (SCP)	1
Soils	0.4
BBSRC research	4
Total	**30[137]**

[133] This includes some expenditure on electric railways, which we have not been able to split out.
[134] As noted above, this will capture any relevant expenditure by the Carbon Trust, TSB and Research Councils against the areas identified.
[135] According to estimates provided by BIS a further £12m is spent on the development of aviation technologies by the Devolved Administrations and RDAs. However, we have not added these to our estimate of expenditure on aviation technologies as it could have included an element of double counting. At least a proportion of the £12m is likely to be included as part of the DA/RDA spend that cannot be allocated to a particular sector.
[136] Note that this figure relates to 2008/09 not 2009/10
[137] This includes some expenditure on adaptation that we have not been able to split out.

Total public sector spending on technologies to convert waste to energy, and promote waste management (and reduction) was £20m in 2009/10.

Table 10: Estimates of public sector expenditure on RD&D in the waste sector (£m)

Area	DEFRA	IEA	RDA
Waste	0.4		
Biofuels waste to energy		7	
Environmental technologies (including waste management)[138]			13
Total		**20**	

Energy use in buildings and industry

The Government has spent £90m on RD&D aimed at reducing emissions in buildings and industry:

Table 11: Estimates of public sector expenditure on RD&D in the buildings and industry sector (£m)

Area	DECC submission to the IEA[139]	RDA	CLG	Scotland	Wales
Energy efficiency - industry, residential and commercial[140]	39				
Biofuels for heat and electricity	9				0.3
Other bioenergy	6				
Low-carbon buildings		2			
Energy management		10			
Microgeneration		1		8	1
Renewable construction demonstration			10		
Heat				0.5	
Total			**90**		

Current government support for deployment

In addition to support for RD&D, the Government spent up to £5 billion in 2009/10 encouraging the uptake of technologies, both through direct intervention and by promoting various market pull incentives. Direct government funding for deployment is outlined first, followed by indirect, consumer funded incentives and lost revenue due to tax breaks.

Direct government support

The Government provides direct funding through various schemes to promote the deployment of low-carbon technologies. In cases where funds are committed across a number of years, we have assumed that this funding is split equally across the time period. Direct funding includes:

- £400m p.a. on Warm Front, a government funded scheme to deliver heating and insulation

---

[138] This includes funding for areas that go beyond waste management, however we have not been able to split this out

[139] As noted above, this will capture any relevant expenditure by the Carbon Trust, TSB and Research Councils against the areas identified.

[140] This includes some expenditure on transport energy efficiency, which we have been unable to split out.

measures to fuel poor households[141].

- £130m p.a. spent through the Environmental Transformation Fund (ETF)[142] (of which £26m is included in DECC's submission to the IEA[143]), which encourages the deployment of low-carbon energy and energy efficiency technologies in the UK. The ETF has a budget of £400m between 2008-11[144].
- Defra spent £110m on deployment to support investment in waste infrastructure capital[145] in 2009/10. There has also been other deployment support including:
  - £70m to support WRAP[146] activities
  - £30m on the New Technologies Demonstrator Programme and the Technology Research and Innovation Fund (both of which have now closed) to stimulate the demonstration and deployment of innovative technologies.
- CLG spent around £800m in 2009/10 to support the deployment of technologies to reduce emissions from UK's housing stock.

Table 12: Estimates of deployment support to reduce emissions from housing stock (£m)

Programme	Funding (£m)
Eco-towns	41
Kick-start (economic stimulus for stalled schemes)	0.2
Social housing energy saving programme	31
Decent Homes	722[147]
Total	**800[148]**

- The Scottish Government has spent around £20m on the deployment of low-carbon technologies through the Community and Renewable Energy Scheme and Scottish Enterprise Co-investment Funds.

Overall we judge that Government spent around £1.5bn on direct deployment support in 2009/10.

---

[141] This includes spending on similar schemes run by Scotland, Wales and Northern Ireland. We have drawn data from announcements made by the Government (including the Devolved Administrations).
[142] In addition to some new programmes, the ETF consists of several government programmes that existed prior to the creation of the ETF, but that have now been consolidated under one programme. The ETF includes the Low-carbon Buildings Programme, bio-energy capital grants and bio-energy infrastructure schemes, Offshore wind capital grants programme, Marine Renewable Deployment Fund, Carbon Abatement Technology Demonstration Programme, and the Hydrogen and Fuel Cell Demonstration Programme. Note that this figure may include some support for demonstration.
[143] The IEA submission covers research, development and demonstration spend but not deployment spend.
[144] DECC recently announced a £34m cut to the ETF budget. More information on which technologies will be affected by these cuts can be found at http://www.decc.gov.uk/en/content/cms/news/pn10_84/pn10_84.aspx
[145] The Waste Infrastructure Capital Grant funds front-end waste infrastructure, e.g. recycling and composting facilities, to help England meet landfill targets.
[146] http://www.wrap.org.uk/
[147] Breakdown of Local Authority spend: £273m spent on windows, £407m on heating and £42m on insulation. In addition Registered Social Landlords (or Registered Providers) spend £178m on making social housing more decent, although this would be considered private finance. Some measures may lead to an increase in carbon emissions through rebound effects. For example, improved heating systems may induce consumers to use more energy, which will reduce the amount of carbon saved.
[148] This does not include £21m CLG spent on the Low-carbon Infrastructure Programme as this includes money set aside as part of LCIF, and some funds delivered through the Low-carbon Buildings Programme, which to a certain extent has been captured by DECC's submission to the IEA.

Indirect government support

In addition to direct support, the Government supported deployment activities through various consumer incentives and indirect support mechanisms that are usually passed on to consumers in the form of higher fuel bills:

- The Renewable Obligation provided financial support worth around £1 billion in 2008/09[149].
- The annual cost of the Carbon Emissions Reduction Target (CERT) is around £1.3bn. CERT is an obligation on energy companies to reduce the level of household carbon emissions. Electricity and gas suppliers are required to improve energy efficiency, and increase the amount of energy generated from renewable technologies[150].
- The Renewable Transport Fuel Obligation (RTFO) requires suppliers of fossil fuels to ensure that a specified proportion of road fuels supplied to the UK is made up of renewables. The RTFO costs the Treasury £300m p.a. in lost revenues[151].

The Government also offers tax breaks to incentivise investment in low-carbon innovation. However, most of these instruments are generic, and do not apply to the low-carbon sector in particular. A high level estimate suggests that Levy Exemption Certificates, Climate Change Agreements, Enhanced Capital Allowances and Vehicle Excise Duty differentials cost the Exchequer around £700m in forgone revenues. This estimate of forgone revenues includes an allowance for R&D tax credits, which we estimate to cost around £20m (Section 3.2 and Box 4).

Overall, we estimate that indirect deployment support measures cost of the order of around £3.2bn in 2009/10.

Announced public sector expenditure

The estimates already set out reflect policy decisions made in previous years. However, the previous Government made a series of funding commitments, which if maintained, would add significantly to existing public sector support for low-carbon innovation (Table 13).

Table 13: Announced expenditure

Announcement	Consumer levies	Public Expenditure
Low-carbon electricity networks and smart grids[152]	£7 billion over 5 years raised from electricity customers, including £500m for the low-carbon networks fund	
Renewables and CCS	£4.2-£5.3bn for CCS demonstration raised by levy from electricity suppliers.[153]	£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

[149] NAO (2010), *Government funding for developing renewable energy technologies*
[150] http://www.decc.gov.uk/en/content/cms/news/pn10_075/pn10_075.aspx
[151] HMRC (2009) *Tax Ready Reckoner* (assume that the RTFO will cost the same as existing biofuels subsidy)
[152] http://www.ofgem.gov.uk/MEDIA/PRESSREL/Documents1/DP5%20final%20-%20030809.pdf
[153] http://www.decc.gov.uk/assets/decc/Consultations/A%20framework%20for%20the%20development%20of%20clean%20coal/1_20091117144132_e_@@_CoalCCSresponseIA.pdf

Electric vehicles[154]		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.

Estimates of private sector R&D investment

Sources of data on private sector spend are very limited. We have drawn on work carried out by the EU and the Office for National Statistics (ONS) to estimate the level of private sector investment in low-carbon R&D in the UK. Whilst the two studies come to similar conclusions, this should not be taken to indicate the estimates are robust. The approaches are quite different:

- A pilot survey carried out by the ONS on behalf of DECC and published in the Annex accompanying the Low Carbon Transition Plan[155] suggests that low-carbon private sector R&D investment was around £240m in 2008. The key problems with this survey include:
  - There is an element of double counting. The survey did not ask for the source of funding, and will include some public funding channelled through industry.
  - There are likely to be major differences in how respondents interpreted the definition of low-carbon. It is possible that some respondents over-estimated their expenditure on low-carbon R&D, while others under-estimated their spend.
  - Completion of the survey was voluntary. Expenditure by significant investors may not have been captured.
- The EU Joint Research Centre carried out a study to evaluate private sector R&D spend in the technology priority areas of the European Strategic Energy Technology Plan (SET). Using the EU Industrial R&D Scoreboard they estimate that UK R&D investment was around £200m in 2007.
  - The R&D Scoreboard only captures the 1000 biggest companies in the EU, and excludes many smaller firms that invest in R&D.
  - R&D is allocated based on where the company is registered, not necessarily where R&D is carried out. However, multinational companies that have factories and research bases in several countries tend to carry out R&D at different locations, and this metric fails to capture these differences.

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. 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 (Box 4).

[154] http://www.dft.gov.uk/pgr/sustainable/olev/
[155] DECC (2009), *Analytical Annex: The UK Low-carbon Transition Plan*

Box 4: Estimating the impact and cost of tax credits

If £240m of private sector R&D qualifies at the large firm's corporation tax rate, then tax credits will cost the Exchequer approximately £20m (calculated using 30% additional R&D allowance multiplied by corporation tax rate of 28% multiplied by £240m)

Estimates* suggest that a 10% reduction in the cost of R&D leads to a 10% increase in the amount of R&D carried out (in the long-term). A 30% R&D allowance with a corporation tax rate of 28% reduces R&D costs by 8%.

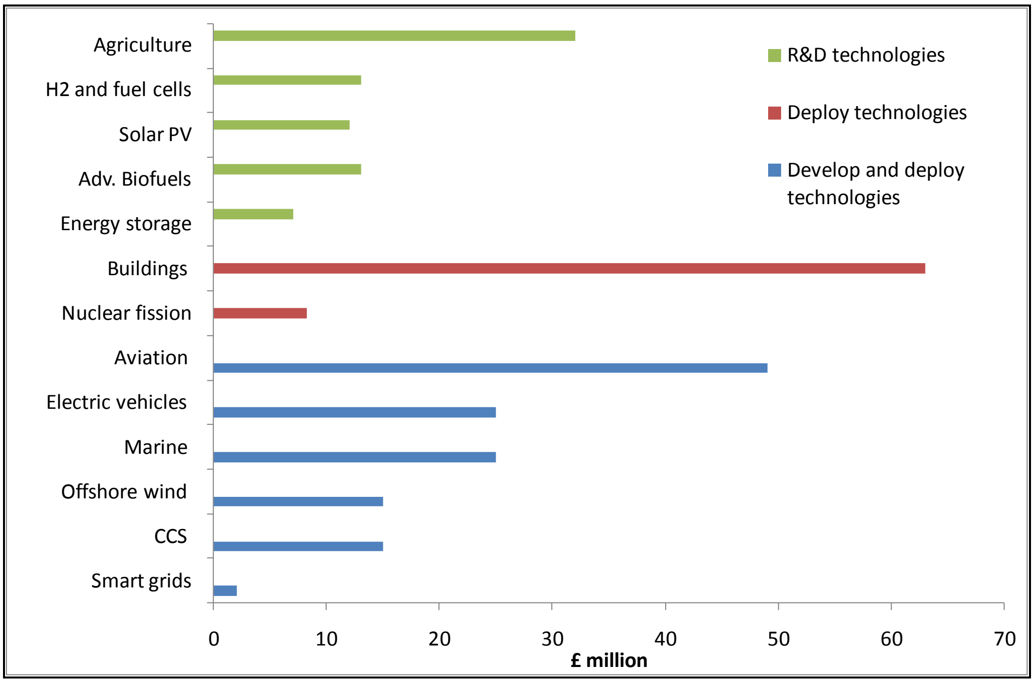
Multiplying the change in cost by the price elasticity of R&D by the value of current R&D spend yields additional R&D of £20m.

*IFS (2001), Issues in the design and implementation of a R&D tax credit for UK firms

3.3 The overall adequacy of public RD&D funding

Our analysis suggests that government RD&D support exists for most of the technologies contained within the portfolios described earlier in the report (Figure 13).

Figure 13: UK public RD&D support for identified technologies (2009/10)



Notes:

(i) Buildings includes energy efficiency, energy management, microgeneration, biofuels for heat and electricity, and renewable construction.

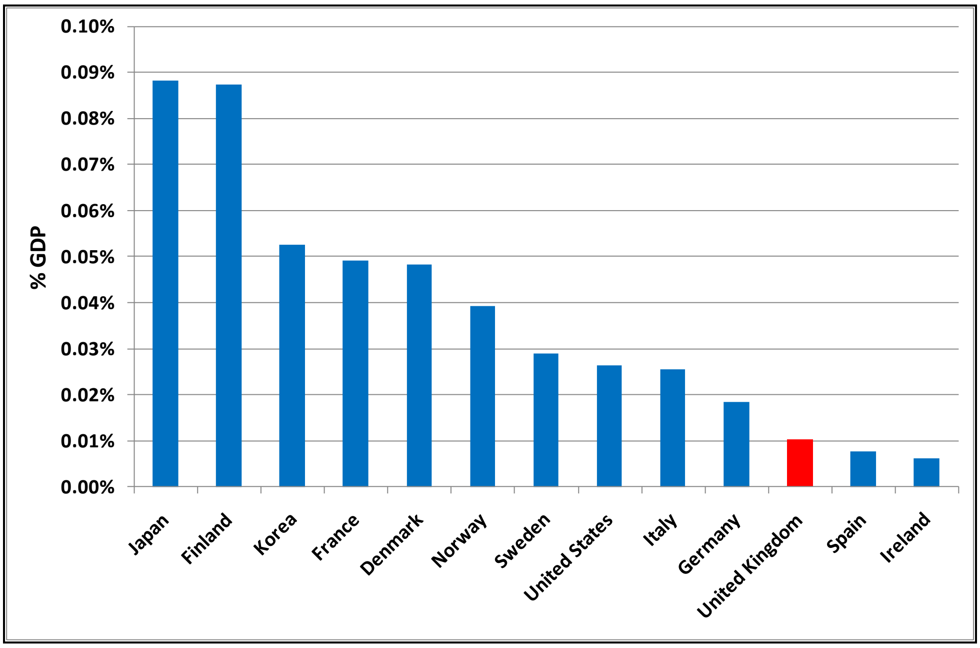
(ii) Excludes expenditure on energy efficiency measures for automotive internal combustion engines, which amounted to £50m in 2009/10.

(iii) Excludes expenditure which could not be attributed to particular technologies.

According to available international comparisons UK support for energy RD&D is low relative to other developed economies which face similar challenges in decarbonising their economies (Figure 14). Benchmarks used by the Stern Review, the International Energy Agency (IEA) and the EU suggest that global and UK low-carbon RD&D needs to rise substantially:

- In the recently published Energy Technology Perspectives 2010, the IEA estimate that global public-sector low-carbon energy technology RD&D spending will need to increase by between two and five times.[156]
- The Stern Review recommended that global public energy expenditure would need to at least double[157].

Figure 14: International comparisons of public sector energy RD&D spend (2007)



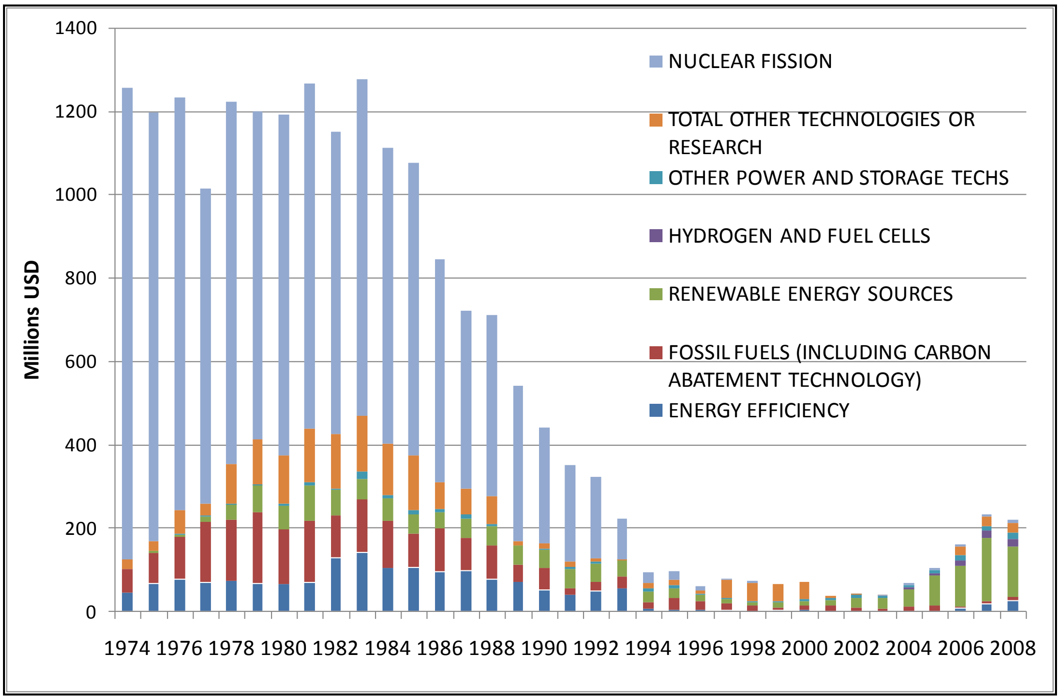
Source: IEA data

UK public sector support for energy RD&D is also low compared to historical levels (Figure 15), although it has been increasing since around 2001. The drop since its early 1980s peak was driven by a combination of energy sector privatisation in the 1980s, and the discovery of North Sea oil and gas (which reduced incentives to invest in alternative forms of energy).

With the Government placing greater emphasis on climate change recently, the downward trend was reversed at the beginning of the decade, with current estimates for public sector expenditure in 2009/10 showing a significant increase on the previous year.

[156] IEA (2010), *Energy Technology Perspectives*
[157] Stern (2007), *The Stern Review: Economics of Climate Change*, Chapter 16 – this was labelled as R&D expenditure in the Stern Review, however, the numbers that were presented seem to reflect RD&D

Figure 15: UK public sector expenditure on energy RD&D (1974-2008)



Source: IEA Database

3.4 The effectiveness of public RD&D funding

It is important that public support leverages, rather than displaces, private investment. There is a limited amount of evidence on the effectiveness of public sector funding of low-carbon RD&D in generating additional activity and outputs. However, evidence about public support more generally sets out the conditions under which it is most effective and suggests that public funding via grant programmes does stimulate additional activity.

In cases where the rationale for public funding is strong we would expect to see high levels of input additionality, i.e. government funding leads to higher levels of investment by the private sector than would otherwise be the case. 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[158]. The general evidence for government support suggests that levels of additionality are high:

- 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[159].
- 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)[160].
- A recent evaluation of support for small firms R&D161 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

[158] National Audit Office (2010), *Government funding for developing renewable energy technologies*
[159] Technopolis (2005), *Review of Projects Selected for Funding under the DTI Technology Programme*
[160] DTI (2003), *Competing in the Global Economy: The innovation challenge*
[161] PACEC (2009), *Evaluation of Grant for Research and Development & Smart*

scope).

RD&D support needs to be material, consistent and long-term, particularly for capital intensive energy technologies where market failures seem to be greatest and where market incentives alone are almost certainly not enough[162]. Based on the experience of solar PV and onshore wind in other countries, successful technology development and deployment, requires public sector RD&D support that is:

- Material – both by individual countries and globally. For example, the key countries that developed and deployed onshore wind (the US, Germany and Denmark) all spent significant sums on public sector RD&D support (an average of 45, 23 and 16 US$m/year respectively) and overall IEA countries as a whole have spent c.$150m/year on RD&D support[163] since 1974.
- Consistent and long-term – for example in solar PV Japan spent US$60m/year rising gradually to US$170m/year over a period of over 25 years.
- Comprehensive, covering a variety of enablers such as the setting of safety and performance standards, sponsoring networks for knowledge transfer and certification as well as direct support for developers.

Making investments now to induce additional technological change could reduce overall costs of meeting climate change targets in the longer run. UKERC[164] estimates that over the period 2010-2050, accelerated development could be associated with a total saving in 'welfare costs'[165] of £36bn. Benchmarked against the added investment costs of accelerated development, this 'saving' could justify an additional annual budget for UK RD&D investment in low-carbon technology development of around £1bn p.a. (and much of this investment would need to be committed well before significant 'returns' start appearing after 2030).

---

[162] Grubb.M,(2004), *Technology Innovation and Climate Change Policy, an overview of issues and options*
[163] Source: IEA, all figures at 2008 prices
[164] UKERC (2009), *Decarbonising the UK Energy System: Accelerated Development of Low-carbon Energy Supply Technologies*
[165] The sum of consumer and producer surplus

Chapter 4 – Framework for deploying low-carbon technologies

This chapter sets out the issues that need to be addressed to ensure the deployment of technologies identified in the earlier chapters. It focuses on some of those technologies that are closest to market, which we described in the 'deploy' and the 'develop and deploy' technology portfolios presented in Chapter 2.

Overall, while the policy framework has evolved considerably over last decade, there are significant gaps in deployment support which will compromise the UK's ability to deliver key low-carbon technologies.

We now consider:

4.1 The key features of a good framework

4.2 Current measures to support deployment

4.1 The key features of a good framework

Earlier we noted that in many cases the market will not deliver the range of low-carbon technologies required because they will initially be more expensive or may offer inferior performance compared to their high-carbon equivalents or they need new infrastructure. Government policy therefore needs to encourage cost reductions and improved performance and the provision of appropriate public infrastructure. Broadly, required measures fall into the following categories[166]:

- Measures to increase demand so that the technology is pulled through to market ('market pull'),
- Sufficient public support for RD&D to adapt new technologies to UK conditions,
- The removal of administrative, infrastructure and public acceptability barriers,
- Ensuring access to skills and capabilities in the UK.

The adequacy of existing public support for RD&D was discussed in Chapter 3. Failure to develop credible and appropriate policies in all these areas could make the development and deployment of technologies less likely or more costly. But the nature of the framework also needs to be tailored to the UK's interest in the technology, as well as the specific characteristics of the technology such as its maturity, capital intensity and market competitiveness:

- It is vital that there is sufficient market pull – generated by price signals or regulation – to make private sector investment in deployment viable once technologies are demonstrated. As far as possible policy should be framed in a way that does not exclude specific technologies. Government has a key role to play in establishing market pull (e.g. overcoming the lack of a price for carbon emissions in some sectors).

[166] In developing this framework the Committee has drawn on published work by the Carbon Trust (e.g. *Focus for success*, 2009) and the IEA (e.g. *Energy Technology Perspectives,* 2010) as well as our interviews

  - If a price signal is used, government has a role in establishing the level and nature of the incentive, establishing the best balance between market mechanisms, which reduce costs, and fixed-price measures which provide more certainty and which in turn increase deployment.

  - Market pull needs to be strong and long-term in order to help incentivise technology developers, who want assurance that a market will exist once the technology is ready for launch. For example, in the power sector or parts of the transport sector a deployment investment could take 10-15 years to pay-off. A similar, albeit less extreme situation is found in other key low-carbon sectors.

- The testing and adaptation of new technologies to UK conditions potentially requires ***RD&D support***. For example, UK housing has a unique combination of building types, climatic conditions and heating systems. New heating and microgeneration technologies that work in other countries will not necessarily work effectively in the UK without potentially significant modifications. In most circumstances, the private sector will take the lead in this area. The role of government support is to ensure that: objective data is generated and made available; knowledge spillovers do not inhibit private sector investment; and, if market incentives are relatively weak, direct financial incentives are in place.

- Administrative, infrastructure and public acceptability **barriers** must not unnecessarily impede the deployment of viable technologies. Government has a major role to play in all these areas though the nature of intervention can be highly varied (e.g. establishing an appropriate trade-off between the costs of mitigating carbon and loss of amenity such as changing the face of the countryside).

- The **skills** required for deployment must be readily available. For the develop and deploy technology portfolio, this should go beyond skills development, to ensure, using tools of industrial policy, that leading players in technology development are attracted to invest in the UK.

The relative importance of getting each of these conditions right depends, among other factors, on the type of technology (e.g. its capital intensity) and its stage of development.

4.2 Current measures to support deployment

We have identified only a limited amount of real world evaluation data on the many policies and instruments in place. This limits our ability to assess the effectiveness of delivery. However, we have pieced together the existing evidence, including that developed from our interview programme, focusing on market pull which cuts across a number of technologies. Focusing on technologies that are currently closest to market (those in the 'develop and deploy' or 'deploy' categories set out in Chapter 2), our analysis shows that none of the technologies considered has all the conditions in place for effective innovation.

The sections below set out any issues relevant to each sector as a whole and then consider the points specific to each technology in more detail.

Power sector

Volatile electricity and carbon prices, and uncertainties over development of electric vehicle and heat markets, means there is a significant risk that current electricity market arrangements will not deliver the required investments in nuclear, CCS, energy storage and renewable energy technologies during the 2020s. Current market arrangements were designed for a system with excess capacity and where most new investment was expected to be in gas-fired generation. Low-carbon technologies have higher capital costs and lower marginal costs than conventional technologies. Exposure to volatile prices makes high-capital cost investments more risky to investors.

New arrangements could be strengthened through:

- Introduction of an Emissions Performance Standard (EPS) for coal fired generation as proposed by the Government and an EPS for new gas generation as recommended by the Committee[167].
- Introduction of a carbon price floor as proposed by the Government to complement market reforms, and to provide transitional support for investments before new arrangements are introduced.

The Committee will present new analysis of the path for electricity investment through the 2020s, and high-level implications for levers to drive required investments, as part of advice on the fourth carbon budget, to be published before the end of 2010, and to feed into the new Government's work on electricity market reform.

Public sector deployment support for renewable technologies is currently provided through a levy on fuel bills, which is recycled to renewable energy suppliers:

- The Renewables Obligation (RO) provides a financial incentive to invest in renewable energy by placing an obligation on electricity suppliers to source a certain proportion of their electricity from renewable sources. The RO was banded in 2009 to offer targeted support to renewable technologies based on their relative maturity.
- The IEA has reviewed the RO and concluded that it was relatively high cost and ineffective as a deployment mechanism[168] when compared with alternative schemes in other countries. However, this was based on data up to 2005 and the changes introduced in 2009 (e.g. introduction of banding, head room) have not yet been evaluated.
- Feedback from investors (including large businesses, venture capitalists and SMEs) has indicated that the RO is working as an incentive for technologies which are deployable. The high levels of both onshore and offshore wind in the project development pipeline support this view. However, it is considered less effective for early stage technologies which require considerable development over a long period of time. In particular, the views emerging from our interviews were that it was neither sufficiently stable nor long-term to provide an adequate market pull for technology development which requires over 20+ years to pay back.

Offshore wind

Offshore wind is at the early deployment stage. The Renewable Energy Strategy envisages that 13 GW of offshore wind capacity will be added in the UK in the period to 2020 to help achieve the UK's 15% renewable energy target. The Committee's indicator trajectory sets out a similar level of ambition[169] and suggests that this level of offshore wind investment is feasible and desirable in terms of emissions reduction. Failure to deliver offshore wind at this level would increase reliance on other technologies for required power sector decarbonisation, and increase risks to meeting carbon budgets.

- Market pull is generated mainly by the RO. This appears to be providing sufficient incentive for some investors, although it is unlikely to be sufficient to stimulate technology

[167] http://hmccc.s3.amazonaws.com/gas%20CCS%20letter%20-%20final.pdf
[168] IEA (2008), *Deploying Renewables: Principles for Effective Policies*
[169] Committee on Climate Change (2010), *Meeting Carbon Budgets – ensuring a low-carbon recovery*

development – particularly RD&D to improve reliability and reduce costs. As a capital intensive technology, offshore wind will also suffer from the issues of carbon price and electricity price volatility.

- There is scope for driving down offshore wind costs through learning, therefore providing a potentially low cost option for deployment through the 2020s. Analysis by the Carbon Trust suggests that up to £50m/year of public support is required for offshore wind[170], which is higher than the current level of support identified in Section 3.3.

- 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 across on and offshore wind remained at 15 months, well above the statutory target (16 weeks for onshore)[171].

  - The average planning period for larger projects (over 50MW) has increased to 41 months[172].

  - Evidence from RenewableUK suggests that approval rates for projects at the Local Planning Authority level fell to 53% by MW in 2009, relative to 68% in 2008[173].

Recent activities, including the announced competition for port infrastructure development, appear to have been successful in attracting leading or potentially leading technology developers to the UK such as Siemens, General Electric, Mitsubishi and Clipper Wind.

Marine

Marine power technologies include wave power, tidal stream and novel forms of tidal range. These range from the early development to the early demonstration stage, with considerable RD&D needs to prove concepts, reduce costs and improve performance. Carbon Trust analysis suggests that there is a funding gap for some marine technologies.[174]

However, the previous Government announced substantial new funding for marine technologies and the UK is home to many device developers:

- A quarter of the world's wave technologies are being developed to some extent in the UK; the US has the next highest share with 16%[175].

- Most of the UK marine device developers are SMEs although these have attracted the interest of larger businesses with acquisitions / equity investments made by major engineering companies such as Rolls-Royce and Siemens.

It is uncertain whether the level of investment pull through will be sufficient, as it appears that the RO is neither sufficiently stable nor long-term to provide an adequate market pull for technology development. Marine renewables require a significant ramp-up of the supply chain infrastructure and an increase in the availability of the appropriate skills, building on expertise in the UK maritime sector[176].

---

[170] Carbon Trust (2008), *Offshore wind: big opportunity, big challenge*
[171] Committee on Climate Change (2010), *Meeting Carbon Budgets – ensuring a low-carbon recovery*
[172] Committee on Climate Change (2010), *Meeting Carbon Budgets – ensuring a low-carbon recovery*
[173] BWEA (now RenewableUK) (2009), *Wind Energy in the UK: State of the Industry Report*
[174] Carbon Trust (2009), *Focus for success – A new approach to commercialising low carbon technologies*
[175] Carbon Trust (2009), *Focus for success – A new approach to commercialising low carbon technologies*
[176] Department of Energy and Climate Change (2010), *Marine Energy Action Plan 2010*

Carbon Capture and Storage (CCS)

CCS has yet to be fully demonstrated as a system at commercial scale:

- Market pull is currently limited to the EU Emissions Trading System (ETS) and the expectation that new coal power stations will be fully CCS once it has been shown to be economically and technically viable (probably after 2020)[177].
  - The new Government has committed to funding four CCS demonstration projects. These will 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. Failure to support demonstration at this level would push back feasible deployment dates, resulting in greater reliance on nuclear and other low-carbon power generation for required power sector decarbonisation and increased risks to meeting carbon budgets.
  - There may well be a need for deployment support to supplement the EU ETS in the post-demonstration phase (i.e. early 2020s), as the costs of abatement may still be higher than the carbon price.
  - Our analysis suggests that gas CCS is likely to be competitive with coal CCS 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. However, there are currently no plans to demonstrate gas CCS in the UK. There is an opportunity to demonstrate gas CCS as at least 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.
- The recent publication of an industrial strategy for the development of carbon capture and storage across the UK and the announcement of the first 'Low-carbon Economic Area for CCS' indicates that moves are being made to attract investment and leading companies to the UK.

Nevertheless, the lack of CO_2 infrastructure is a barrier to deployment of CCS beyond the demonstration stage. 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.

Nuclear fission

3rd Generation-plus nuclear is ready for deployment, with new reactors currently under construction in France and Finland, though none are yet operational. Market incentives, barrier removal and skills building are therefore the most important conditions to have in place:

- Current UK Government policy is not to provide market incentives for nuclear power other than those provided by the EU ETS but it is not clear whether the EU ETS carbon price signal alone will be strong enough to pull through nuclear power[178]. Current electricity market arrangements do not seem adequate to incentivise low-carbon investment. There is now a short window for full consideration of the options available for reform to occur if key investments are to go ahead in time[179].
- Government has taken action on the planning barriers faced by nuclear although it must ensure

---

[177] Department of Energy and Climate Change (2009), *A framework for the development of clean coal Consultation response*
[178] Committee on Climate Change (2009), *Meeting Carbon Budgets – the need for a step change*
[179] Committee on Climate Change (2010), *Meeting Carbon Budgets – ensuring a low-carbon recovery.*

that the proposed abolition of the Infrastructure Planning Commission in its current form does not adversely impact the efficiency of the planning system[180].

- Skills and supply chain issues have begun to be addressed through the Nuclear Advanced Manufacturing Centres in Sheffield and Manchester. However, delivery of the new nuclear build programme requires a steady flow of graduates into the nuclear industry. Lack of UK participation in the Generation IV International Forum puts this flow at risk, since the best way to maintain teaching capacity in nuclear related industries is to support R&D in universities, particularly in areas such as Generation IV technologies and advanced fuel cycles.

Transport sector

Electric / plug-in hybrid electric vehicles

Electric vehicles and plug-in hybrid electric vehicles (EV / PHEV) are about to enter the early deployment stage, although still requiring significant RD&D to improve, for example, driving range and cost. 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.

- Market pull is being established through:
  - EU New Car CO_2 regulation encouraging the industry to improve the efficiency of internal combustion engines. For the future, however, through proposed progressive tightening of the regime, it is possible that this could provide some assurance that there will be a future market for electric vehicles.
  - Zero vehicle excise duty, enhanced capital allowances (for businesses) and no fuel duties.
  - The previous Government's intention to provide a consumer incentive of up to £5000/car between 2011 and 2014, costing £230m. Previous analysis by the Committee 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.
- 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 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 – the new Government has committed to roll out a national battery charging network, although there are key questions of detailed design outstanding.

Aviation

Developments in aviation are likely to include a variety of incremental improvements in aircraft engine efficiency and airframe design, and radical changes such as the open rotor engine and the blended wing airframe. Developments in aviation technologies are already subject to strong market

[180] The Government aims to bring forward legislation next year to replace the Infrastructure Planning Commission (IPC) with a unit within the Department for Communities and Local Government. The processes of the IPC will be retained but final decisions on nationally significant infrastructure projects will be made by the relevant Secretary of State

pull as aircraft fuel efficiency is a key concern for airlines (fuel costs are a significant share of total costs - up to 35%[181]). Additional market pull is likely with the inclusion of airlines within the EU ETS in 2012. Further RD&D support would be necessary to bring more radical designs, such as blended wing, to market. Achievement of UK targets to reduce aviation emissions to 2005 levels by 2050 would require a much stronger carbon price or additional instruments to reduce demand.

Buildings sector

The Government has set specific targets that all new homes must be zero-carbon from 2016 and all new non-domestic buildings must be zero-carbon from 2019. These targets will be achieved by a progressive tightening of Buildings Regulations over the period. Interview feedback has indicated that the progressive tightening of part L of the Building Regulations has provided a clear vision for a zero-carbon home and has acted as a strong stimulus for private sector innovation.

The Carbon Emissions Reduction Target (CERT) requires domestic energy suppliers with more than 50,000 customers to deliver measures that will reduce emissions from the residential sector. The CERT has been effective as a mechanism to deploy existing technologies such as loft and cavity wall insulation, as well as compact fluorescent lightbulbs. Energy suppliers can use CERT for other measures such as solid wall insulation or microgeneration technologies, although this has not generated much uptake as suppliers try to meet the target in the cheapest possible way.

Heat pumps

Heat pumps (both air source and ground source) are currently on the market:

- RD&D is required to ensure they work effectively in the UK climate and building stock (e.g. work in on-off mode, include heat storage) and to reduce costs.
- Field trials are underway (by the Energy Saving Trust). However, these focus on UK homes rather than on commercial and industrial applications, where there is a high potential for carbon savings[182].
- Heat pumps are part of the proposed Renewable Heat Incentive, which should, depending on how it is implemented, provide a strong market pull. 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.
- Even with an effective Renewable Heat Incentive in place, a number of barriers may still impede the penetration of heat pumps including lack of awareness, inconvenience of some of the solutions (e.g. space requirements) and whether the Standard Assessment Procedure (SAP) rating will adequately reward buildings with heat pumps. It is also important to note that deployment of heat pumps will not result in significant carbon savings until sufficient power sector decarbonisation has been achieved.
- Skills issues may also need to be addressed as high growth in system installations could lead to a shortage of suitably trained personnel[183].

[181] Committee on Climate Change (2009), *Meeting the UK aviation target – options for reducing emissions to 2050*
[182] NERA / AEA (2009), *The UK Supply Curve for Renewable Heat*
[183] Environment Agency (2009), *Ground source heating and cooling pumps – state of play and future trends*

Advanced insulation

Advanced solid wall insulation covers products ranging from those just entering the market through to those at the research stage. Market pull for these technologies is low at the moment. There were only around 15,000 solid wall insulation installations in 2009 under CERT [184], and most of these were carried out with established insulation materials rather than more advanced materials suitable for a wider range of homes.

Although ambitious targets for deployment of solid wall insulation were set in DECC's Household Energy Management Strategy[185] (e.g. 2.3 million insulations annually), there is currently no policy in place to deliver this ambition. A new policy approach which addresses both financial and non-financial deployment barriers (such as the thickness of available insulation) is required. RD&D appears limited with no systematic and comprehensive field trials and limited support for new development. Barriers, such as planning (for exterior solid wall insulation), the lack of credit for solid wall insulation in energy performance certificates and the lack of a certification scheme for installers are also hindering progress.

---

[184] Energy Savings Trust (2009), *Solid Wall Insulation Supply Chain Review*
[185] Department of Communities and Local Government and Department of Energy and Climate Change (2010), *Warm Homes, Greener Homes: A Strategy for Household Energy Management*

Chapter 5 – The effectiveness of the institutional landscape

To achieve the emissions reduction required to meet 2050 targets implies a radical re-engineering of existing power and energy systems. This can only be achieved by substantial public and private investment in technologies. The challenge for policy makers is to ensure that institutional frameworks incentivise the development of these technologies in sufficient scale and in a timely way.

This chapter considers:

5.1 Key features of a good institutional framework

5.2 The UK's current institutional framework

5.3 How the UK's existing framework compares to good practice

5.1 Key features of a good institutional framework

The establishment of a robust and effective framework that is still sufficiently flexible to deal with the myriad of differentiated technologies and varying development timescales is clearly not an easy task. This is particularly true when institutional structures have evolved and grown over time to meet new demands and reflect changes in policy direction.

A number of organisations have identified several key features which should underpin institutional frameworks in order to increase the effectiveness of public RDD&D support (Table 14[186]). A number of common characteristics appear in the three examples shown, including requirements for:

- An overarching objective and long-term focus, which:
  - Defines desired outcomes,
  - Links outcomes to available resources.
- Clear alignment between the overarching objective and the objectives of delivery bodies.
- Strong links between all stages of the innovation process.
- Monitoring frameworks with feedback to objectives, allowing flexibility to adapt the approach in light of scientific, technological or policy developments.
- Integration with international research programmes and overseas technology developers.

[186] The table has been divided into a number of broad categories to allow easier comparison of desirable traits across the three examples.

Table 14: Core Principles and Requirements for an effective innovation system

IEA	NESTA	PEW
Strategic direction and objectives		
A clear definition of the government's role		
A national energy strategy (policy directions and goals)		
An accompanying technology and R&D strategy	Public programmes on R&D should be structured to support and encourage broad dissemination of knowledge created	
Well-defined and transparent R&D prioritisation and evaluation processes	Development of criteria and processes for identifying where and how public investments can catalyse, complement and usefully augment private sector investments	Generally support a suite of options rather than a specific technology or design
Clear focus of support and support structure		
	Need central administrative structure to set priorities, monitoring progress and evaluating performance. Importance of stability and credibility	
	Must support the development and deployment of many different technologies (both long-term and demonstration)	Channel funds for technology development and diffusion through multiple agencies and programmes
Adequate and stable funding	Focus on long-term support for development and improvement of relevant technologies.	Effective programmes require insulation from short-term political pressures
Appropriate linkages – between actors at different stages of the process		
Involvement of R&D stakeholders in priority setting and evaluation	Should maintain good communications with users of technologies developed	
Public private partnership	Ensure that feedback loops are effective	
Appropriate linkages –with other strategies / policies		
Linkage with national science, research and innovation strategies	Should complement policies that help better price carbon (e.g. cap & trade or carbon tax)	Importance of 'non-technology' policies e.g. GHG cap & trade
Linkages with policies for commercialisation and deployment	Policies to directly / indirectly support demand (e.g. public procurement & specific regulatory requirements)	Balanced policy portfolio needs to support R&D and promote diffusion of knowledge and deployment
		Importance of 'downstream' adoption and learning (including public procurement)
		Support for education and training should supplement research funding.
International collaboration		
Strategy for international R&D collaboration	Importance of international co-operation (multidisciplinary)	

Sources: OECD/IEA (2007), Reviewing R&D policies: guidance for IEA review teams; NESTA (2009), Technology policy and global warming; Pew Centre (2003), US technology and innovation policies: lessons for climate change.

5.2 The UK's current institutional framework

This section provides a brief description of the institutional framework currently in place for delivering reductions in carbon emissions in four key sectors – energy generation, transport, buildings / industry and agriculture. It covers:

- Policy responsibilities
- Delivery bodies

Policy responsibilities

The following Departments have responsibilities for the main sectors:

- **Department of Energy and Climate Change** (DECC) has responsibility for the energy sector and provides funding support for renewable technologies.
- **Department for Transport** (DfT) has responsibility for the transport sector and provides funding support for low-carbon transport technologies.
- **Department for Business, Innovation and Skills** (BIS) is responsible for the general framework of innovation policy, supports the wider innovation infrastructure such as the national measurement system, the intellectual property framework and the development of standards, funds the Science Base and provides support to industries that will need to introduce low-carbon technologies.
- Although the **Department of Communities and Local Government** (DCLG) has responsibility for housing policy, building standards and planning regimes, DECC is responsible for developing a vision and putting a policy framework in place to reduce emissions from buildings and industry more generally.
- **Department for Environment, Food and Rural Affairs** (Defra) is the lead department for delivering agricultural emissions reduction, and is responsible for the development of the policy framework and engagement with industry in this sector.

Responsibilities for delivering emissions reduction can be shared between departments. For example, BIS has responsibility for the aerospace industry and DfT has a broader responsibility for air transport, including the provision of potential infrastructure. Policy is also influenced by European legislation – a lead department will ensure this is enforced in the UK. For example, DEFRA will negotiate and implement regulations and directives arising from the Common Agricultural Policy or specific legislation on environmental quality.

Delivery bodies

There are a number of bodies that are responsible for the delivery of policy, developing the regulatory framework and addressing barriers to deployment. These are listed briefly below.

Within DECC, there are three main delivery bodies:

- ***Office of Renewable Deployment*** *(ORED)* is responsible for delivering the UK's Renewable Energy Strategy by putting in place financial incentives to support the deployment of renewable energy, including reform of the Renewables Obligation, the introduction of feed-in tariffs and the Renewable Heat Incentive. In addition, ORED helps overcome non-financial barriers and supply chain bottlenecks that inhibit the deployment of renewable technologies.

- ***Office of Carbon Capture and Storage*** *(OCCS)* facilitates the delivery of CCS technology in the UK. It is specifically responsible for setting out a strategic path for CCS deployment, including support for CCS demonstration; developing a policy framework to attract private sector investment; and working with stakeholders to remove barriers to deployment both in the UK and globally.
- ***Office of Nuclear Development*** *(OND)* is streamlining the application process and developing a robust regulatory framework to support the deployment of nuclear power in the UK. It works in close collaboration with industry and other stakeholders to meet new nuclear skill requirements, and develop a competitive UK supply chain.

In the area of transport:

- ***The Office of Low-Emission Vehicles*** (OLEV) is a cross-government team that is responsible for developing the policy framework to take forward the development programme for low-emission vehicles and coordinate ongoing programmes in this area across government.

In the area of residential housing:

- The ***Zero-Carbon Homes Hub*** is responsible for coordinating the delivery of new low- and zero-carbon homes. It is an industry-government partnership and has a number of strands of work covering Building Energy Efficiency, Energy Supply, Examples and Scale Up, Skills and Training, and Consumer Engagement.

In the area of agriculture:

- Defra is independently assessing the Action Plan put together by the industry. The Department intends to establish a ***joint DEFRA-industry delivery board***, which will be responsible for the implementation of the Action Plan.

In terms of delivering programmes of financial support, a number of bodies provide funding alongside non-financial support. In addition to programmes that are directly funded by central government departments, and the programmes undertaken by the ***Research Councils*** in the generation of fundamental knowledge and ideas, there are five main bodies that provide funding for the development and demonstration of low-carbon technologies:

- The ***Technology Strategy Board*** (TSB) operates at arms-length from Government as a business-led executive non-departmental public body. It is sponsored and funded by BIS. The TSB delivers programmes targeting the development and demonstration of a number of low-carbon technologies, core components and infrastructure and systems options. This is part of a broader objective to stimulate technology-enabled innovation with a view to boosting UK growth and productivity.
- The ***Carbon Trust*** is a not-for-profit company primarily grant-funded by DECC and the Devolved Administrations. The Carbon Trust provides support through a number of programmes to assist the commercialisation of low-carbon technologies as part of a broader programme to facilitate carbon emissions reduction and energy efficiency across businesses and the public sector.

- The ***Energy Technologies Institute*** (ETI) is a Limited Liability Partnership between six private sector companies and the UK Government. It is funded equally by member companies and UK Government. The primary objective of the ETI is to accelerate the development, demonstration and commercial deployment of a portfolio of energy technologies.
- The ***Energy Saving Trust*** (EST) is a non-profit government funded organisation providing free advice on saving energy, conserving water and reducing waste. The EST has also run some technology trials to test the performance of new technologies in real world conditions.
- The ***Regional Development Agencies*** (RDAs) are non-departmental public bodies, funded by central government. RDAs help to deliver central government objectives at a regional level.

5.3 How the UK's existing framework compares to good practice

As part of our evidence gathering process we met with a variety of stakeholders including small, medium and large companies, trade associations, funding bodies, industry groups and academics. We sought their views on a number of questions[187] (Box 5). The key themes that emerged, including some direct quotes, are presented in more detail below. These were:

- Overarching objective and long-term focus
- Integration with international programmes
- Delivery bodies with clear objectives
- Monitoring frameworks with feedback to objectives

Overarching objective and long-term focus

> ***"Nobody's steering the ship...***
> ***the engine room is empty"***
> - Interview comment

There was a common view that 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 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 and businesses and investors generally feel that the UK Government's objectives are unclear (Box 6)

[187] The questions were revised slightly for different types of organisation

Box 5: Questions for stakeholders

Innovative activity and technology development

1) What is your view on the level of R&D and D&D activity going on in the sector related to cleantech/low-carbon?
2) Do you have much interaction with the UK research base (Research Councils)? Do you have a view (positive or negative) on the quality of the research base in the UK with respect to low-carbon? What about later stage D&D activity?Do you think that that distribution of RDD&D support is appropriate across the various stages of the Innovation process? Are there gaps?
3) In your view should the UK prioritise its low-carbon RDD&D efforts, and if so, how?

UK's innovation institutional framework

4) What is your view of the effectiveness of the economic instruments (for example, R&D tax credits, Enhanced Capital Allowances, direct grants etc) that you are exposed to?
5) Which are the primary innovation institutions that you have been/are engaged with respect to low-carbon? Are there any particularly important programmes?
6) Are there any gaps in the institutional landscape and if so at what point? Is the landscape easy to navigate? Where is further guidance/advisory support required?

Regulatory and competitive framework

7) Does the current regulatory and competitive framework for pricing carbon (for example the EU ETS or the CRC) provide sufficient incentive to invest in RDD&D activities developing low-carbon products, services and technologies?

International comparison

8) Have you engaged with any European/international institutions or programmes for supporting innovative activity and technology development? In your view how successful are UK bids in receiving funding from these programmes?
9) What is the extent of your experience of working under the innovation systems in other countries, both for earlier stage R&D and later stage D&D?
10) In your view how does the UK innovation system compare with respect to the countries, both in the context of earlier stage R&D, and later stage D&D?
11) Are there good examples in other countries which the UK can learn from (either in terms of whole-systems approaches or parts of the system)?

Box 6: Global Business Perspectives

Research suggests that Government needs to provide leadership on moving to a low-carbon economy.

Regulatory compliance is viewed by the majority of business executives (85%) as the most influential lever open to governments in comparison to other behavioural drivers including reputation, cost savings and competition. Further, the responses showed that 95% agreed that tax and regulation will help reach a global climate deal, particularly given the scope to ensure that companies are competing on a level playing field over the longer term.

Although highlighting that business leaders around the world recognise the need for meaningful emissions targets, the analysis shows that the business community believes that existing taxes, regulations and incentives are ineffective, inconsistent and unclear. Carbon trading is undermined by issues around certainty and simplicity, while carbon taxes have issues around flexibility and the availability of incentives. Business executives appear to prefer the hypothecation of carbon and other environmental taxes, enabling the tax revenue to be used to fund environmental and low-carbon programmes; governments that strongly link new taxes with environmental outcomes are more likely to gain support from the business community.

The importance of regulatory compliance, reputation management and stakeholder relations is expected to increase with government action on climate change. The drive to introduce and improve environmental policies and corporate strategies that cover climate change is expected to affect operations, key performance indicators and innovations. Over half of the business leaders surveyed stated that they had already changed the way that they conduct business as a result of climate change, and over 80% expect changes in the next two to three years.

Source: PwC (2010), *Appetite for Change*

- **Need for clear objectives**: Lack of clarity concerning government objectives and uncertainty over the UK's future low-carbon policy direction was highlighted by stakeholders during this review as a key barrier to developing low-carbon technologies:
  - Technology development and asset lives can be very long, in terms of decades. Private sector investors inevitably want confidence that once they have made an investment they will be able to recoup a return over the asset's lifetime. Uncertainty over government objectives increases risks and makes it less likely that technologies will be deployed at sufficient scale and in a timely way.
  - Other studies have also reported similar findings.[188] In the area of renewable energy RD&D, the National Audit Office (NAO)[189] reported that the lack of strategic objectives and sharply defined outcomes make it difficult to establish the link between spend and policy, and therefore to confirm whether programmes and projects are value for money.

- **Need for a long-term plan**: The formation of DECC and the publication in 2009 of the *UK Low-carbon Transition Plan: National Strategy for Climate and Energy* (LCTP) and related strategies, together with EU legislation on renewable energy, have provided greater clarity on the Government's objectives. However, the LCTP and EU renewable energy targets only cover the period to 2020. 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.[190] This uncertainty is compounded by short timescales for funding, with limited confidence around which technologies will be supported beyond the next few years. This has the following implications:
  - Some assets could be constructed in the period to 2020 which later need to be scrapped prematurely because they prove too expensive under future policies or are inconsistent with future policies. This increases the cost to society of meeting climate targets.
  - Where there is uncertainty, investors are likely to take a more conservative view in the treatment of potential downside risk and hence the costs of investment are likely to be greater than they otherwise would be.
  - Clarity on longer term objectives is fundamental to leveraging in private sector investment from companies and third party investors. Without certainty of strategic objectives, the public sector is unlikely to address fully the market failures associated with low-carbon innovative activity. The probable consequence is a greatly reduced likelihood of private sector investment.

[188] Including PwC (2009), *Market research into the barriers to developing low-carbon energy supply technologies*
[189] NAO (2010), *Government funding for developing renewable energy technologies*
[190] A number of examples were cited by stakeholders where previous policy has provided a clear sense of direction for the period to 2020. For example, the policy on zero-carbon buildings for new build in the UK provides, through the progressive tightening of buildings regulations, strong incentives for the industry to deploy new technologies, and has mobilised government technology funders and users around a common purpose.

Integration with international programmes

> ***"UK approach to EU funding is not strategic... Weak influence on programme design"***
>
> \- Interview comment

Our interviews with stakeholders suggested that the UK is not perceived to be as effective as other EU Member States at influencing the design of the Framework Programme for low-carbon technologies. Despite the existence of a government funded programme to promote EU energy programmes in the UK[191], stakeholders felt that the Government should do more to assist UK companies engage with international programmes.

More specifically, stakeholders suggested that, while large companies were engaging in programmes across a number of different sectors, SMEs struggled with engaging in the programmes. The level of complexity and bureaucracy of the programmes presents a major barrier, especially for small companies.

- **International collaboration**: There is scope for collaborating with other countries in developing key technologies. Collaborations will play an important role in developing the technologies required to address climate change and other energy related challenges[192]. However, they should not be seen as a substitute for domestic research, since a country's ability to participate in international networks depends on a vibrant research community at home. There are three broad classes of benefit from international collaboration:
    - An opportunity to share costs for technology development which would otherwise be beyond the reach of one country alone. Nuclear is one example, where the costs are so large that technology development needs to undertaken at an international scale. For example, the Gen IV programme is a major collaborative effort with substantial engagement by a number of countries.
    - Access to specialised expertise that resides in one country to the benefit of all countries involved in the collaboration.
    - An opportunity to strengthen technology deployment by combining different kinds of national comparative advantages (e.g. combining science and technology strengths with lower manufacturing costs).

Outside the nuclear field, the European Framework Programme (FP) for Research and Technological Development is the most significant instrument for international collaboration in the development of low-carbon technologies. The FPs have been an important instrument for building and expanding networks within Europe and increasing opportunities for knowledge sharing and boosting scientific capability. Looking at the FP in its entirety, UK performance has been strong:

[191] http://www.energiehelpline.co.uk/
[192] http://www.iea.org/about/sharedgoals.htm

- UK participants have received just over €5.7 billion across FP5-7 (since 1998) out of a total of just over €38.7 billion across all countries (15%). UK overall income from the annual €7bn FP7 budget is set to exceed £500m a year (equivalent to 5% of the national science budget).[193]

- Recent analysis suggests FP participation is shaped by national strengths. The breadth and depth of UK research strengths underpins the UK's ability to consistently secure a disproportionate share of EC income. Further, there appears to be greater strategic alignment, particularly with FP6 and FP7, which appears to reflect an evolution over time of the FPs rather than changing UK priorities.

However, when assessing the UK's relative performance in areas related to low-carbon[194], the picture appears to be less strong across all recipients of FP funding:

- Overall, the UK's share of total FP7 funding on low-carbon activities is around 11%, i.e. less than its share of all FP funding (15%). Of the UK allocation, over half of the funding received went towards energy.

- The UK's share of total FP7 funding on low-carbon activities is significantly less than Germany (21%) and lower than France (13%).

- Going forward, the focus of the European innovation landscape is shifting from the Framework Programme towards a structure that encourages greater collaboration and partnership working. These changes will need to be reflected as the UK develops its strategy for European engagement.

- The European Institute of Innovation and Technology (EIT) has been established to grow and capitalise on the innovation capacity and capability of higher education, research, business and entrepreneurship across the EU and beyond.

- The EIT has created three Knowledge and Innovation Communities (KIC), including an energy KIC and a climate change mitigation and adaptation KIC. The KICs are partnerships that will deliver the aims of the EIT, with the private sector partners expected to contribute a significant proportion of the funding required.

- The EU Strategic Energy Technology Plan (SET-Plan) aims to establish a new energy research agenda for Europe, to make better use of and increase resources, and to accelerate the development and deployment of low-carbon technologies of the future. The European Energy Research Alliance (EERA) is one element of the SET-Plan and aims to improve cooperation between national research institutes so they are collectively devising and implementing joint programmes. The relatively fragmented nature of UK energy research activity and the absence of large centres of excellence create barriers to effective UK participation in EERA.

---

[193] Technopolis (2010), *The impact of the EU RTD Framework Programme on the UK* (forthcoming)
[194] Thematic Priorities under FP7 which had a clear link to low-carbon were considered to be Energy, Aeronautics & Air Transport, Sustainable Surface Transport, and Horizontal Activities for Implementation of the Transport Programme.

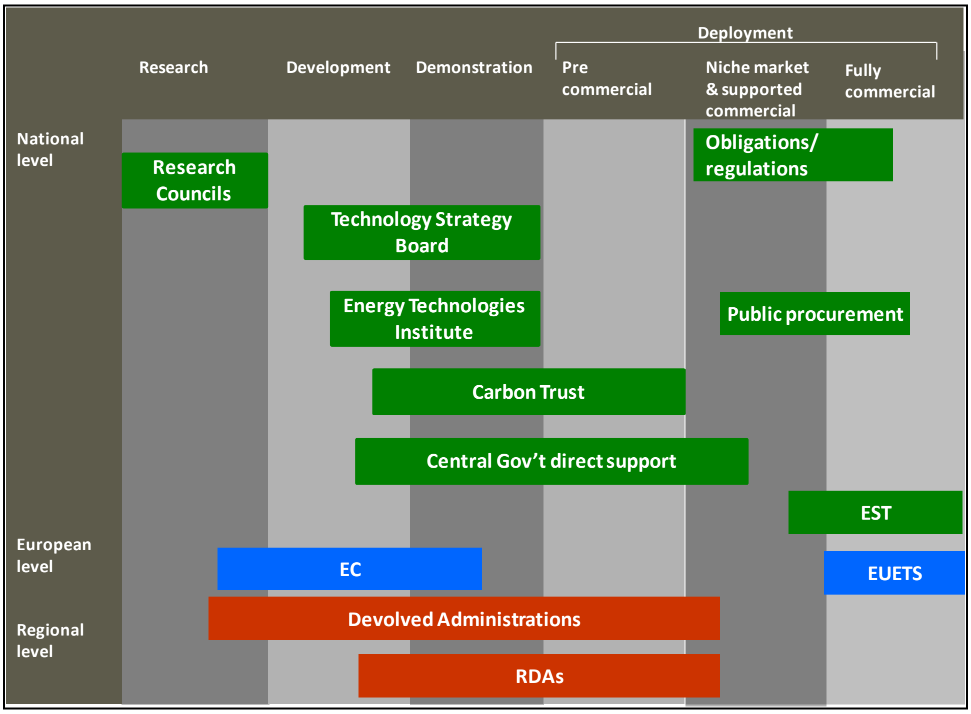
Delivery bodies with clear objectives

> ***"No focus or concentration of support... spray and pray"***
> - Interview comment

Lack of a consistent vision across delivery bodies was noted by stakeholders but the two key issues identified in relation to delivery bodies were the lack of consistent objectives with central government and the complexity of the overall landscape.

- **Consistent objectives**: In order to enable appropriate action to be undertaken, there needs to be a clear line of sight between government objectives and the objectives of delivery bodies.
  - Government support offered to private sector technology developers should be sufficiently clear and should be relatively straightforward for businesses to navigate through the various funding bodies.
  - Whatever the precise institutional structure, it should 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.
- **Complexity**: Evidence gathered from stakeholders suggests that the landscape is considered to be complex and that it is not easy to navigate through the many different departments and agencies that are engaged in low-carbon technology development. In particular, stakeholders considered that the system as a whole lacks clarity and connectivity, with a number of different institutions appearing to cover a similar space (either in terms of stage of innovation process, or in terms of technology or sector coverage, Figure 16).

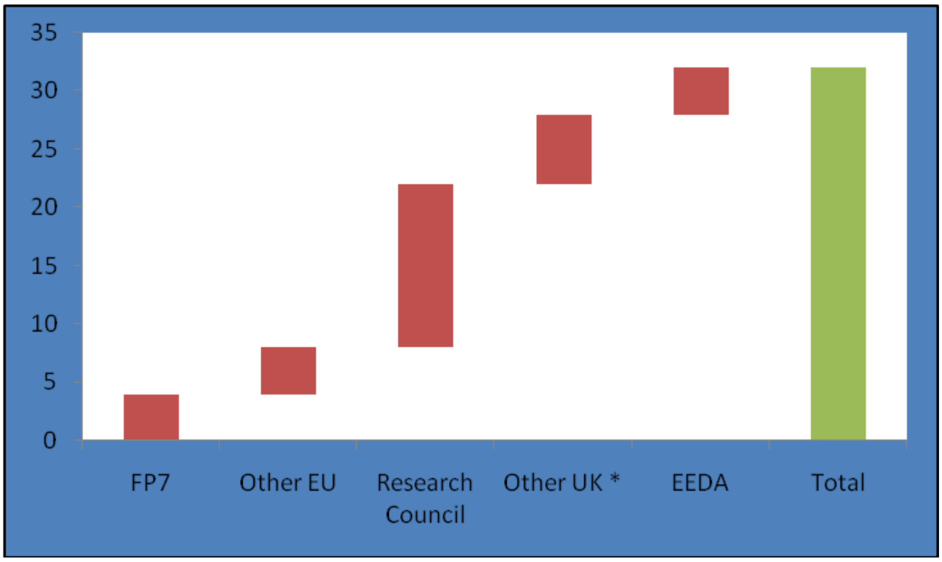
Figure 16: The public support landscape for energy innovation programmes



Source: Adapted from Environmental Transformation Fund: Strategy

The complexity of the system is further increased because of additional layers introduced by devolution and regionalisation. For example, there are over 30 schemes available for supporting R&D into algae biofuels in the East of England alone (Figure 17). This has led others to argue that national and regional energy priorities need to be more aligned to ensure value for money and that all opportunities are fully explored[195]

Figure 17: Number of funding schemes for Algae R&D in the East of England



Note: *Technology Strategy Board and Carbon Trust

Source: B Forte and B Schlarb-Riley (2009), Funding for Algae R&D in the East of England

[195] DECC (2009), *Low-carbon energy generation innovation review*

Overlapping remits may not necessarily be a concern[196]. Some competition between government agencies may help improve performance in fostering innovation, through encouraging diversity by opening up different alternatives for exploration.

- DECC's Energy Generation Landscape Review (2009) suggests that each of the bodies in the landscape highlighted above (Figure 16) has different objectives and that a single body would find it difficult to provide the range of support offered by each of the individual bodies. Further, DECC's Review suggests that the bodies have diverse but complementary operating models which strengthen their collaborative offering. However, these potential benefits come at a cost.
- Greater complexity introduces the possibility that promising technologies do not transition through to deployment because they are not the specific responsibility of any institution. There needs to be continuity and integration of support across the different stages of technology development (e.g. as might be allowed through the creation of a Green Investment Bank, Box 7) – any framework should support far from market technologies as well as the deployment of near to market technologies.

Funding bodies recognise that the landscape is complex, and DECC, the Carbon Trust, the Technology Strategy Board, UKERC and the Energy Generation and Supply KTN are collaborating to produce a funding landscape navigator for businesses. Funding bodies also engage in formal (through the Low Carbon Innovation Group), and informal co-operation.

Nevertheless, that is not the entire answer.

The engagement of industry at all stages of the innovation process (both in terms of major manufacturing companies and technology users such as energy utility companies or major construction firms) is vital to ensuring that the innovation system works effectively throughout every stage. Stakeholders highlighted the need to ensure that there are stronger mechanisms in place that enable delivery or systems issues to be fed back.

- The process of innovation is not linear. Feedback loops from later stage development and deployment to earlier stage research increase the speed at which technologies progress from concept to deployment. Strong links back to academia therefore need to be in place to enable those involved at the later stages to be able to access research capability that they are unlikely to possess themselves
- The New and Renewable Energy Centre[197] (NaREC) in the North East and the Nuclear Advanced Manufacturing Research Centre[198] (NAMRC) aim to improve links between academia and technology users. However, stakeholders felt that there is still scope for strengthening these links in designing research programmes related to low-carbon. Within this, there should be an appropriate balance which also allows academics freedom to develop ideas at the earliest stages of research, which may lead to the development of new technological options.

---

[196] Pew Centre (2003), *U.S. Technology and Innovation Policies: Lessons for Climate Change*
[197] NaREC provides facilities for companies to develop and demonstrate a range of technology systems and components
[198] NAMRC is based at the Universities of Sheffield and Manchester and is focussed on helping companies develop and improve production and installations for the planned programme of nuclear new build, and helping them build the knowledge and capability required to gain the necessary level of accreditation for participation in such a high spec supply chain

Box 7: Green Investment Bank

> On 29 June 2010 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.

Monitoring frameworks with feedback to objectives

> ***"There is a need for robust data to monitor progress... Will help de-risk use of innovative products"***
>
> \- Interview comment

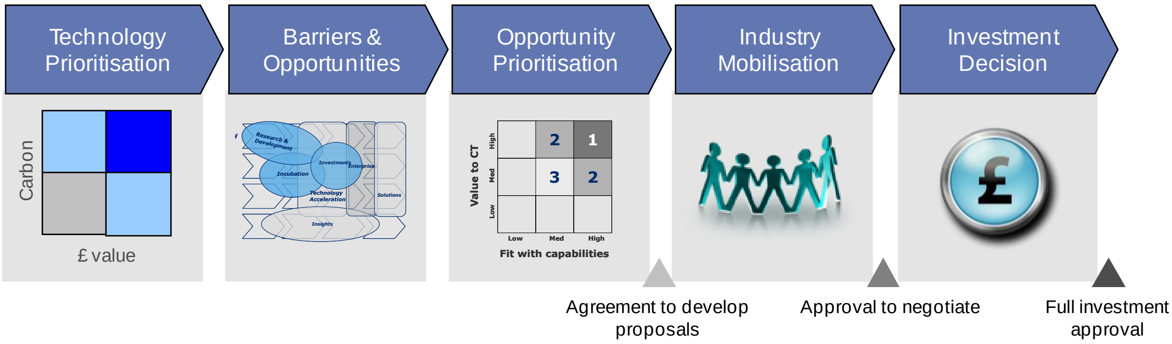
Stakeholders felt that the UK Government was not as effective at appraising, monitoring and evaluating the progress of projects and programmes as it needed to be (although they did highlight that this was not a UK-specific problem).

In relation to appraisal, the Carbon Trust's Investment Appraisal Process (Figure 18) is one example of good practice:

- The Carbon Trust has established a clear framework and process based on the relative potential benefits of different technologies which helps them prioritise where to invest.[199] The framework enables both absolute and relative priorities to be identified, and then a clear identification of where the barriers are, what actions need to be taken and where the strongest opportunities are. Through engagement with industry and academic partners as to who is best placed to deliver the identified actions, the final investment decision can then be matched to purpose and hence maximise the chances of delivering a viable and successful programme.

[199] The detailed frameworks developed by the Carbon Trust, Energy Technologies Institute and Technology Strategy Board to prioritise their funding are acknowledged in NAO (2010), *Government funding for developing renewable energy technologies*

Figure 18: Carbon Trust Investment Appraisal



Source: Carbon Trust

In relation to evaluation (though also touching on appraisal), the recent NAO review highlights that evaluation evidence on the effectiveness of instruments to stimulate private sector renewable energy technology RD&D is generally lacking.[200] The review identifies a number of weaknesses in the programme management of publically funded support for renewable energy technologies, while noting that at least some of these have been identified in NAO examination of other areas:

- For some schemes, an incomplete or inconclusive evidence base used to determine funding priorities,
- Variable objectives and performance measure between the various delivery bodies (including the Government Department),
- Not routinely evaluating performance and a lack of common methods for evaluation,
- Difficulty, therefore, in measuring overall impact of public support.

Given the levels of uncertainty involved in technology development there is a possibility that some technologies supported by Government will not deliver the levels of performance that the market requires. Alternatively, technologies may deliver better than expected performance and hence change the case for public sector support. There therefore needs to be:

- Flexibility in the Government's approach to supporting technological development that allows adaptation of support to take into account changing circumstances.
- The option to introduce, where appropriate, new forms of financial or non-financial support, for example establishing technology standards, as new barriers to technology development emerge.

The appraisal, monitoring and evaluation of projects and programmes is therefore vital to ensure that policy has the best information available to make these decisions. Assessments about whether there needs to be a change to a programme have to be made in real time, with lessons learnt being fed back into policy development to allow better targeting of policy instruments. In addition monitoring data is important in the context of large scale demonstration, where robust data sets help innovators prove the commercial viability of the product, process or technology to potential customers and gain access to the third party financing required for commercial production.

[200] NAO (2010), *Government funding for developing renewable energy technologies*

The lack of information, and the lack of a clear framework within which to appraise, monitor and evaluate programmes, potentially constrains the ability of Government to meet the ambitious climate change targets that Parliament has set.

Table 15: Summary table

Key theme	Current UK position
Overarching objective and long-term focus	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
Clear alignment between overarching objective and objectives of delivery bodies	The number of bodies and differences in approach mean that the landscape lacks clarity and is considered complex. Objectives of delivery bodies need to be fully consistent with government objectives
Strong links between all stages of the innovation process	Scope for strengthening links in designing research programmes related to low-carbon. Within this, need for appropriate balance to allow academics freedom to develop new ideas at the earliest stages of research.
Monitoring frameworks with feedback to objectives	Little evaluation evidence on the effectiveness of spend and a lack of resources dedicated to the long-term monitoring of measures
Integration with international programmes	Need to increase UK influence over the design of EU programmes and take advantage of the scope for collaboration with other countries in developing key technologies

Committee on Climate Change
4th Floor Manning House
22 Carlisle Place
London, SW1p 1JA